NASA

National Aeronautics and
Space Administration

Budget Estimates

FISCAL YEAR 1989

Volume I

Agency Summary

Research and Development

Space Flight, Control and Data Communications

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FISCAL YEAR 1989 ESTIMATES

VOLUME I

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AGENCY SUMMARY

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FISCAL YEAR 1989 ESTIMATES

GENERAL STATEMENT

The National Space Policy recently approved by the President, reaffirms America's commitment to space leadership as a fundamental national objective. The policy recognizes the necessity to explore space's vast frontier, to expand human activity and presence into the solar system. The policy stresses the important roles of the Space Shuttle and the permanently manned Space Station and the need to begin systemmatic development of "Pathfinder" technologies that will provide the basis for future decisions on where this adventure will take us. In achieving the national objective, both private sector and government activities are important. The policy stresses the importance of involvement of American private enterprise, by beginning to lay the infrastructure necessary for research and manufacturing in space, by assuring access to space through a strong commercial expendable launch vehicle industry and by building a strong technology and scientific talent base for the future.

The President's commitment to his National Space Policy is clearly demonstrated by the increased funding recommended for civil space programs in this budget.

The NASA FY 1989 budget request of $11.5 billion supports the National Space Policy by providing the resources necessary to support a vigorous and national program contributing to leadership in space as well as continued preeminence in aeronautics. This budget concentrates on:

- Returning the Space Shuttle to safe and effective flight status and developing significant improvements in technology;

- Moving forward in development of a permanently occupied Space Station in Earth orbit;

- Using space capabilities for the expans on of human scientific knowledge of planet Earth, the solar system and the universe;

- Further strengthening the technology on which our country's leadership in aeronautics and space depends; and

- Building the technology base for greater accomplishments in space in the future.

Space Transportation

As a matter of top priority, current Space Shuttle program activities focus on resumption of flight in 1988 and preparation for a safe and effective buildup of flight activity during 1989. Implementation of the recommendations of the Rogers' Commission as well as corrective actions identified by NASA internal reviews are in progress to enhance our ability to sustain safe and effective operation of the Shuttle system. Production of a new orbiter to replace the Challenger is in progress using funds appropriated in FY 1987. The FY 1989 budget request provides for initiation of development of an Advanced Solid Rocket Motor to enhance flight safety and reliability and to achieve increased payload delivery capability for the Space Shuttle system. The budget also provides for development of hardware to extend the on-orbit stay time of the Shuttle orbiter to 14-16 days.

In other aspects of Space Transportation, the FY 1989 budget includes funding for definition activity on advanced launch systems focusing on critical propulsion systems for the next generation heavy lift unmanned cargo vehicle; for expendable launch services for selected Space Science and Applications missions consistent with implementation of the mixed fleet concept; and for other activities necessary to provide the basis for a robust space transportation system.

Space Station

The Space Station program is an essential element of U.S. leadership in space. The Station will provide our first opportunity to gain direct experience in permanent human operation in space. It will enable us to conduct scientific experiments in space beyond our current capabilities, to promote commercial utilization of space and to stimulate the development and application of technologies of great national significance. The program is moving ahead with the initiation of the full-scale development phase in FY 1987. The contractors have been selected for the major hardware elements of the program as well as for the management and integration support and software support environment functions. NASA and the

contractor teams are in the process of more specifically defining the detailed program content and schedules consistent with the appropriated and projected funding levels. This activity is directed toward the initiation of a formal in-depth program requirement review in the second quarter of this year. Build up of the activity levels associated with major hardware element contracts will grow substantially in FY 1989. This buildup is necessary for the preliminary design review to evaluate the design approach, then work proceeds into detailed design and development of the Space Station flight and ground hardware and software. In addition to supporting the request for $1 billion of new obligational authority in FY 1989, the Administration is proposing legislation for a firm three year Congressional commitment now for advanced authorization and appropriations of $6.0 billion including the FY 1989 amount.

Space Science and Applications

The FY 1989 budget provides for a carefully coordinated and logically phased set of research and development activities to:

- Advance our scientific knowledge of planet Earth and of the forces and systems that shape our home planet;
- Explore the solar system using automated spacecraft in conjunction with groundbased observations and research;
- Expand our comprehension of the universe beyond the solar system using the full range of capabilities from Explorer spacecraft to the orbiting great observatories;
- Increase our knowledge in the Life Sciences on key issues ranging from human performance in space to the basic life processes and the potential of life elsewhere in the universe; and
- Understand and develop the potential benefits of the microgravity environment in materials sciences and other applications.

Some of the key elements of the program plan for 1989 include launch on the Space Shuttle of the Hubble Space Telescope, of the Magellan mission to Venus and of the Galileo mission to Jupiter; the launch of the Cosmic Background Explorer mission on a Delta launch vehicle; final preparation for the launch of Ulysses; continued development of the Gamma Ray Observatory, the Upper Atmosphere Research Satellite, the Mars Observer, Ocean Topography Experiment and Global Geospace Science; and development and integration activity in preparation for future Spacelab missions and for secondary payloads to conduct microgravity

and life sciences research and experimentation. Augmented effort will be directed toward the development of a new generation of flight hardware for advanced experiments in microgravity materials sciences, initially on Spacelab, leading to comprehensive long term research on the Space Station, and on Life Sciences experiment hardware for use on Spacelab, Space Station and any promising commercial space facilities. Development will be in progress on relatively low cost free flying payloads in the Explorer tradition. Funds are also included to initiate design and development activities on the AXAF (Advanced X-ray Astrophysics Facility), an orbiting observatory which will provide an opportunity to detect x-rays from sources throughout the universe with an unprecedented degree of sensitivity and precision. The AXAF will sense the electromagnetic spectrum between the visible, infrared and ultraviolet regions covered by the Hubble Space Telescope and the highest energy regions of the spectrum covered by the Gamma Ray Observatory. These three observatories operating together will provide a scientific resource with capability well in excess of the sum of the capabilities of these three powerful observatories considered separately.

Commercial Activities

The FY 1989 budget supports developing the private sector's innovative excellence and confirms NASA's commitment to encouraging a healthy and expansive commercial space industry. Action has been taken to lease government owned facilities to companies planning to provide commercial launch services. NASA has in place a plan to procure launch services from the private sector for a number of important scientific satellite missions. Commercially developed upper stages are being used where appropriate for planned missions. Commercial microgravity experiments to be conducted as secondary payloads are being manifested aggressively on planned Shuttle missions. There are several initiatives underway to involve the private sector in developing the infrastructure necessary for research and manufacturing in space. NASA strongly supports these initiatives.

Space Research and Technology

This program develops the technology base on which our current and future capabilities in space depend. The program was strengthened in FY 1988 by the Civil Space Technology Initiative which involves a refocusing and augmentation of key technologies directed primarily at enhancing our capabilities for operations to, from and in Earth orbit. The FY 1989 budget includes the further thrust needed to provide the base for enhanced capabilities for future operations beyond earth orbit. Project Pathfinder will push American technology forward in the areas of robotic exploration and data gathering, in-space staging and operations, humans in-space productivity and performance and transfer vehicle technology. These technologies are fundamental to making informed future decisions on exploration beyond Earth orbit into the solar system. The University Space Research Program will help foster creative and innovative concepts for future space systems and expand the nation's engineering talent base for research and development. This program is an integral part of the strategy to strengthen the space research and technology base.

Aeronautical Research and Technology

The NASA aeronautical research and technology program is intended to develop and validate emerging technologies for use by the aviation industry, well in advance of specific applications, through long-term independent research and technology development. These activities are pursued concurrently through fundamental research in the traditional aeronautical disciplines and systems research and technology validation.

The FY 1989 research and technology program is committed to developing the technology basis for improving the nation's competitiveness and clear-cut product superiority in the international marketplace, enhancing the safety of aviation, and increasing the margin of the country's preeminence in aviation for national security. Technologies are being pursued that offer the potential of a major increase in vehicle capabilities and substantial positive impact on U.S. competitiveness. Research efforts have been expanded in composite materials, advanced propulsion, and aviation safety. The demands for NASA's unique wind tunnels are growing with research on high-speed civil transports, the emergence of the National Aero-Space Plane (NASP) program, and a new generation of military aircraft. In order to ensure wind tunnel availability to meet these demands, a major revitalization program has been budgeted in the CofF appropriation over the next five years to modernize NASA's major wind tunnels for productive use for the next decade and into the 21st century.

Transatmospheric Research and Technology

The NASA efforts in this area are aimed at accelerating the development of critical technologies intended to enable a potential new class of vehicles in the future capable of flight to orbit and/or hypersonic cruise. Work will continue in the development of technology for hypersonic and transatmospheric vehicles for the National Aero-Space Plane program with emphasis on light weight thermal structures and subsonic and supersonic propulsion. Possible opportunities in this regime include vehicles to transport people to orbit, hypersonic transport between points on earth and military applications.

Work Force Capability

Leadership in Space demands a strong technical and management capability within NASA. In recognition of this requirement, an increase of 625 people (about 3%) was recommended in the FY 1988 budget. The FY 1989 budget recommends a further increase of 525 people. This increased capability, which is being applied primarly to strengthen the space transportation program including safety and reliability activities, is a key ingredient in moving ahead in space.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

BUDGET SUMMARY
(Millions of Dollars)

	Budget Plan		
	1987	1988	1989
RESEARCH AND DEVELOPMENT	3.153.7	3.294.5	4,446.7
Space station	420.0	392.3	967.4
Space transportation capability development	491.1	609.8	631.1
Space science and applications	1,547.6	1,575.8	1,859.6
Technology utilization	15.7	17.7	19.1
Commercial use of space	25.2	56.0	38.8
Aeronautical research and technology	374.0	334.8	414.2
Transatmospheric research and technology	45.0	52.5	84.4
Space research and technology	206.0	223.6	390.9
Safety, reliability and quality assurance	12.0	14.1	22.4
Tracking and data advanced systems	17.1	17.9	18.8
SPACE FLIGHT. CONTROL AND DATA COMMUNICATIONS	5,999.5	3,810.7	4,841.2
Shuttle production and operational capability	3,408.1	1,088.3	1,400.5
Space transportation operations	1,746.0	1,838.0	2,405.4
Space and ground networks, communications and data systems	845.4	884.4	1,035.3
CONSTRUCTION OF FACILITIES	169.3	178.3	285.1
RESEARCH AND PROGRAM MANAGEMENT	1,451.5	1,743.0(1)	1.915.0
TOTAL BUDGET SUMMARY	10,774.0	9,026.5	11,488.0
OUTLAYS	7.591.4	9,111..9	10,977.7

(1) Does not include $42.0 million to cover the impact of the pay raise and supporting activities. The source of these funds has not been determined.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FISCAL YEAR 1989 ESTIMATES

SUMMARY RECONCILIATION OF APPROPRIATIONS TO BUDGET PLANS
(Millions of Dollars)

	Total	Research and Develop	SFC&DC	Cof F	R&PM
Fiscal Year 1987					
Appropriation PI 99-591	10,875.0	3,153.7	6,099.5	169.3	1,452.5
Transfer from FY 87 to FY 88	-100.0		-100.0		
Lapse	-1.0	---	---	---	-1.0
Total Budget Plan	10,774.0	3,153.7	5,989.5	169.3	1,451.5
Fiscal Year 1988					
Appropriation PI 100-202	8,856.5	3,274.2	3.908.3	178.3	1,495.7
Transfer from FY 87 to FY 88	+100.0	+100.0			
Transfers between Accounts	--	-144.8	-97.6	---	+242.4
Transferred from other Accounts	+70.0	+65.1	---	---	+4.9
Total Budget Plan	9,026.5	3,294.5	3,810.7	178.3	1,743.0
Fiscal Year 1989					
Appropriation Request/Budget Plan	11.488.0	4,446.7	4,841.2	285.1	1.915.0

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FISCAL YEAR 1989 ESTIMATES

SUMMARY OF BUDGET PLANS BY INSTALLATION BY APPROPRIATION

(Thousands of Dollars)

	Total			Space Flight Control and Data Communications			Research and Development			Construction of Facilities			Research and Program Management		
	1987	1988	1989	1987	1988	1989	1987	1988	1989	1987	1988	1989	1987	1988	1989
Johnson Space Center	2,909,349	1,465,796	1,903,553	2,337,905	870,700	980,300	325,132	301,170	588,182	18,400	10,395	33,545	227,912	283,531	301,526
Kennedy Space Center	908,023	1,057,010	1,249,142	642,100	709,100	816,300	53,757	83,276	126,217	11,919	26,230	36,150	200,247	238,404	270,475
Marshall Space Flight Center	2,523,296	2,200,155	2,711,615	1,580,085	1,227,300	1,461,600	721,070	717,949	957,431	10,095	17,375	43,480	212,046	237,531	249,104
National Space Technology Laboratories	45,835	53,242	59,298	15,800	18,500	20,200	11,830	8,040	8,165	6,185	5,745	7,585	12,020	20,957	23,348
Goddard Space Flight Center	1,129,876	1,239,671	1,591,800	416,903	468,100	623,700	483,896	508,084	694,357	15,225	19,825	16,920	213,852	243,662	256,823
Jet Propulsion Laboratory	593,046	609,242	738,646	124,322	130,900	142,000	452,424	466,642	579,146	16,300	11,700	17,500	0	0	0
Ames Research Center	454,211	480,399	550,691	16,300	15,300	18,200	282,068	259,065	307,461	22,225	33,970	45,632	133,618	172,064	179,398
Langley Research Center	389,957	388,686	481,248	100	100	23,700	217,645	201,800	250,533	17,875	7,090	21,760	154,337	179,696	185,255
Lewis Research Center	446,672	470,056	712,450	5,100	3,500	125,700	277,762	261,068	363,567	12,061	22,190	31,730	151,749	183,298	191,453
Inspector General	6,337	7,722	9,447	0	0	0	0	0	0	0	0	0	6,337	7,722	9,447
Headquarters	1,328,395	1,072,741	1,449,312	860,885	367,200	629,500	328,116	487,406	571,641	0	0	0	139,394	218,135	248,171
Agencywide Activities	0	0	0	0	0	0	0	0	0	0	0	0			
Undistributed Construction of Facilities:															
Various Locations	22,015	7,752	10,798	0	0	0	0	0	0	22,015	7,752	10,798	0	0	0
Facility Planning and Design	17,000	16,000	20,000	0	0	0	0	0	0	17,000	16,000	20,000	0	0	0
Pay Raises and Supporting Activities	0	-42,000	0	0	0	0	0	0	0	0	0	0	0	-42,000	0
Total Budget Plan	10,774,012	9,026,472	11,488,000	5,999,500	3,810,700	4,841,200	3,153,700	3,294,500	4,446,700	169,300	178,272	285,000	[illegible]	1,743,000	1,915,000

* Does not include $42.0 million required to cover the impact of the pay raise and supporting activities. The sources of these funds has not been determined.

DISTRIBUTION OF PERMAMENT WORKYEARS BY PROGRAM
TOTAL NASA

	1987 ACTUAL	FY 1988 REVISED ESTIMATE	FY 1988 CURRENT ESTIMATE	1989 BUDGET ESTIMATE
SPACE STATION	1,819	2,779	2,095	2,095
SPACE FLIGHT PROGRAMS	5,343	4,883	5,420	5,905
SPACE TRANSPORTATION CAPABILITY DEV.	1,442	1,174	1,394	1,435
SPACE SHUTTLE	3,901	3,709	4,026	4,470
SPACE SCIENCE AND APPLICATIONS	3,980	3,754	3,745	3,720
PHYSICS AND ASTRONOMY	2,120	1,943	1,962	1,933
LIFE SCIENCES	241	246	248	248
PLANETARY EXPLORATION	203	180	191	190
SPACE APPLICATIONS	1,416	1,385	1,344	1.319
AERONAUTICS AND SPACE TECHNOLOGY	4,704	4,812	4,899	4,892
AERONAUTICAL RESEARCH AND TECHNOLOGY	3,121	3,192	3,153	3,124
SPACE RESEARCH AND TECHNOLOGY	1,334	1,296	1,433	1,455
TRANSATMOSPHERIC RESEARCH & TECH	249	324	313	313
COMMERCIAL PROGRAMS	134	129	151	150
SAFETY, RELIABILITY a QUALITY ASSURANCE.	46	60	60	60
TRACKING AND DATA PROGRAMS	687	668	695	684
SUBTOTAL DIRECT	16,713	17,085	17,065	17,506
CENTER MANAGEMENT AND OPERATIONS	4,559	4,593	4,629	4,703
SUBTOTAL (FULL-TIME PERMANENTS)	21,272	21,678	21,694	22,209
OTHER CONTROLLED FTE'S (PMI's/CO-OPS/OTFTP's)	729	747	731	741
GRAND TOTAL (FULL-TIME EQUIVALENTS)	22,001	22,425	22,425	22,950

RESEARCH
AND DEVELOPMENT

SUMMARY
INFORMATION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND DEVELOPMENT

FISCAL YEAR 1989 ESTIMATES

GENERAL STATEMENT

The objectives of the National Aeronautics and Space Administration program of research and development are to extend our knowledge of the Earth, its space environment, and the universe; to expand the technology for practical applications of space technology; to develop and improve manned and unmanned space vehicles; and to assure continued development of the long-term aeronautics and space research and technology necessary to accomplish national goals. These objectives are achieved through the following elements:

SPACE STATION: A program to develop a United States space station to continue the Nation's leadership in space and to provide for enhancement of science and applications programs and to further the commercial utilization of space while stimulating advanced technologies.

SPACE TRANSPORTATION CAPABILITY DEVELOPMENT: A program to provide for the development and use of capabilities related to the Space Shuttle. The principal areas of activity in Space Transportation Capability Development are efforts related to the development and flight certification of the jointly developed U.S./Italy Tethered Satellite System, development of the Orbital Maneuvering Vehicle, development and operations of the Spacelab systems, the development and procurement of upper stages that place satellites in high altitude orbits, the engineering and technical base support at NASA centers, payload operations and support equipment, and advanced programs study and evaluation efforts.

SPACE SCIENCE AND APPLICATIONS: A program using space systems, supported by ground-based and airborne observations, **(1)** to conduct a broad spectrum of scientific investigations to advance our knowledge of the Earth and its space environment, the Sun, the planets, interplanetary and interstellar space, the stars of our galaxy and the universe; and (2) to identify and develop the technology for the useful applications of space techniques in the areas of advanced communications satellite systems technology; materials processing research and experimentation; and remote sensing to acquire information which will assist in the solution of Earth resources and environmental problems.

TECHNOLOGY UTILIZATION: The program includes activities to accelerate the dissemination to both the public and the private sectors of advances achieved in NASA's research, technology, and development program.

COMMERCIAL USE OF SPACE: A program to increase private sector awareness of space opportunities and encourage increased industry investment and participation in high technology, space-based research and development.

AERONAUTICS AND SPACE TECHNOLOGY: A program to conduct the fundamental long-term research and to develop the discipline and systems technology required to maintain United States leadership in aeronautics and space.

TRACKING AND DATA ADVANCED SYSTEM: This program includes activities to perform studies and provide for the development of systems and techniques leading to improved tracking and data program capabilities.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND DEVELOPMENT
FISCAL YEAR 1989 ESTIMATES

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Millions of Dollars)		
SPACE STATION	420.0	734.3	392.3	967.4
SPACE TRANSPORTATION CAPABILITY DEVELOPMENT	491.1	563.7	609.8	631.1
SPACE SCIENCE AND APPLICATIONS	1.547.6	1.458.8	1.575.8	1.859.6
Physics and astronomy.....	554.0	542.8	610.8	791.6
Life sciences.....	71.8	70.0	69.5	101.7
Planetary exploration.....	359.2	304.3	329.2	404.0
Solid earth observations.....	72.4	74.3	74.3	82.1
Environmental observations.....	318.3	385.9	313.5	368.3
Materials processing.....	47.3	42.7	62.7	73.4
Communications.....	103.4	17.9	94.9	16.2
Information systems.....	21.2	20.9	20.9	22.3
COMMERCIAL PROGRAMS	40.9	52.7	73.7	57.9
Technology utilization.....	15.7	17.7	17.7	19.1
Commercial use of space.....	25.2	35.0	56.0	38.8
AERONAUTICS AND SPACE TECHNOLOGY	625.0	636.9	610.9	889.5
Aeronautical research and technology...	374.0	332.8	334.8	414.2
Transatmospheric research and technology	45.0	65.5	52.5	84.4
Space research and technology.....	206.0	238.6	223.6	390.9
SAFETY, RELIABILITY AND QUALITY ASSURANCE	12.0	14.1	14.1	22.4
TRACKING AND DATA ADVANCED SYSTEMS	17.1	17.9	17.9	18.8
TOTAL	3,153.7	3,478.4	3,294.5	4,446.7

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
PROPOSED APPROPRIATION LANGUAGE

RESEARCH AND DEVELOPMENT

For necessary expenses, not otherwise provided for, including research, development, operations, services, minor construction, maintenance, repair, rehabilitation and modification of real and personal property; purchase, hire, maintenance, and operation of other than administrative aircraft, necessary for the conduct and support of aeronautical and space research urd development activities of the National Aeronautics and Space Administration; [$3,374,200,000] *$4,446,700,000,* to remain available until September SO, [1989, of which $100,000,000 shall be derived by transfer from funds appropriated in section 101(g) of Public Law 99-591 for orbiter production: *Provided.* That of the funds made available by this Act. $225,000,000 is for space station only. which amount shall not become available for obligation until June 1, 1988, and pursuant to section 202 of the Balanced Budget and Emergency Deficit Control Reaffirmation Act of 1987, this action is a necessary (but secondary) mult of a significant policy change] *1890, of which $967,400,000 is for space station only.*

Further, fir the space station only, $2,130,200,000 to be available for obligation on *October 1. 1989* and *to remain available until September 30, 1991.* and *further, for the space station only. $2,912,500,000 lo be available for obligation on October 1. 1990* and *to remain available until September 30, 1992 (Department of Housing and Urban Development-Independent Agencies Appropriations Act, 1988, additional authorizing legislation to be proposed.)*

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH AND DEVELOPMENT

REIMBURSABLE SUMMARY
(In thousands of dollars)

	Budget Plan		
	FY 1987	FY 1988	FY 1989
Space Station	35	200	400
Space Transportation Capability Development	110,179	172,000	125,500
Space Science and Applications	509,001	482,790	570,650
Technology Utilization	2,462	3,100	1,250
Safety, Reliability and Quality Assurance	3,133	3,400	3,500
Space Research and Technology	18,866	57,900	70,700
Aeronautical Research and Technology	117,628	76,100	42,GOO
Transatmospheric Research and Technology	782	750	550
Energy Technology	44.030	33,600	20,800
Total	806.086	818,840	835,950

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FISCAL YEAR 1989 ESTIMATES

DISTRIBUTION OF RESEARCH AND DEVELOPMENT BUDGET PLAN BY INSTALLATION AND FISCAL YEAR

(Thousands of Dollars)

Program		Total	Johnson Space Center	Kennedy Space Center	Marshall Space Flight Center	National Space Tech Lab	Goddard Space Flt Center	Jet Propulsion Lab	Ames Research Center	Langley Research Center	Lewis Research Center	NASA HQ
Space Station	1987	420,000	154,400	10,700	81,200	700	43,400	14,200	2,400	11,200	51,400	50,400
	1988	392,300	126,200	10,300	57,200	100	40,500	6,200	100	100	31,300	112,300
	1989	967,400	354,000	36,000	195,200	400	80,000	6,000	300	400	156,000	144,300
Space Trans Cap Dev	1987	491,100	110,000	34,700	303,400	8,400	3,900	1,400	1,300	1,500	1,100	24,800
	1988	609,800	112,100	61,400	332,900	5,100	4,200	1,100	1,500	900	500	90,100
	1989	631,100	146,000	78,400	329,500	5,600	6,400	1,500	1,300	800	500	61,100
Space Sci and Apps	1987	1,547,600	46,157	7,217	275,193	1,052	422,513	402,669	80,969	23,260	101,023	177,547
	1988	1,575,000	51,865	10,139	278,814	1,000	439,121	413,962	86,723	28,563	93,753	179,840
	1989	1,859,600	61,602	12,287	336,441	1,000	507,669	506,241	105,461	23,165	25,862	198,792
Physics and Astronomy	1987	554,000	9,810	4,217	248,070	---	179,545	13,995	32,580	100	100	65,566
	1988	610,800	13,260	7,239	253,677	---	229,924	15,510	12,985	150	---	77,777
	1989	791,600	12,677	8,087	307,696	---	777,777	15,005	15,542	150	---	89,032
Life Sciences	1987	71,800	23,600	3,000	100	100	200	1,700	30,200	500	---	11,777
	1988	69,500	23,000	2,900	100	100	200	1,700	29,500	500	---	11,500
	1989	101,700	32,300	4,200	200	100	300	3,700	44,300	600	---	16,000
Planetary Exploration	1987	359,200	12,029	---	394	---	10,579	274,391	19,310	29	195	42,265
	1988	329,200	10,025	---	237	---	9,284	251,887	77,777	13	---	41,399
	1989	404,000	10,855	---	245	---	9,710	325,300	77,777	15	---	42,080
Solid Earth Obs	1987	72,400	36	---	360	647	35,728	25,672	812	---	---	9,145
	1988	74,300	---	---	400	800	39,000	25,700	900	---	---	7,500
	1989	82,100	---	---	400	800	41,300	30,500	1,000	---	---	8,100
Environmental Obs	1987	318,300	77	---	12,025	50	177,139	64,441	7,777	21,061	---	38,266
	1988	313,500	100	---	6,450	100	139,600	95,600	27,100	17,400	---	27,200
	1989	368,300	---	---	6,800	100	176,100	107,900	28,100	19,800	---	29,500
Materials Proc in Space	1987	47,300	2,605	---	14,235	---	---	11,160	---	1,570	11,710	6,000
	1988	62,700	4,700	---	18,000	---	---	13,700	---	2,500	15,500	8,300
	1989	73,400	6,050	---	21,100	---	---	13,900	---	2,600	21,450	7,500
Communications	1987	103,400	---	---	---	---	5,269	6,710	---	---	69,010	2,303
	1988	94,900	---	---	---	---	6,669	5,765	---	---	78,253	4,213
	1989	16,200	---	---	---	---	7,777	5,500	---	---	4,412	3,503
Information Systems	1987	21,200	---	---	---	255	14,033	4,500	810	---	---	7,777
	1988	20,900	---	---	---	---	14,444	4,100	[illegible]	---	---	7,777
	1989	22,300	---	---	--	---	14,233	4,346	777	---	---	2,997
Commercial Programs	1987	40,900	1,060	828	5,353	1,678	1,897	953	654	1,067	2,012	24,806
	1988	73,700	615	937	10,320	1,040	1,425	1,030	642	1,360	1,720	53,603
	1989	57,900	600	1,130	20,365	1,165	1,500	1,055	950	1,775	1,405	27,955
Technology Utilization	1987	15,700	335	752	534	940	1,247	953	474	1,097	825	6,543
	1988	17,700	515	492	640	840	1,275	1,030	460	622	355	11,471
	1989	19,100	500	670	665	865	1,300	1,055	500	600	300	12,485
Commercial Use Of Space	1987	25,200	725	68	4,819	738	650	---	100	570	1,187	16,263
	1988	56,000	100	445	9,680	1,000	150	---	382	746	1,365	42,132
	1989	38,000	100	460	19,700	300	200	---	450	1,095	1,025	15,470
Aero & Space Technology	1987	625,000	10,169	180	55,239	---	6,298	19,136	188,330	177,925	122,054	45,669
	1988	610,900	9,600	400	38,300	---	8,700	29,700	169,300	177,900	132,500	44,300
	1989	889,500	24,000	4,300	75,500	---	11,000	40,300	199,000	223,100	178,300	125,200
Aero Research & Tech	1987	374,000	---	---	1,506	---	273	240	167,087	777,777	81,327	5,602
	1988	334,800	---	---	1,700	---	200	300	142,300	108,100	75,100	7,100
	1989	414,200	---	---	4,100	---	200	300	157,900	144,300	100,200	7,200
Space Research & Tech	1987	206,060	10,169	160	53,653	---	6,025	18,896	18,931	52,830	38,662	6,654
	1988	223,600	9,600	400	36,600	---	8,500	29,400	23,600	56,800	49,200	9,500
	1989	390,900	24,000	4,300	71,400	---	11,000	40,000	37,100	65,600	74,500	54,400
Transatmos Res & Tech	1987	45,000	---	---	---	---	---	---	2,312	7,210	2,065	33,413
	1988	52,500	---	---	---	---	---	---	3,600	13,000	8,200	27,700
	1989	84,400	---	---	---	---	---	---	4,000	13,200	3,600	63,600
Tracking & Data Acqui	1987	17,100	---	---	---	---	5,000	11,841	---	---	---	259
	1988	17,900	---	---	---	---	5,300	12,600	---	---	---	---
	1989	18,000	---	---	---	---	5,000	13,000	---	---	---	---
Safety,Reliability & QA	1987	12,000	740	140	685	---	836	2,225	415	2,693	173	4,635
	1988	14,100	770	180	415	---	830	2,050	400	969	1,295	7,263
	1989	22,400	900	100	425	---	1,100	2,250	450	1,202	1,500	14,294
TOTAL BUDGET PLAN	1987	3,153,700	325,132	53,757	721,070	11,830	483,896	452,424	282,058	217,645	277,762	328,116
	1988	3,294,500	301,170	83,276	717,949	8,040	508,684	466,642	259,065	281,800	281,068	487,406
	1989	4,446,700	588,102	126,217	957,431	8,165	694,357	579,146	307,461	250,533	363,567	571,641

SPACE STATION

RESEARCH AND DEVELOPMENT
FISCAL YEAR 1989 ESTIMATES
BUDGET SUMMARY

OFFICE OF SPACE STATION

SUMMARY OF RESOURCES REQUIREMENTS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
		(Thousands of Dollars)			
Definition	250,000	-	---	---	---
Development	147,000	700,800	366,800	935,400	RD 1-6
Flight telerobotic system	20,000	21,500	21,500	20,000	RD 1-22
Operations	---	7,000	---	---	---
Transition definition	---	5,000	4,000	12,000	RD 1-23
Crew emergency return vehicle (CERV)	3,000	---	---	---	
Total	420.000	734,300	392.300	967,400	

Distribution of Program Amount bv Installation:

Johnson Space Center	154,400	236,600	126,200	354,000
Kennedy Space Center	10,700	31,200	10,300	30,000
Marshall Space Flight Center	81,200	204,500	57,200	195,200
National Space Technology Laboratories	700	900	100	400
Goddard Space Flight Center	43,400	70,000	48,500	80,000
Jet Propulsion Laboratory	14,200	13,000	6,200	6,800
Ames Research Center	2,400	4,800	100	300
Langley Research Center	11,200	5,600	100	400
Lewis Research Center	51,400	88,700	31,300	156,000
Headquarters	50.400	79.000	112.300	144.300
Total	420,000	734.300	392,300	967.400

Authorization and appropriation of funds necessary for the Space Station program is also requested for FY 1990 and FY 1991. For FY 1990, the amount requested is $2,130,200,000, to become available for obligation on October 1, 1989, and to remain available until September 30, 1991. For FY 1991, the amount requested is $2,912,500,000, to become available for obligation on October 1, 1990, and to remain available until September 30, 1992.

OFFICE OF SPACE STATION **SPACE STATION PROGRAM**

OBJECTIVES AND JUSTIFICATION

Development of the United States permanently manned Space Station, as directed by President Reagan, will add new momentum to the civil space program and is essential to realizing the national goal of U.S. leadership in space. The Space Station program gives us our first opportunity to gain direct experience in long term human operations in space, and knowledge essential to future space exploration. The Station will uniquely enhance the U.S. Space Science programs, further the commercial utilization of space, and stimulate the development and application of advanced technologies of national importance. It is also an avenue of cooperation with our allies, demonstrating the peaceful use of space for the benefit of all.

The Space Station will be unique because it will provide the United States with a permanently manned presence in space. It will be versatile because its capabilities will be remarkably diverse. This diversity is reflected in the Station's design, which features pressurized laboratories, accommodations for attached payloads, and free-flying unmanned platforms. This new national laboratory, a research center in space, will stimulate new technologies, enhance industrial competitiveness, further commercial space enterprises, and add greatly to our storehouse of scientific knowledge. Perhaps the most significant feature of the Space Station, essential to its utility for science, commerce, and technology, is the continuing presence of its crews. Men and women will be aboard the Station base full-time. The potential of humans--their creativity, their dexterity, their ability to perceive, to interact with instruments, and to respond to the unexpected--is unique and essential. The Space Station will be designed to exploit these human capabilities. The Space Station's microgravity environment, high levels of power, and extended time in orbit, will enable scientists to make new discoveries in materials research and life sciences. The Space Station's substantive research capabilities include far more than its pressurized volume. Its free-flying platforms will enable truly synergistic studies of the Earth's atmosphere, land masses, and oceans--referred to as Earth system science. Moreover, the Station's external structure is designed to be a stable platform that will be available for mounting a number of specialized instruments and telescopes. Scientific instruments, whether in a laboratory or on a boom, require maintenance, upgrading, repair and replacement. The Station will accommodate these servicing functions. The Space Station will be designed to evolve, to be capable of growth in its capabilities, so that future needs and challenges can be met.

The U.S. Space Station will be a multi-purpose, international facility. In 1984, President Reagan invited the full participation of other nations. During the ensuing definition phase, Canada, member states of the European Space Agency (ESA), and Japan worked closely with the U.S. to define their participation. These parallel definition and preliminary design studies have resulted in the identification of the Space Station elements they are considering for development. Negotiations with these international partners for the development phase of the program are in their final stages. Negotiators from NASA and the Canadian Ministry of State for Science and Technology reached agreement in December 1987 on the text of a memorandum of understanding for the Canadian cooperation, whereby Canada will provide a mobile servicing system for use on the Station. A preliminary agreement has also been reached with ESA members and Japan on their participation in the Space Station program.

The basic configuration of the Space Station and the supporting elements has been arrived at as a result of a lengthy and iterative three-year process involving NASA centers, U.S. industry, our international partners, and the national and international science communities. A detailed assessment of the Space Station program was also conducted by the National Research Council's Committee on Space Station. During this definition period, the design evolved in response to user requirements, developments of advanced technology, trade studies and cost assessments. The evaluation of the various Space Station options led to the selection of a baseline configuration, commonly known as the "dual keel" configuration. The launch of the first element of this configuration was planned for January 1994. Since this estimate represented a considerable cost increase over the target cost estimate made in 1983-84, the reasons for the increase were closely examined. Following intensive review during early 1987, a phased approach for development of the Space Station was adopted. A "Revised Baseline Configuration" which includes major elements of the dual keel configuration was selected, with a commensurate reduction in design and development costs. As a result of necessary fiscal restraint during the FY 1988-1990 period, the planned launch date for the first element launch was adjusted to March 1994. This schedule is currently under review as a result of the funding revised in the 1988 budget. This revised baseline is comprised of a single horizontal boom structure with 75 KW of photovoltaic power, the U.S. laboratory and habitability modules and two international laboratory modules (one European and one Japanese), and a Canadian mobile servicing capability. These elements comprise the manned base, and provide both internal and external accommodations for (attached) science and application payloads. There are also two science and applications platforms, one U.S. and one European, to be launched into polar orbits. A Man-Tended Free Flyer is also under consideration by the European Space Agency as a co-orbiting platform with the manned base.

In addition to the development of the manned base and U.S. polar platform, the Space Station program will include development of a Flight Telerobotics System (FTS). The FTS will be a highly automated telerobotic device capable of precise manipulations in space. The FTS onboard the Space Station will

increase crew safety and productivity by reducing EVA time, allowing the use of robotics for hazardous tasks, and free crew members for scientific tasks. The FTS will play a key role in the development of automation and robotics (A&R) technologies.

As noted above, a key design objective of the Space Station is to enable hardware and software to evolve in response to increased user demands and the need for augmented operational capabilities. The Transition Definition activities will provide for systems studies to define options for evolution of the Space Station consistent with future agency missions and for technology developments, primarily in automation and robotics, that will enhance Space Station productivity. These activities are essential for the long-term cost-effective utilization of the Space Station.

The Office of Space Station initiated a definition study during FY 1987 to reevaluate the requirements for an assured crew return capability. This activity, the crew emergency return vehicle definition study will be continued in FY 1988 and FY 1989 under Space Transportation Capability Development and managed by the Office of Space Flight.

Space Station operations encompass all activities required to maintain the Space Station and platforms for its planned lifetime. This includes logistics support, crew training, mission operations, engineering support, launch processing, and user training and operations. The FY 1988 budget requested funds to support preliminary operations planning. These funds have been deferred based on an assessment that it was premature to initiate operations planning tasks at this time.

Since submission of the FY 1988 budget last year, the Space Station program has completed a series of intensive reviews regarding program content and rationale, flight system configuration, and overall reasonableness of the total cost estimates.

The most comprehensive review was conducted at the request of the President by the National Research Council Committee on Space Station. The NRC's task was to assess NASA's cost estimates for the Space Station program and to examine Space Station mission requirements and alternative configurations. This Committee issued its final report on September 10, 1987. The Committee found that the revised baseline configuration was "a satisfactory starting point for the Space Station...and reflects thoughtful compromises amcng the priorities and sometimes conflicting requirements of its early scientific and engineering users." The Committee also stressed the importance of having a robust space transportation system, development of an adequate ground test program and backup hardware policy, strengthened Space Station program management, and emphasis on the operational aspects of the program. Preparation of a new Space Station program cost estimate in early 1988 was also advocated. These recommendations will receive special attention during the upcoming Program Requirements Review.

The NASA studies include an extensive series of analyses relating to the Space Station operations, led by the Space Station Operations Task Force (SSOTF). The results of the SSOTF's work were sent to Congress in the fall of 1987. Concurrent and subsequent study efforts were also conducted in the areas of operations cost management and Space Station science operations management concepts, These reports were sent to Congress in August and October 1987, respectively. NASA also conducted a transportation study that reviewed the capability of the Shuttle as well as other unmanned launch vehicle systems to provide space transportation in support of on-orbit assembly and Space Station operations. Results of this study were furnished to the NRC and subsequently documented in a report transmitted to Congress in January 1988.

Also, as directed in Congressional legislation, NASA prepared and forwarded to Congress an additional Development report; the Space Station program plan for selective design parameters, submitted in April 1987. This report is consistent with and supportive of the revised baseline program's flight hardware configuration and overall transportation, assembly, and operations planning.

Due to the bipartisan budget agreement, the Congress directed a significant reduction in the funding appropriated for the Space Station program in FY 1988. The amount requested by NASA for FY 1988, $767.0 million, was reduced to $425.0 million including $100.0 million transferred from 1987 replacement orbiter production funds. After adjustments for a directed realignment between the research and development appropriation and the research and program management appropriation, the revised plan for FY 1988 is $392.3 million.

NASA is developing revised program cost estimates, both annual and total consistent with the current budget allocation. The revised estimates will include necessary adjustments to program milestones. The report requested by Congress in late February will provide NASA's initial assessment. In addition, NASA will complete a management plan responsive to the recommendations of the National Research Council which will also address necessary civil service staffing levels to support the program. The final capital development plan and a revised Space Station development plan will be submitted following review of the revised program costs and milestones.

This budget requests the funding levels for the Space Station of $962.5 million for the present budget year, $2,130.2 million for FY 1990 and $2,912.5 million for FY 1991. The Administration is requesting legislation for a Congressional commitment to a three year advance authorization and appropriation of Space Station funds for FY 1989 through FY 1991. Later this year, the Administration plans to request legislation to establish a total program cost ceiling. These measures on the part of Congress and the Administration will provide increased program stability while maintaining cost control discipline for both development and operations. The long term commitment will help assure potential international participants that the U.S. will recognize the importance of cooperation on the Space Station program.

In support of the President's policy on the commercial use of space, **NASA** will, in consultation with OMB, revise its guidelines on the commercialization of the Space Station to reaffirm, clarify and strengthen its commi'tment to private sector investment and involvement in the Space Station program. Proposals for commercial involvement in the development of the revised baseline program will be considered in the Program Requirements Review (PRR). NASA will give positive consideration to proposals to accelerate private sector investment in Space Station development and operations in the form of either goods or services which have not yet been contracted. Further, **NASA** will seek to reply on private sector design, financing, construction and operation of future Space Station requirement, including those currently under study.

RESEARCH AND DEVELOPMENT

FISCAL YEAR 1989 ESTIMATES

BUDGET SUMMARY

OFFICE OF SPACE STATION — SPACE STATION PROGRAM

SUMMARY OF RESOURCES REQUIREMENTS

DEVELOPMENT	1987 Actual	1988 Revised Budeet	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Management and integration.....	17,900	121,100	146,500	169,400
Pressurized modules.....	47,500	195,000	55,000	188,000
Assembly hardware/subsystems.....	39,700	197,400	82,000	288,000
Platforms and servicing.....	10,100	57,500	26,000	56,000
Power system.....	29,300	81,700	31,000	154,000
Operations/utilization capability.....	2,500	48,100	26,300	80,000
Total.....	147,000	700,800	366,800	935,400

OBJECTIVES AND STATUS

As a research facility in space, the Space Station will provide opportunities for significant advances in science, technology and commerce. It must be flexible yet durable in its capabilities, as the Station will be on orbit for many years. It must be operationally affordable for its success will be measured by its operational utility. The objectives of the program are: (1) to establish a permanently manned research facility in low-Earth orbit by the mid-1990's with the capability to evolve to meet future needs; (2) to enhance mankind's evolving ability to live and work safely in space; (3) to stimulate technologies of national importance (especially automation and robotics) by using them to provide needed capabilities; (4) to provide cost-effective operation and utilization of continually improving facilities for

scientific, technological, and operational activities enabled or enhanced by the presence of man in space; (5) to foster mutually beneficial international cooperation in space; (6) to create and expand opportunities for private sector activity in space; (7) to enable the evolution of the Space Station to meet future needs and challenges; and, (8) to provide unmanned platforms for long duration scientific and operational observations. The combination of manned, unmanned, and automated systems will establish a broad spectrum of capabilities responsive to both currently identified and evolutionary needs of space science, technology, and commerce.

Following completion of a three-year definition and advanced technology development phase, the development program was initiated in FY 1987. The selected revised baseline configuration includes a permanently manned Space Station, unmanned platforms, and the associated ground-based infrastructure. The major physical elements of the configuration to be developed by the U.S. include pressurized habitation and laboratory modules, with a shirt-sleeve environment for crew habitation and for conducting experiments under microgravity conditions; resource nodes linking the modules in which command and control, docking, and extravehicular activity (airlocks) functions will be based; high power solar arrays; a truss structure featuring accommodations for attached payloads and the Flight Telerobotic Servicer; logistics elements; extravehicular capabilities; and, a polar platform carrying Earth Observing System instruments to be developed under the Space Science and Applications program. The configuration is expected to include elements provided by the Program's international partners. These elements are the Japanese Experiment Module, which includes a pressurized laboratory, an exposed module for payloads, and a logistics module; the Canadian Mobile Servicing System; and, the European Space Agency's pressurized laboratory, polar platform, and Man-Tended Free Flyer. The Space Station will be able to support a crew of eight and provide a total average power level of not less than 75 kilowatts, using photovoltaic arrays.

The ground-based infrastructure needed for the development and operations of the Space Station include the development of capabilities for systems engineering and integration, a distributed system for technical and management information transmission, software development tools, prelaunch processing, mission operations, engineering support, integrated testing, and payload operations support.

The U.S. Station space hardware elements will be developed by four NASA field centers. The Space Station Program Office in Reston, Virginia has the task of managing and integrating the technical development of the entire program. The four "work package" centers are the Marshall Space Flight Center in Huntsville, Alabama; the Johnson Space Center in Houston, Texas; the Goddard Space Flight Center in Greenbelt, Maryland; and the Lewis Research Center in Cleveland, Ohio. While not work package centers, the Kennedy Space Center at Cape Canaveral, Florida, and the Langley Research Center in Hampton, Virginia have key Space Station responsibilities. The Jet Propulsion Laboratory in Pasadena, California, will also play a central role in Space Station program requirements and assessment. NASA's development strategy for

the Space Station deliberately precluded utilization of a single prime contractor. For a program of such extended duration as the Station, dependency upon one company was not viewed as being in the best interest of the government. Moreover, the work package approach better utilizes NASA expertise at the field centers and fosters greater competition among U.S. industry. An essential component of this strategy is that NASA will have the responsibility to perform the overall systems engineering and integration and program management. The Space Station Program Office (SSPO) will be assisted in these program-wide integration functions by a Program Support Contractor (PSC), a Software Support Environment (SSE) contractor and a Technical and Management Information System (TMIS) contractor.

In 1987, the development contractors for the Space Station were selected. In May 1987, Boeing Computer Services was selected for the TMIS contract. This contract will facilitate both program control and engineering by enabling the transmission of information products and providing a means of distributing, maintaining, and archiving controlled data throughout the program. In July 1987, Grumman Aerospace was selected for the Program Support Contract. Grumman and its team will support NASA in a variety of areas, including systems engineering and analysis, distributed systems integration, technical integration, element and launch package integration, user interface planning, and program management and control. Also in July, the Lockheed Missiles and Space Company was selected for the SSE system contract. The SSE system is designed to assure a standardized software development and maintenance environment, in order to minimize the development and cost risk inherent in the task of integrating flight and ground systems software developed by the various Space Station contractors. On December 1, 1987, NASA announced selection of four aerospace firms--Boeing Aerospace Company; McDonnell Douglas Astronautics Company; General Electric Company; and the Rocketdyne Division of Rockwell International--for final negotiations leading to award of contracts for the design, development and support of the components and systems comprising the permanently manned Space Station. Signing of these detailed contracts is anticipated in the spring of 1988.

The development program also includes the critical supporting development activities at the four NASA work package centers, and the development of the capability to operate and utilize the Space Station. Work package supporting development includes design engineering, hardware integration and test capabilities, and assembly and check-out test capabilities; the provision of Government Furnished Equipment (GFE); R&D facility outfitting; and, engineering management and analysis. These efforts support all of the work package prime contractors as well as overall NASA system engineering and integration efforts. The Operational and Utilization Capability Development (OUCD) activities support major facility development at the NASA work package centers and the Kennedy Space Center. These facilities are critical to the integration, pre-launch processing, and the missions operations and crew training of the Space Station systems.

Due to budgetary reductions made by the Congress in the FY 1988 appropriation process, Space Station development activities will build up at a slower pace than originally planned. Funding constraints will delay the accomplishment of the program requirements review (PRR) process. The PRR will provide the requirements baseline from which the prime work package contractors will proceed to design Space Station systems and elements. This will lead into the integrated Space Station Preliminary Design Review (PDR) in 1989, which will provide an evaluation of the design approach of the work packages. Successful completion of the PDR will result in the readiness to proceed with detailed design of the Space Station flight and ground hardware and software. The effects of the FY 1988 funding cutbacks and the revised phasing of subsequent year funding are currently being assessed by the Space Station Program Office, in concert with the development contractors.

BASIS OF FY 1989 FUNDING REQUIREMENT

Management and Integration

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Management and integration.....	17,900	121,100	146,500	169,400

OBJECTIVES AND STATUS

The Space Station program includes the participation of all NASA centers, numerous contractors from all over the United States, and international partners. An activity this large and complex requires a central focus for managing the systems engineering and integration (SE&I), data management and information systems efforts, and safety, reliability, and quality assurance (SR&QA) activities. NASA, rather than a single prime contractor will perform this essential task. To assist NASA in this function, the Space Station Program Office has procured the services of a Program Support Contractor (PSC), a Software Support Environment System Contractor (SSE) and a Technical and Management Information System Contractor (TMIS). The Jet Propulsion Laboratory is providing an independent assessment capability of program requirements and status.

The SE&I responsibilities include overall systems engineering; work package integration for prime contractors and supporting development activities; integration of potential international elements and private sector goods or services, as well as the U.S. Flight Telerobotics System (FTS) into the Space Station system; and overall safety, reliability, and quality assurance program. Also included are the development of integrated engineering models, trade-off studies on design parameters, allocation of Space Station resources among the program elements, configuration control of the overall design, and resolution of competing design requirements. Grumman Aerospace, Bethpage, New York, was awarded the Program Support Contract (PSC) in July 1987 to assist the Space Station Program Office in these and other activities.

Management and Integration also include responsibility for the Space Station Information System (SSIS). The primary SSIS tools are composed of the Technical Management and Information System (TMIS) and the Software Support Environment (SSE). The SSIS is the operational end-to-end system by which the data flow between the onboard systems and ground control or data processing systems and the scientific users will be provided. The SSIS will be a distributed system spanning the total information flow networks required to operate the Space Station.

TMIS is an integrated system of technical and management information processes, automatic data processing hardware and software, communications networks, and procedures designed to support the design, development, and operations of the Space Station. TMIS will allow all NASA centers and contractors to have a standardized process and procedure for the sharing of information. Boeing Computer Services was selected in May 1987 as the TMIS prime contractor.

The Software Support Environment contract provides a set of rules and tools used to govern the development of Space Station software. The SSE development facility will be used to develop and maintain the SSE software requirements, design and test tools, compilers, debuggers, models and simulations. These tools will be used by the software production facilities to develop, integrate, and maintain the program's ground and flight software. The SSE system will be developed incrementally with its capabilities time-phased to meet essential program needs. In July 1987, Lockheed Missiles and Space Company was selected for this contract. The Johnson Space Center will be responsible for the SSE contract management.

CHANGES FROM FY 1988 REVISED BUDGET

Management and Integration has increased from $121.1 million to $146.5 million, an increase of $25.4 million over the FY 1988 revised budget. This adjustment is the net result of reductions made in TMIS and a revised estimate of the necessary staffing for the Program Support Contract to support critical program requirements.

BASIS OF FY 1989 ESTIMATE

In FY 1989, the Program Support Contractor (PSC) will support the critical System Engineering activities that will begin after completion of the Preliminary Requirements Review in 1988. This system engineering effort includes activities at the Space Station Program Office, along with critical system engineering and integration support to the Program Integration Offices at each Work Package center as well as at KSC. This includes updating all key systems level schedules and documentation, refining systems level assembly and check-out logic, and establishing systems level verification requirements and procedures. The PSC effort is key to successful completion of the system-level Preliminary Design Reviews currently anticipated to begin in late 1989.

During 1989, the TMIS contractor will be working under the direction of SSPO to define, design, and implement the requisite components of the system as well as provide training to TMIS users as the system evolves. During 1989, the SSE contractor will prepare the preliminary design document for the software production facility, complete the facility contract end item list, and bring the facility on line to support the preliminary and critical design reviews.

Safety, reliability, and quality assurance reviews have been an essential element of the Space Station program since inception. FY 1989 emphasis will be on the development of criteria to perform critical reviews at both the black box and system level, application of the criteria to assess safety of the proposed design, and refinement of established program-wide quality assurance standards.

BASIS OF FY 1989 FUNDING REQUIREMENT

Pressurized Modules - Work Package 1, Marshall Space Flight Center

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Pressurized modules.....	47,500	195,000	55,000	188,000

OBJECTIVES AND STATUS

Boeing Aerospace Company of Huntsville, Alabama has been selected for negotiations and is proceeding under letter contract in support of the Program Requirements Review (PRR). As the prime contractor Boeing will develop flight hardware for the pressurized modules and related services. Members of the Boeing prime contract team include Teledyne Brown Engineering (Huntsville, Alabama), Lockheed Missile and Space Company (Sunnyvale, California), Hamilton Standard (Windsor Locks, Connecticut), Garrett Airesearch (Torrance, California), Grumman Aerospace Corporation (Houston, Texas), ILC Space Systems (Houston, Texas), and Fairchild-Weston Systems (Syossett, New York).

Major components of this work package include the U.S. laboratory and habitability modules and logistics modules and elements; nodes structure; airlock systems; environmental control and life support system; internal thermal, audio, and video systems; basic module outfitting; and associated software.

On-going activities include procurement and development of the engineering breadboard components, including long-lead ECLSS components; development and evaluation of computerized structural models of the manned modules' components; preparation of Pressurized Module program requirement documents in support of the Program Requirements Review; and, continued evaluation and testing of critical materials and on orbit maintenance techniques. Integration of prime contractor efforts into the continuing supporting development activities is a critical part of the on-going effort.

CHANGES FROM FY 1988 REVISED BUDGET

The revised FY 1988 budget estimate of $195.0 million was reduced by *$140.0* million to $55.0 million, The impact of this reduction is currently under review. In general, the reduction will be accomplished by deferring the build-up of the prime contractor manpower, limiting supporting development manpower hiring and equipment purchases, and constraining supporting engineering development capabilities.

BASIS OF FY 1989 ESTIMATE

Specific prime contract activities planned to occur in FY 1989 include preparation of preliminary design specifications of all the pressurized modules elements and systems; commonality analyses and trade studies for evaluation of the use of common hardware; mock-up drawings; long lead procurements for the labs and racks; manned systems testing; and detailed engineering drawings for the nodes and airlocks. Also occurring during this period will be the design, development and long lead procurements for internal audio/video and thermal subsystems.

Planned supporting development efforts are necessary to assist the hardware contractors in areas such as overall module integration, independent engineering safety and quality assurance assessments, establishment of test requirements, development of test and test bed facilities, and establishment of design requirements. Critical activities in the Work Package 1 supporting development area include completion of the test beds and breadboards in preparation for extensive use throughout the development phase in areas such as attitude control, audio and video systems, process material management system, electrical systems, propulsion thruster assembly, and mechanisms. Also planned is procurement and testing of the Environmental Control Life Support System (ECLSS) technology demonstration hardware; development of data bases for materials and materials evaluation, including atomic oxygen exposure simulation work as well as evaluation of corrosion, compatibility, and contamination properties; and the development and evaluation of the design requirements for the flight elements (modules and nodes).

BASIS OF FY 1989 FUNDING REQUIREMENT

Assemblv Hardware/Subsystems - Work Package 2, Johnson Space Center

	1987 Actual	1988 Revised Budeet	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Assembly hardware/subsystems.....	39,700	197,400	82,000	288,000

OBJECTIVES AND STATUS

McDonnell Douglas Astronautics, of Huntington Beach, California, and Houston, Texas, has been selected as the prime contractor for Work Package 2 and is currently proceeding under letter contract to support the Program Requirements Review (PRR). Assisting them will be IBM (Houston, Texas, and Owego, New York), Lockheed Missile and Space Company (Houston, Texas, and Sunnyvale, California), RCA Corporation (Camden, New Jersey), Honeywell (Clearwater, Florida), and Astro-Aerospace Corporation (Carpinteria, California). The scope of this contract encompasses the design and development of the hardware and software for: the data management system; the truss structure, mechanisms, and utilities; airlocks; guidance, navigation, and control; communication and tracking; propulsion; thermal control; and EVA equipment. Also included are the resource node outfitting; on-orbit assembly planning; mobile servicing system transporter; and associated software.

On-going prime contractor and supporting development contractor activities include design efforts in the areas of supporting truss structure, the mobile base for use with the Canadian Mobile Servicing Center, outfitting requirements of the airlocks and modes, and subsystem requirements for thermal, data management, communications and tracking, propulsion, guidance, navigation and control, and extravehicular activity. All of these efforts are critical to support the PRR schedule for 1988.

CHANGES FROM FY 1988 REVISED BUDGET

The revised FY 1988 budget estimate of $197.4 million was reduced by $115.4 million to $82.0 million. The impact of this reduction is currently under review. In general, the reduction will be accomplished by deferring the build-up of the prime contractor manpower, limiting supporting development manpower hiring and equipment purchases, and constraining supporting engineering development capabilities.

BASIS OF FY 1989 ESTIMATE

Specific activities being performed by the prime and subcontractors during 1989 include the hardware evaluation of breadboards and engineering models for communications and tracking; development testing of fluid system components, rotary joints, and utility mock-up of the truss structure; fabrication of the model to be used for testing the mobile transporter; development and testing of the prototype engineering units for the data management and thermal control systems; real time simulation of the guidance, navigation, and control system; development and testing of the prototype propulsion assembly systems; breadboard mock-up and development testing of the airlock structures; and build up of a high fidelity mock-up of the resource nodes.

Critical supporting development work managed by the Johnson Space Center will be pursued in the areas of technical program design support; automated assembly, test, and analysis; and Government Furnished Equipment (GFE) hardware development. Other supporting development activities include integration and engineering analyses of data management, thermal, communication, manned systems, mechanical, propulsion, EVA, and guidance/navigation subsystems. Government furnished equipment and engineering test beds for thermal, communications, data management, EVA, and manned systems will be developed and utilized to test contractor hardware to ensure a thorough understanding of the functions, performance, and interfaces necessary to build and operate the Station.

Supporting development activities during 1989 include subsystem model development, preliminary design evaluation, breadboard tests of the EVA life support system, hard suit and glove technical demonstration hardware development, and preliminary integration, test, and verification plans. Also included is development of the Multi Systems Integration Facility (MSIF) which will be used for system to system integrated verification testing and hardware/software verification testing.

BASIS OF FY 1989 FUNDING REQUIREMENT

Platform and Servicing - Work Package 3. Goddard Space Flight Center

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars		
Platform and servicing.....	10,100	57,500	26,000	56,000

OBJECTIVES AND STATUS

General Electric Company, Astro Space Division with locations in Valley Forge, Pennsylvania, and East Windsor, New Jersey was selected to design and develop the platform and servicing facility planning activities. GE is currently proceeding under letter contract in support of the Program Requirements Review (PRR). Assisting them will be the TRW Corporation, Redondo Beach, California.

This work package provides for the design and development of a free flying, unmanned, polar-orbiting platform which will carry scientific experiments in Sun-synchronous or other near polar inclination orbits; two sets of attached payload accommodation equipment for the mounting of various scientific instruments on the manned base; and a pointing system for manned base attached payloads requiring a high degree of pointing accuracy, including both Earth-viewing and space-viewing instruments. Also included in this work package is the integration of the Flight Telerobotic System (FTS) to the Station and the definition of requirements and interfaces for a satellite servicing facility which could be used to service Station payloads and free flying spacecraft. Effective interface with potential users is a key component of this effort and will continue at a high level throughout the entire development program.

Both prime contractor and in-house efforts are focused on developing an integrated, comprehensive set of system requirements to support the upcoming PRR. The Polar Platform requirements for hardware and subsystem technology development, shared with the manned base, will require close integration of Polar Platform and Payload Servicing design requirements with the manned base subsystem design activities. Emphasis is being placed on maintaining an effective interface with potential users of the Station to assure adequate accommodation of the requirements into the baseline manned base design.

CHANGES FROM FY 1988 REVISED BUDGET

The revised FY 1988 budget estimate of $57.5 million was reduced by $31.5 million to $26.0 million. The impact of this reduction is currently under review. In general, the reduction will be accomplished by deferring the build-up of the prime contractor manpower, limiting supporting development manpower hiring and equipment purchases, and constraining supporting engineering development capabilities.

BASIS OF FY 1989 ESTIMATE

Significant activities being performed by the prime contractor during FY 1989 include polar platform design and development; design and development of payload accommodation equipment and course pointing systems; subsystem commonality analysis; evaluation of Phase I servicing architecture; and applications software development.

In order to support the work being done by the prime contractor and his subcontractors, vital supporting development activities will be carried out under NASA direction. This includes technical support studies to define polar platform user requirements and performance; user integration activities, integration planning, software development, and the design and development of thermal and data management test beds. Other efforts encompass platform subsystem and component trade studies; servicing strategy studies; analysis of requirements for common hardware for attached payloads; payload pointing system base motion disturbance studies; and engineering support for early STS thermal flight test experiments.

BASIS OF FY 1989 FUNDING REQUIREMENT

Power System - Work Package 4, Lewis Research Center

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Power system.....	29,300	81,700	31,000	154,000

OBJECTIVES AND STATUS

Rocketdyne Division, Rockwell International, Canoga Park, California, was selected as the prime contractor to design and develop the power system for the Space Station. Rocketdyne is currently proceeding under letter contract in support of the Program Requirements Review (PRR). Assisting them will be Ford Aerospace, Palo Alto, California; Harris Corporation, Melbourne, Florida; The Garrett Corporation, Tempe, Arizona; General Dynamics Corporation, San Diego, California; and Lockheed Missiles and Space, Inc., Sunnyvale, California.

The scope of this work package consists of development of a 75 KW photovoltaic (PV) power system, using solar arrays to collect power and batteries for storage; the manned base Power Management and Distribution (PMAD) systems; the engineering and system architecture to accommodate the future addition of solar dynamic capability to the manned base; and fabrication of the power systems components for the polar platform.

Early flight hardware delivery requirements impose a strict delivery schedule on this work package to provide hardware in a timely fashion to other centers for inclusion in their development activities. In-house efforts will be focused on procurement and testing of longlead hardware that will be used in the power subsystems of both the Polar Platform and the Manned Base. Component testing continues on battery life, power management and distribution (PMAD) breadboard module design, and solar cell life-cycle testing. The prime contractor is beginning development of power system design requirements that are consistent with development of the overall Space Station hardware design. Critical activities include design and development of engineering test hardware and identification of critical long-lead components required for the fabrication of the power subsystem flight hardware.

CHANGES FROM FY 1988 REVISED BUDGET

The revised FY 1988 budget estimate of $81.7 million was reduced by $50.7 million to $31.0 million. The impact of this reduction is currently under review. In general, the reduction will be accomplished by deferring the build-up of the prime contractor manpower, limiting supporting development manpower hiring and equipment purchases, and constraining supporting engineering development capabilities.

BASIS OF FY 1989 ESTIMATE

The prime contractor will be working towards baselining the technical specifications and doing the initial design activities required to support the PDR. The prime contractor will prepare the test cells needed for testing the various components of the system; continue the design and development of the flight application and ground support software; continue the design and development of the photovoltaic power module; initiate the electrical systems integrated tests: and continue design and development of the power management and distribution system, including software and hardware verification testing.

The critical supporting development activities that will continue include power subsystem and battery life tests as well as overall evaluation of the contractor design. This involves the construction of breadboards for the power management and distribution system and subsystem engineering support, power system integration planning, and power system operations planning and analysis. In-house design and evaluation of solar array test hardware; models and dynamic analysis and testing of nickel-hydrogen cells are planned. The power systems test equipment and the power management and distribution system breadboards will be acquired so that intensive analysis of the various designs and components can be performed.

BASIS OF FY 1989 FUNDING REOUIREMENT

Operations/Utilization Capability Development

	1987 Actual	1988 Revised Budnet	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Operations/utilization capability.....	2,500	48,100	*26,300*	80,000

OBJECTIVES AND STATUS

The purpose of the Operations/Utilization Capability Development (OUCD) program is to integrate operational support planning, and develop the capability to conduct flight and ground operations in support of the Space Station and to fully integrate the users into the planning for and actual operations of the Space Station. The majority of this work is being performed at the Kennedy Space Center, the Marshall Space Flight Center, and the Johnson Space Center, although a number of key operations elements are being designed and developed at other NASA centers. Goddard Space Flight Center will develop engineering support centers for both the platform and attached payload work. Johnson Space Center will be home to the Space Station Training Facility as well as the Space Station Control Center. The Kennedy Space Center will provide much of the user integration, pre-launch and post-landing capability, integrated logistics capability, and ground data management systems. Kennedy will also have responsibility for the planning and outfitting of their Software Production Facility and the Space Station Processing Facility. Marshall Space Flight Center will develop, outfit, and manage the Payload Operations Integration Center, develop the payload mission planning center, and be actively involved in the operations training simulation development.

Each of the above centers will also be involved in developing user integration capabilities for the Space Station program. This work will include the development of procedures to establish user requirements and assist in user selection as well the tools, equipment and systems necessary to plan for and integrate the user fully into the operation of the Space Station ground and flight systems.

CHANGES FROM FY 1988 REVISED BUDGET

The revised FY 1988 budget estimate of *$48.1* million was reduced by $21.8 million to $26.3 million. The impact of this reduction is currently under review. This reduction is consistent with the schedule delay anticipated in the development program. This will involve deferral of design and development activities for planned operational facilities and pre-launch processing and checkout systems.

BASIS OF FY 1989 ESTIMATE

In FY 1989, the detailed and development efforts for the Space Station Control Center (SSCC) and Space Station Training Facility (SSTF) at JSC will increase in order to support the late 1989 Preliminary Design Reviews (PDRs). Also, the design and development of the government furnished equipment (GFE) for equipment transportation and the ground data management system hardware used to outfit the Space Station Processing Facility (SSPF) at KSC will continue. Finally, the development of the Payload Operations Integration Center (POIC) at MSFC will continue in order to support early identification and integration of user requirements into the Space Station PDR process.

BASIS OF FY 1989 FUNDING REQUIREMENT

FLIGHT TELEROBOTICS SERVICER

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Flight telerobotics servicer.....	20,000	21,500	21,500	20,000

OBJECTIVES AND STATUS

The Flight Telerobotics Servicer will be a highly automated telerobotic device capable of precise manipulations in space. It will be operated by the astronauts using a mix of remote and supervisory controls. The FTS will be used to assist in assembly and servicing operations. It is intended that the FTS will be an evolutionary product capable of accommodating increasingly sophisticated operations for wide application in space as well as application of the technology for use on the ground. The program is managed by Goddard Space Flight Center with support from other NASA centers and contractors. The definition and development effort includes a program to select and modify evolving technology and identify requirements for new technology; a flight demonstration to verify design and operations concepts; the design and development of the Space Station flight system; and a ground system program to provide continuing capability to evaluate and implement advanced robotic technology and assist in training and on-orbit operations.

In January 1988, two separate $1.5 million contracts for a Phase B definition of the FTS were awarded. The recipients of these firm fixed price, nine month contracts were Grumman Corporation and Martin Marietta. These contracts will culminate in the selection of a concept for the FTS which will be designed and developed by one prime contractor.

BASIS OF FY 1989 ESTIMATE

During 1989 work will continue on the design of the flight and ground systems that will support the FTS and the preparation for an STS demonstration test flight that will be conducted in the early 1990's. The FTS, as a vital part of the Space Station assembly process, is planned to be used to reduce EVA requirements during the assembly of the Station.

BASIS OF FY 1989 FUNDING REOUIREMENT

TRANSITION DEFINITION

	1987 Actual	1988 Revised Budnet	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Transition definition.....	---	5,000	4,000	12,000

OBJECTIVES AND STATUS

Because the Space Station is planned to have an operational life spanning several decades and because the inherently dynamic nature of the program will require a continuously evolving set of capabilities, it is necessary to provide for evolution planning and advanced development work. The Transition Definition effort which began in FY 1988 has two main components, evolution studies and advanced development. One main objective of this program is to determine the appropriateness and readiness of major new technologies prior to their incorporation in the Space Station system. A second main objective is to define the direction and scope of future Space Station growth capabilities consistent with user requirements. A third main objective is to develop greater private sector investment and involvement in development and operations. The results from the Transition Definition program will provide NASA substantive data on new technologies and changing user requirements, and opportunities for private sector participation in the Space Station thereby enhancing decisions as to applicability and expected performance of new missions and technologies on whatever evolutionary path the Space Station follows.

CHANGES FROM FY 1988 REVISED BUDGET

The revised FY 1988 budget estimate of $5.0 million was decreased by $1.0 million. Lower priority tasks have been deferred, while retaining those tasks which need to be accomplished in preparation for the initial requirements definition and design reviews of the Space Station.

BASIS OF FY 1989 ESTIMATE

FY 1989 Transition Definition activity will include studies involving the definition of Station evolution requirements; operations analyses to establish growth modes to optimize user accommodations; and technology forecasts that will enable cost-effectiveness upgrades to increase the operational efficiency and productivity of the Station.

During 1989, efforts will continue on evolutionary proof-of-concept technology as well as identification of technology that may be a good candidate for advanced development in terms of increasing Space Station systems productivity. Areas of focus will be on enabling technology changes to be transparent to users, advanced power systems, and advanced systems automation technology. Efforts to be studied in the area of productivity enhancement may include ECLSS automation enhancements, advanced intelligence systems, and robotics.

OFFICE OF SPACE FLIGHT **SPACE TRANSPORTATION PROGRAM**

PROGRAM OBJECTIVES AND JUSTIFICATION

The principal areas of activity in Space Transportation Capability Development include the Spacelab; the Upper Stages required to place satellites in high altitude orbits; the Engineering and Technical Base support at the manned space flight centers; Payload Operations and Support Equipment for accommodating NASA payloads; Advanced Programs study and evaluation efforts; the development and first flight of the United States/Italian Tethered Satellite System; and the development and first flight of the Orbital Maneuvering Vehicle.

Spacelab was developed jointly by NASA and the European Space Agency (ESA). It is a major element of the Space Transportation System (STS) that provides a versatile, reuseable laboratory which is flown to and from Earth orbit in the orbiter cargo bay. The development program continues with a recertification program to insure flight safety, the procurement of flight hardware to support the flight program and necessary modifications including replacing the onboard computer system.

Upper Stages are required to deploy payloads to orbits and trajectories not attainable by the Shuttle or expendable launch vehicles alone. The program provides for procurement of stages for NASA missions, for technical monitoring and management activities for government and commercial Upper Stages, and a solid rocket motor integrity program to establish an engineering data base for improving the success rate of U.S. built solid stage components.

The Engineering and Technical Base provides the core capability for the engineering, scientific, and technical support required at the Johnson Space Center (JSC), the Kennedy Space Center (KSC), the Marshall Space Flight Center (MSFC), and the National Space Technology Laboratories (NSTL) for research and development activities. Additional requirements above the core level of capability are funded by the benefitting programs.

The Payload Operations and Support Equipment program develops and places into operational status the ground and flight systems necessary to support the STS payloads during pre-launch processing, on-orbit mission operations and, when appropriate, post-landing processing. Included within this program area are the STS support services for NASA payloads, satellite servicing tools and techniques development, flight demonstrations, and multi-mission payload support equipment.

RESEARCH AND DEVELOPMENT

FISCAL YEAR 1989 ESTIMATES

BUDGET SUMMARY

OFFICE OF SPACE FLIGHT — SPACE T I TY DEVELOPMENT

SUMMARY OF RESOURCES REQUIREMENTS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
		(Thousands of Dollars)			
Spacelab	72.000	72.300	66.500	80.400	RD 2-6
Upper stages	156.100	159.500	154.900	146.200	RD 2-9
Engineering and technical base	133.400	137.200	133.900	158.900	RD 2-11
Payload operations and support equipment	40.400	83.000	84.600	67.300	RD 2-13
Advanced programs	33.600	24.900	46.400	45.000	RD 2-15
Advanced launch systems	---	---	65.100	13.000	RD 2-18
Tethered satellite system	10.600	7.100	12.100	23.800	RD 2-20
Orbital maneuvering vehicle	45.000	79.700	46.300	96.500	RD 2-21
Total	491.100	563.700	609.800	631.100	

Distribution of Program Amounts By Installation

Johnson Space Center	110.600	106.600	112.100	146.000
Kennedy Space Center	34.700	66.400	61.400	78.400
Marshall Space Flight Center	303.400	343.400	332.900	329.500
National Space Technology Laboratories	8.400	5.100	5.100	5.600
Goddard Space Flight Center	3.900	1.600	4.200	6.400
Jet Propulsion Laboratory	1.400	1.500	1.100	1.500
Langley Research Center	1.500	600	900	800
Lewis Research Center	1.100	500	500	500
Ames Research Center	1.300	1.400	1.500	1.300
Headquarters	24.800	36.600	90.100	61.100
Total	491.100	563.700	609.800	631.100

Advanced Programs conducts concept feasibility studies and selected system definitions and preliminary design (Phase B) studies and undertakes related high leverage advanced development to provide the technical and programmatic data to identify evolving space transportation and system requirements and to evaluate new space transportation initiatives. Complementary objectives are to assimilate generic technology and advanced planning activities, and to provide an advanced planning programmatic link between the Office of Space Flight and other NASA program offices. Activity is focused on four major areas--advanced transportation, advanced operations support, satellite servicing and advanced missions. Concept definition and key advanced development are underway and planned in these areas to assess performance, reliability and operational efficiency improvements, and to reduce future program risks and development costs through the effective use of new technology. Included as part of the Advanced Programs Development Program are definition studies of a Crew Emergency Return Vehicle (CERV) to provide approaches for additional crew return capability from the Space Station manned base.

The Advanced Launch System (ALS), as outlined in the joint DOD/NASA Report to Congress, is a joint DOD/NASA program to develop and field this nation's next generation of unmanned launch system. The ALS program, will permit this nation to achieve the goal of reduced cost to space. Both NASA and the DOD are moving aggressively forward with ALS and are jointly managing the effort. As directed by Congress in the FY 1988 DOD Appropriation Bill, a total of $70 million has been transferred from DOD to NASA to fund the NASA directed ALS-Propulsion Focused Technology program activities. Within this total, $65.1 million will be utilized in STS Capability Development and $4.9 million will be used in the Research and Program Management Appropriation to fund the necessary support to these propulsion activities. Advanced Program Development will direct and fund study efforts for unique civil mission requirements not satisfied in the joint DOD/NASA ALS baseline design.

The Tethered Satellite System (TSS), a joint Italian/United States development effort, will provide a new reusable capability for conducting space experiments and unique tethered applications in regions remote from the Shuttle orbiter. The objectives of the initial TSS mission are twofold: (1) to verify the controlled deployment, operation, and retrieval of the TSS, and (2) to quantify the interaction between the satellite/tether and space plasma in the presence of a current drawn through the tether.

The development of the Orbital Maneuvering Vehicle, initiated in 1986, will provide a capability for payload delivery, retrieval, and servicing beyond the reach of the Space Shuttle or the Space Station.

OBJECTIVES AND STATUS

Four dedicated Spacelab flights have been flown on the STS including the first Spacelab reimbursable flight, Deutschland-1 (D-1). In addition, several smaller Spacelab elements have flown on other STS flights as partial payloads. These flights have demonstrated the unique capabilities and benefits offered by many of the Spacelab elements. The Spacelab Astro-1 mission, scheduled for the first quarter of 1989, will be the first Igloo Pallet Configuration of the Spacelab Pallet System (SPS). Preparations are now in process for resumption of operational flights for DOD, international, and NASA scientific experiments.

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In Upper Stages, funding is included for production, launch, flight support, and integration of Inertial Upper Stages (IUS) vehicles to accommodate the TDRS D, E, and F missions, and the Galileo, Ulysses (including a PAM-S vehicle), and Magellan planetary missions. The IUS was developed under a DOD contract to provide the capability to place payloads of up to 5,000 pounds into geosynchronous orbit. There are currently no STS requirements for the commercially developed PAM, which is capable of transporting up to *4100* pounds of payload into geosynchronous transfer orbit. The PAM, when utilized in the Delta ELV configuration, is funded with the ELV in Space Flight Control and Data Communications.

The Transfer Orbit Stage (TOS) is a three-axis stabilized perigee stage that is being commercially developed by the Orbital Sciences Corporation for use with the Shuttle or on Titan. It will have the capability of placing up to 13,000 pounds into geosynchronous transfer orbit. Production of a TOS vehicle for the Mars Observer mission is included in the FY 1989 budget.

The Solid Propulsion Integrity Program (SPIP) objective is to lay in place the necessary engineering capability for improving the success rate of U.S.-built solid rocket motors. The initial phase of the program, started in 1984, addressed motor nozzles and has made good progress in determining root causes and solutions to the persistent problems plaguing motor nozzles. The results and findings are being used in the Shuttle Solid Rocket Motor redesign effort. The program scope is being expanded to examine motor bondlines as well as continuing the nozzle efforts.

In Payload Operations and Support Equipment, payload integration support and payload-related hardware are developed and furnished for NASA payloads. Multi-mission payload support equipment is developed and procured including fiber optic cabling and equipment for communication links between the payload processing facilities; standard sets of wire harnesses for interconnection of mixed cargoes in the orbiter payload bay; and payload display and controls in the orbiter vehicle crew cabin.

The Advanced Programs effort is focused on four major areas--advanced transportation, advanced operations support, satellite servicing, and advanced missions. Concept definition and key advanced development are underway and planned in these areas to assess performance, reliability, and operational efficiency improvements, and to reduce future program risks and development costs through the effective use of new technology. Advanced transportation study efforts focus on cargo vehicles, manned vehicles, and space transfer vehicles. Studies are underway to define the evolution of manned vehicles, including Space Shuttle enhancement concepts (Shuttle Block II), and next generation concepts (Shuttle 11). In addition, definition studies are underway to analyze mission requirements for the design and development of a Crew Emergency Return Vehicle (CERV) to provide approaches for additional crew return capability from the Space Station. Advanced operations support systems efforts focus on the study and assessment of innovative ground, flight and on-orbit operations techniques to achieve improved safety as well as reduced life-cycle costs for space transportation and orbital systems. The complementary Advanced Operation Effectiveness activity will focus on demonstration of autonomous and expert systems technology to improve the safety and reduce the costs of Shuttle operations. The satellite servicing study effort, encompassing

satellite servicing systems and tether applications, focuses primarily on the development of systems and procedures designed to utilize Shuttle capabilities that are compatible with the Space Station and the Orbital Maneuvering Vehicle. Advanced missions activity will continue to focus, with expanded scope and increased depth, on potential manned and unmanned missions beyond the Space Station. Focused orbital debris studies, augmented by the development of a debris measurement radar, will be continued.

Studies, with a directed focus building upon the joint DOD/NASA Advanced Launch System (ALS) baseline design, are planned to examine vehicle and propulsion systems to satisfy national requirements. The ALS-Propulsion Focused Technology program, a NASA-directed element of the core DOD/NASA ALS program, is focused on demonstrating the performance and operating capabilities of critical propulsion system components.

The Tethered Satellite System (TSS) hardware development was initiated in N 1984 and systems definition studies were completed in FY 1985. Comprehensive design and requirements validation; procurement of long lead time flight hardware elements and tooling; systems development and integration; and deployer manufacturing and integration will continue through FY 1989. The Italians started satellite and core equipment development in N 1984. U.S. science instruments for the satellite are being funded in the Physics and Astronomy budget. A cooperative first flight on the Space Shuttle is presently planned for 1991.

The OMV will be a reuseable, remotely operated propulsion vehicle with the capability to deliver, retrieve and service payloads and spacecraft deployed at a wide range of altitudes and inclinations. The development contract was initiated in late 1986 with a planned initial capability in 1991. Based on budgetary reductions and current shuttle manifest planning, the initial capability requirement has been rescheduled to 1993. The initial operational use of the OMV is in support of the Hubble Space Telescope servicing requirements. The N 1989 budget request includes funds for continuation of the design and development, initial testing, and production of flight hardware.

BASIS OF FY 1989 FUNDING REQUIREMENT

SPACELAB

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Development	26,000	14,200	16,100	15,300
Operations	46.000	58.100	50.400	65,100
Total	72.000	72.300	66.500	80.400

OBJECTIVES AND STATUS

The Spacelab is a versatile facility designed for installation in the cargo bay of the orbiter which affords scientists the opportunity to conduct scientific experiments in the unique environment of space. The reuseable Spacelab system enhances the advancement of scientific research by serving as both an observatory and laboratory in space. Ten European nations, including nine members of the European Space Agency (ESA), have participated in this joint development program with NASA. ESA designed, developed, produced, and delivered the first Spacelab hardware: consisting of a pressurized module and unpressurized pallet segments, Igloo, instrument pointing subsystem (IPS), and much of the ground support equipment and software for both flight and ground operations.

NASA procured an additional set of Spacelab hardware from ESA under terms of the ESA/NASA Memorandum of Understanding and the Intergovernment Agreement. The remaining development activities include additional hardware to complete the Spacelab system, ground support equipment, hardware modifications, hardware acquisition, system recertification, qualification and procurement of reliable and high capacity AP-101S computers. Support software and procedures development, testing, and training activities not provided by ESA, which are required for the Spacelab, are also included in NASA's funding. Additional Spacelab hardware, including the initial lay-in of spare hardware, is being procured from European sources.

NASA is developing two principal versions of the Spacelab Pallet System (SPS). One will support missions requiring the igloo and pallet in a mixed cargo configuration like the Astro series; the other version will support missions that do not require use of the igloo such as the Space Technology Experiment Platform (STEP) and the Tethered Satellite System. Development of the Hitchhiker system is nearly complete. The Marshall Space Flight Center (MSFC) version of the Hitchhiker will fly at the next available opportunity.

The Spacelab operations budget includes mission planning, mission integration, and flight and ground operations. This includes integration of the flight hardware and software, mission independent crew training, system operations support, payload operations control support, payload processing, logistical support and sustaining engineering.

The first Spacelab reimbursable flight, Deutschland-1 (D-1), was flown during the first quarter of FY 1986. Astro-1, originally planned for flight in FY 1986 for observation of Halley's Comet, was delayed to FY 1989 due to the January 1986 Shuttle accident. The initial flight of the Goddard Space Flight Center Hitchhiker (HG-1) took place in the first quarter of FY 1986.

In addition to these missions, analytical and physical integration, configuration management, and software development for future flights will be conducted. Procurement of spares for both NASA-developed hardware and for hardware developed by U.S. companies under contract with ESA will continue throughout FY 1988. Operation of the depot maintenance program for U.S.-provided and European-supplied hardware and the procurement of replenishment spares will continue in FY 1989.

CHANGES FROM FY 1988 REVISED BUDGET ESTIMATE

The $5.8 million decrease reflects the delay in the Shuttle return-to-flight date, from last years plan of February 1988. The delay in STS flights reduced requirements for direct mission-related manpower for mission integration at MSFC and payload processing at KSC.

BASIS OF FY 1989 ESTIMATE

The FY 1989 request reflects signficant program restructuring and rescheduling of Spacelab missions resulting from the stand-down of the Shuttle. The current program provides leadtime for the integration and payload processing for launching two to three major Spacelab missions per year.

The FY 1989 development funds are required to complete development and verification of the MSFC Hitchhiker and the Enhanced Multiplexer Pallet System (EMPS) programs, complete the lay-in of both U.S. and European source spares, and for continuation of necessary hardware and GSE modifications and upgrades for return-to-flight recertifications as recommended by the Rogers' Commission in preparation for reflight in 1989.

In addition, funds are required to support payload operations and to continue payload integration support, mission independent training, and logistic support in preparation for launch of the Astro-1 mission and two Hitchhiker systems in FY 1989, and the Materials Science Laboratory (MSL-3 and MSL-4), and two to three Hitchhiker systems in FY 1990. Preliminary operations support will begin on the U.S. Microgravity Laboratory (USML) mission, which is planned for flight in 1992. The support for these missions includes analytical integration, configuration management, hardware integration and software

development and integration. Further, funding is also included to operate and maintain the MSFC Payload Operations Control Centers (POCC) required to support training and operations for all the Spacelab missions. Spacelab Operations also provides for replenishment spares, the operation of the depot for United States and European hardware and software, and sustaining engineering of all hardware and software. The FY 1989 estimate also includes activity on the Getaway Special (GAS) program which has been transferred from Shuttle Operations.

In addition to NASA missions the Spacelab program will also support three reimbursable missions: the U.S. DOD Starlab, the German D-2, and the Japanese SL-J.

BASIS OF FY 1989 FUNDING REOUIREMENT

UPPER STAGES

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Development	11,200	17,100	16,000	6,700
Procurement and operations	144.900	142.400	138.900	139.500
Total	156,100	159.500	154.900	146.200

OBJECTIVES AND STATUS

The STS upper stages are required to deploy payloads to orbits not attainable by the Shuttle or core stage expendable launch vehicle alone. The Inertial Upper Stage (IUS), and the commercially developed Payload Assist Modules (PAM-A, PAM-D and PAM-DII) are currently available for use. Several other upper stages are now being commercially developed, including the Transfer Orbit Stage (TOS), which will become available for use in the near future.

The IUS was developed under a DOD contract to provide the capability to place payloads of up to 5,000 pounds into geosynchronous orbit. The IUS has been launched from both the Shuttle and Titan 34-D Expendable Launch Vehicle. Four IUS vehicles were procured by NASA for launch of the initial four Tracking and Data Relay Satellite System (TDRSS) spacecraft; later, two additional IUS vehicles were ordered for TDRSS launches. The first three were funded through the TDRSS contract while the others are funded under this budget element. In addition, IUS vehicles will be used for the Magellan, Galileo and Ulysses planetary launches. These vehicles are being configured for launch on the STS although a modification kit is also being procured that will allow launch from a Titan IV in the event the Shuttle schedule cannot support the fixed planetary launch window.

The objectives of the commercially developed PAM program were to provide an early and easy transition from expendable launch vehicles to the STS, and to provide low cost transportation from the Shuttle's low Earth orbit to geosynchronous transfer orbit. The PAM is designed to be launched on the Shuttle, the Delta, and as a kick stage for large payloads in conjunction with other propulsion modules. There have been 41 PAM's flown and they are well established in the U.S. inventory of upper stages. These are no payloads currently planned for STS launch that utilize the PAM exclusively although a PAM is being procured as a kick stage in conjunction with the IUS for the Ulysses launch. The PAM is procured as part of the vehicle when used with the Delta and therefore funding for these requirements is included in the ELV budget under STS Operations.

TOS is a three-axis stabilized perigee stage that is being developed commercially by the Orbital Sciences Corporation for use with the Shuttle. It will have the capability to place 6,000 to 13,000 pounds into geosynchronous transfer orbit. A TOS is being procured for the Mars Observer mission for launch in 1992.

The Solid Propulsion Integrity Program was initiated in FY 1984 to establish an urgently needed engineering data base for use of composite materials in upper stage motor nozzles, to minimize risk to planned missions and to restore user confidence in U.S. launch systems. Underlying root causes of persistent problems in motor nozzles have been identified and required data is being generated. Work to examine motor bondlines has been initiated, in addition to increasing the level of effort in motor nozzle studies. The results of this program will continue to be used in support of the Shuttle Solid Rocket Motor.

CHANGES FROM FY 1988 REVISED BUDGET ESTIMATE

Upper Stage funding requirements for FY 1988 have been decreased by $4.6 million from the revised Budget. This reduction results primarily from a launch delay of two years to 1992 for Mars Observer which is partially offset by adding initial funding for the IUS and TOS modifications necessary to support launch of planetary missions.

BASIS OF FY 1989 ESTIMATE

Development and Operations funds in FY 1989 are required to continue progress on the Upper Stages for the Galileo, Ulysses and Magellan planetary missions, for TDRSS and Mars Observer and the IUS and TOS modification kit for the ELV capability. Funds are also necessary to support continuation of the Solid Propulsion Integrity Program and to support IUS and TOS Mission unique efforts which had previously been funded in Payload Support Operations for STS launches. This will make the funding for STS Upper Stages consistent with the funding for ELV Upper Stages.

BASIS OF **FY 1989** FUNDING REOUIREMENT

ENGINEERING AND TECHNICAL BASE

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Research and test support.....	67,400	72,800	75,700	94,400
Data systems and flight support.....	22,600	24,700	22,700	23,700
Operations support.....	38,600	23,600	22,700	23,900
Launch systems support.....	4,800	16,100	12,800	16,900
Total.....	133,400	137,200	133,900	158,900

OBJECTIVES AND STATUS

The Engineering and Technical Base (ETB) provides the program core capability required to sustain an engineering and development base for various NASA activities at the manned space flight centers. Additional center requirements above the core level are funded by the benefitting programs, such as Space Transportation Operations and Shuttle Production and Capability Development. The centers involved are the Johnson Space Center (JSC), the Kennedy Space Center (KSC), the Marshall Space Flight Center (MSFC), and the National Space Technology Laboratories (NSTL).

The core level of support varies from center to center due to programmatic and institutional differences. At JSC, the core level requirement is that one shift of operations be maintained in the engineering and development laboratories and the White Sands Test Facility. Safety, reliability and quality assurance areas are also supported by the ETB core. The core level for the central computer complex is established as a two-shift operation. At KSC, the core level provides for research and development of technology to enhance launch site hardware, ground processing, support services; and safety reliability and quality assurance. ETB funds at MSFC provide for multi program support activities, including technical labs and facilities, reliability and quality assurance, computational and communications services, and at NSTL for facilities operations.

CHANGES FROM FY **1988** REVISED BUDGET ESTIMATE

The total funding for the ETB has decreased $3.3 million in FY 1988 as the result of a realignment of launch system studies to advanced programs from ETB. In addition, expansion reliability and quality assurance activities were offset by reductions in engineering and development support.

BASIS OF FY 1989 ESTIMATE

The requested funding for the ETB in FY 1989 provides for a continuation of the FY 1988 level of support for basic research and development facilities and services at the centers with an expansion of computational capability by acquiring a class VI computer for use at JSC and increased SR&QA and engineering support at JSC, KSC and MSFC.

In research and test support, funding is required to support the increase in computational capabilities at MSFC for engineering and science projects through the use of a Class VI computer system. This capability is required for the solution of more complex main engine three-dimensional dynamics modeling problems and for complex structural analyses. At JSC, the requested funding will provide for a five-day, one-shift operation for the engineering and development laboratories, such as the Electronic Systems Test Laboratory and the Thermal Test Area. SR&QA activities will also be provided. In addition, a Class VI computer system will be acquired at JSC. The computer is required to obtain numerical solutions of very large sector materials for the aerodynamics, thermodynamics and structural mechanics analysis associated with developing and operating manned and robotic space systems.

Data systems and flight support provide a core level of support based on a five-day, two-shift operation of the central computer complex at JSC. Any additional requirements are the responsibility of the benefiting program.

Operations support funding provides for the maintenance of multi-program research and development facilities and equipment, chemical cleaning, engineering design, technical analysis, component fabrication, and logistics support. Examples of specific services to be provided in FY 1989 include: (1) operation and maintenance of specialized electrical and cryogenic systems; (2) operation of shops to do metal refurbishing, anodizing, plating, stripping, and etching of selected items of in-house hardware; (3) engineering, installation, operation, and maintenance of closed circuit fixed and mobile television required for the support and surveillance of tests; (4) mission imaging services, including audio-visual mission support; (5) fabrication of models, breadboards, and selected items of flight hardware; and (6) technical documentation services. In addition, FY 1989 funds will provide the basic level of collateral support at NSTL for continuing main engine testing activities.

In launch systems support, funding provides for the core capability for the engineering scientific, and technical support for research and development activities at KSC specifically the funds provide for multi-program support activities, including technical labs and facilities, and other engineering support services and safety.

BASIS OF FY 1989 FUNDING REQUIREMENT

PAYLOAD OPERATIONS AND SUPPORT EQUIPMENT

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Payload operations.....	32,400	68,000	69,800	53,300
Payload support equ pment.....	8.000	15,000	14,800	14.000
Total.....	40,400	83,000	84.600	67,300

OBJECTIVES AND STATUS

The Payload Operations and Support Equipment objectives are to centralize payload services, both unique and common, which are required beyond the basic STS standard services for NASA missions, and to provide multi-mission support equipment in support of payload operations. Payload operations provides unique hardware, analyses, and launch site support services to support STS missions. Payload support equipment funds the development and acquisition of multi-mission reuseable ground support equipment required for a wide range of payloads. This includes test equipment required to checkout payload-to-orbiter interfaces at KSC, mixed cargo hardware such as standard cable harnesses, and displays and controls related to payload bay operations.

CHANGES FROM FY 1988 REVISED BUDGET ESTIMATE

The Payload Operations and Support Equipment funding has increased $1.6 million from the revised budget This includes the Congressionally directed addition of initial activities to extend the orbiter on orbit stay time capability (EDO), a study on the use of the commercially developed Industrial Space Facility (ISF), an increase in Space Station interface activities to begin analytical integration, and preliminary design of a docking system between the Shuttle and Space Station. These increases which were partially offset by reduced requirements for NASA payloads caused by the delay in resumption of Shuttle flights.

BASIS OF FY 1989 ESTIMATE

Payload operations funding is required to furnish continued payload services for currently scheduled NASA launches. Major NASA payloads receiving support during this year include Hubble Space Telescope, TDRS, Galileo, Ulysses, Magellan, Astro, Long Duration Exposure Facility Retrieval, Upper Atmospheric

Research Satellite, and Gamma Ray Observatory. Efforts will continue to provide the means to maintain and repair satellites on-orbit by developing a series of tools, aids, and techniques, and to demonstrate capabilities and methods of improving the efficiency of on-orbit operations.

Payload support equipment estimates reflect the requirement to modify and upgrade selected payload integration facilities for safer, more efficient operations. FY 1989 funding for multi-mission payload support equipment is required for development testing and delivery of payload common communication equipment (PCCE) to accommodate required payload data transmission, and initial spares provisioning for Cargo Integration Test Equipment (CITE) and PCCE. Funds for fiber optic cabling and an upgraded operational intercom system in the industrial area at KSC are included in this budget to provide increased reliability and quality of data transmission among cargo facilities. Multi-mission payload support equipment funding also includes orbiter/payload interface hardware for groups of payloads, cargo bay cabling, modified aft flight deck panels, and associated display and controls.

BASIS OF FY 1989 FUNDING REQUIREMENT

ADVANCED PROGRAMS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Advanced programs.....	33,600	24,900	46,400	45,000

OBJECTIVES AND STATUS

The principal objectives of Advanced Programs are to conduct concept feasibility studies and selected systems definitions and preliminary design (Phase B) studies and to undertake related high leverage advanced development to provide the technical and programmatic data to identify evolving space transportation system requirements and to evaluate new space transportation initiatives. Complementary objectives are to assimilate generic technology and advanced planning activities and to provide an advanced planning programmatic link between the Office of Space Flight and other NASA program offices. Past program efforts have provided the technical and programmatic data to support new major Agency programs and systems, including the Orbital Maneuvering Vehicle, the Tether Satellite System, the Shuttle Space Transportation System, and the Space Station. Supporting program objectives emphasize both the conceptual definition of the future space transportation systems architecture and specific elements needed over the next twenty years.

In FY 1988, the Advanced Programs effort is focused on four major areas--advanced transportation, advanced operations support, satellite servicing, and advanced missions. Concept definition and key advanced development are underway and planned in these areas to assess performance, reliability, and operational efficiency improvements and to reduce future program risks and development costs through the effective use of new technology. Advanced transportation study efforts focus on cargo vehicles, manned vehicles and space transfer vehicles. Advanced development efforts are planned for critical launch vehicle and upper stage subsystems including avionics, propulsion, energy storage and cryogenic propellant storage. Conclusions drawn from the joint Space Transportation Architecture Studies (STAS) have permitted NASA and DOD to initiate closely related and coordinated studies (Shuttle C and Advanced Launch System) to define concepts for unmanned heavy lift launch vehicles to satisfy both near and long-term mission requirements. The NASA-led Shuttle C (Cargo) system definition studies, now underway, will define a system making use of existing Shuttle hardware and capable of delivering a minimum of 100,000 lbs. of cargo to low Earth orbit. The system definition studies will assess Shuttle C uses for Space Station assembly and support, and planetary missions. Also, the cost effectiveness of the Shuttle C in terms of the capability and flexibility added to the Space Transportation System will be investigated. Studies

also are underway to define the evolution of manned vehicles, including Space Shuttle improvement concepts (Shuttle Block 11) and next generation concepts (Shuttle 11). In addition, a new study for Liquid Rocket Boosters (LRB) initiated in 1987 examines the feasibility of replacing the Solid Rocket Motors (SRM) with liquid engines that, potentially, could offer advantages in Shuttle performance, safety and operating costs. Definition studies for additional crew return capability were initiated in FY 1987 by the Space Station program, and will be continued under Advanced Programs funding beginning in FY 1988. These definition studies will provide the basis for evaluating and recommending options to provide a crew emergency return vehicle, if required, in support of a permanently manned Space Station.

A new advanced program development thrust, advanced operations support systems, addresses advanced operations effectiveness as the key parameter in improving safety as well as reducing life-cycle costs for space transportation and orbital systems. Innovative ground, flight and on-orbit operations techniques are under study and being assessed for use with existing and future space systems. Program plans focus on techniques and systems to improve the efficiency and reliability of launch and pre-launch operations through the use of autonomous and expert systems technology, improving the efficiency of simultaneously operating multiple vehicles in proximity to each other, and the enhancement of telerobotic-assisted servicing operations.

The satellite servicing effort encompasses satellite servicing systems and transportation-related tether applications. The satellite servicing program focuses primarily on the definition of systems and procedures designed to utilize Shuttle capabilities. The systems are planned to be compatible with the Space Station and the Orbital Maneuvering Vehicle (OMV). The definition of tankers, couplings, telerobotic servicing aids, techniques and procedures to support satellite servicing are well underway. The studies support the servicing activities associated with rendezvous and proximity operations from Shuttle and remote servicing using the OMV. Tether application efforts are directed toward defining and implementing flight experiments and demonstrations for advanced development and proof-of-concept purposes. Applications under study include power generation, orbital altitude changes without the use of propellants, artificial gravity, and tethered space platforms for scientific use.

Advanced mission efforts will continue to focus, with expanded scope and increased depth, on potential manned and unmanned missions beyond the Space Station. Studies will be conducted to explore potential Lunar/Mars missions and their demands on the Space Transportation System. Also, a study is currently underway to define the orbital debris environment. Other studies address identifying ways to minimize orbital debris accumulation and develop prevention and protection/avoidance methods and techniques. The development of a radar to measure and determine orbital debris density of particles on the order of 1 centimeter in diameter is planned to augment this study effort.

CHANGES FROM FY 1988 REVISED BUDGET ESTIMATE

Advanced Program Development funding was increased in FY 1988 by $21.5 million to provide for continuation of studies to support the new advanced program development activities discussed above, including advanced operations support system, advanced transportation systems, development of an orbital debris radar, and in-house definition on studies for a potential crew emergency return vehicle. Also, $3.3 million is provided for advanced operations study tasks that were previously planned under the Engineering and Technical Base line item.

BASIS FOR FY 1989 ESTIMATE

In FY 1989, major emphasis will be placed on concept definition and key advanced development in the following areas: advanced space transportation systems (launch vehicles and space transfer vehicles), advanced operations support systems, satellite servicing systems, and advanced missions. Major goals continue to be the conceptual definition of the system architecture and space elements needed for space operations over the next twenty years including heavy lift cargo vehicles, second generation shuttles and satellite servicing near and remote from the orbiter. Advanced development activities focused on improvements to the existing and evolving space transportation systems are planned.

Studies to define the evolution of manned vehicles, including Space Shuttle improvement concepts and next generation concepts, are underway. An area of increased emphasis will be the assessment of operational improvements of existing and future transportation systems including utilization of expert and autonomous systems. Orbital debris studies will be continued including development of an orbital debris radar. The satellite servicing program will continue to explore effective manned servicing concepts to extend STS operational capability for Earth orbit support of spacecraft, platforms, and constellation aggregates. Detailed engineering systems analysis will be continued to determine the efficiency of future tethered platform applications. Advanced manned and unmanned missions beyond the Space Station will continue to be studied with expanded scope and increased depth. Studies will be conducted to explore potential lunar/Mars missions and their potential demands on transportation systems.

Funding of the crew emergency return vehicle definition effort in FY 1989 will support contractor studies. These definition efforts will build upon the preliminary studies begun in FY 1987 and provide definition of vehicle requirements, identify vehicle capabilities within available funding and schedule constraints, existing technology and mission requirements, and understanding design, schedule, and cost risks as well as Space Station support capabilities. Continuing focused systems definition efforts in FY 1989 is consistent with supporting a decision on whether to proceed with design and development to provide this capability when the Space Station is permanently manned.

BASIS FOR FY 1989 FUNDING REQUIREMENT

ADVANCED LAUNCH SYSTEM (ALS)

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Advanced launch systems.....	---	---	---	13,000
Advanced launch systems.....	---	---	65,100	---
Total.....	---	---	65.100	**13,000**

OBJECTIVES AND STATUS

DOD has full funding responsibilities for the joint DOD/NASA Advanced Launch System (ALS) program. NASA has the funding responsibility to satisfy unique civil requirements not addressed by the joint ALS baseline design. As specified in the joint ALS management plan, the ALS-Propulsion Focused Technology program, will be managed by NASA with DOD participation. Congress has directed that in FY 1988 not less than $70 million be transferred to NASA from the DOD to fund ALS-Propulsion Focused Technology activities. Of this amount $65.1 million is being applied to contractual study and technology activities and $4.9 million to related in-house activity funded under the Research and Program Management appropriation. Study efforts are underway in the areas of vehicle systems and propulsion systems for NASA to augment the DOD funded ALS studies for unique civil mission requirements not addressed by the joint ALS baseline design. The ALS-Propulsion Focused Technology program efforts are directed towards demonstrating the performance and operating capabilities of critical propulsion system components prior to committing to a final design for a flight hardware development program. Components and subsystems that will be part of the ALS-Propulsion Focused Technology program include combustors, gas generators, turbopumps, control systems components and instrumentation, and health monitoring system components and diagnostic sensors for liquid oxygen/hydrocarbon and liquid oxygen/liquid hydrogen engine systems. Because the ALS program is in its early definition stage, definitive program plans have not been developed. Efforts are underway to coordinate ALS-Propulsion Focused Technology program activities with DOD in support of ALS concept definition efforts.

CHANGES FROM FY 1988 REVISED BUDGET ESTIMATE

The increase in FY 1988 reflects transfer of funds from DOD as directed by Congress in the N 1988 continuing Appropriation (P.L. 100-202).

BASIS FOR FY 1989 ESTIMATE

The joint DOD/NASA ALS Program is in its early definition stage. Efforts by NASA and DOD are underway to coordinate the ALS-Propulsion Focused Technology activities to most effectively utilize the expertise and facilities of both agencies. Consistent with the basis agreement, funding for the NASA activity to meet the requirements of this program is included in the DOD budget request. The NASA funding for FY 1989 provides for system definition studies with a directed focus building upon the joint ALS baseline design to examine vehicle and propulsion systems to satisfy unique civil requirements.

BASIS OF FY 1989 FUNDING REQUIREMENT

TETHERED SATELLITE SYSTEM

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Tethered satellite system.....	10,600	7,100	12,100	23,800

OBJECTIVES AND STATUS

The development of a Tethered Satellite System (TSS) will provide a new reuseable facility for conducting space experiments at distances up to 100 kilometers from the Shuttle orbiter while being held in a fixed position relative to the orbiter. A number of significant scientific and engineering objectives can be uniquely undertaken with a TSS facility such as the observation of important atmospheric processes occurring within the lower thermosphere, new observations of crustal geomagnetic phenomena, and entirely new electrodynamic experiments interacting with the space plasma. This is being undertaken as a cooperative development program with the Italian government. Formal signing by representatives of both governments of a Memorandum of Understanding took place in March 1984.

The United States is responsible for overall program management, overall systems engineering and integration, Orbiter integration, ground and flight operations, and development of the deployment mechanism. The U.S. effort was initiated in 1984. The Italians are responsible for the design and development of the satellite and the European instruments being flown on the joint missions. They initiated their development efforts in 1984.

CHANGES FROM FY 1988 REVISED BUDGET ESTIMATES

The $5.0 million increase is due to increases in mission integration and for upgrades to the power systems which will increase available science mission time.

BASIS OF FY 1989 ESTIMATE

The FY 1989 funding supports continuation of TSS Development activities consistent with the planned engineering verification flight (TSS-1) in early FY 1991. Current plans call for completion of U.S. hardware assembly in early FY 1989 followed by deployer qualification. Integration of the Italian-provided satellite and the deployer mounted science instruments will start in FY 1990 to support a delivery date to KSC in mid-FY 1990, in time to prepare the TSS-1 for flight in early 1991.

BASIS OF FY **1989** FUNDING REQUIREMENT

ORBITAL MANEUVERING VEHICLE

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Orbital maneuvering vehicle.....	45,000	79,700	46,300	96,500

OBJECTIVES AND STATUS

The Orbital Maneuvering Vehicle (OMV) will provide a new STS reuseable extension capability for conducting orbital operations with spacecraft and payloads beyond the practical operational accessibility limits of the baseline STS. By means of direct man-in-the-loop control, the spacebasable reuseable OMV, operating as far as 1200 nautical miles altitude above the orbiter, will provide delivery, maneuvering, and retrieval of satellite payloads to and from altitudes or inclinations beyond the existing STS capability; reboost of satellites to original operational altitudes or higher; delivery of multiple payloads to different orbital altitudes and inclinations in a single flight; and safe deorbit of satellites which have completed their useful life. It will be designed to serve the Space Station as well and to accommodate the add-on of future "mission kits" as needed to support more advanced missions such as the servicing of satellites and platforms and the retrieval of space debris which could represent an orbital hazard to all future space missions. TRW was competitively selected and is now under contract to develop the OMV. The preliminary design review will be held in FY 1988 and long lead procurements will be initiated. The flight readiness date for the OMV is mid 1993.

CHANGES FROM FY **1988** REVISED BUDGET ESTIMATE

The $33.4 million decrease from the FY 1988 revised budget estimate reflects a decision to delay the planned first flight of the OMV from late FY 1991 to mid-FY 1993. This delay in capability is consistent with the anticipated delay in the Hubble Space Telescope (HST) launch and the projected solar cycle activity which necessitates the initial operational requirement for OMV to perform the initial servicing of the HST. The later date reflects both the delay in the launch of HST and projected solar cycle effects on the HST orbiter.

BASIS FOR FY **1989** ESTIMATE

The funds provided in FY 1989 will be used to continue OMV hardware design and development and fabrication of test and flight hardware.

SPACE SCIENCE
AND APPLICATIONS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FISCAL YEAR 1989 ESTIMATES

RESEARCH AND DEVELOPMENT BUDGET PLAN FOR SPACE SCIENCE AND APPLICATIONS PROGRAMS

Programs	Budget Plan			
	1987	1988		1989
	Actual	Revised Budget	Current Estimate	Budget Estimate
	(Thousands of Dollars)			
Physics and astronomy	554,000	542,800	610,800	791,600
Life sciences	71,800	70,000	69,500	101,700
Planetary exploration	359,200	304,300	329,200	404,000
Solid earth observations	72,400	74,300	74,300	82,100
Environmental observations	318,300	385,900	313,500	368,300
Materials processing in space	47,300	42,700	62,700	73,400
Communications	103,400	19,300	94,900	16,200
Information systems	21.200	20.900	20.900	22.300
Total	1.547.600	1.460.200	1,575,800	1.859.600

PHYSICS AND
ASTRONOMY

RESEARCH AND DEVELOPMENT

FISCAL YEAR 1989 ESTIMATES

BUDGET SUMMARY

OFFICE OF SPACE SCIENCE AND APPLICATIONS — PHYSICS AND ASTRONOM

SUMMARY OF RESOURCES REQUIREMENTS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Hubble space telescope development.....	96,000	98,100	93,100	102,200
Gamma ray observatory development.....	50,500	48,400	53,400	41,900
Global geospace science.....	(---)	(25,000)	20,000	101,400
Advanced x-ray astrophysics facility development (AXAF).....	---	---	---	27,000
Payload and instrument development.....	(20,100)	(38,700)	43,700	77,100
Shuttle/Spacelab payload mission management and integration.....	72,800	68,300	54,200	61,500
Space station integrated planning and attached payloads.....	15,500	18,900	18,900	8,000
Explorer development.....	55,700	57,900	67,900	82,100
Mission operation and data analysis.....	131,000	121,100	132,000	156,200
Research and analysis.....	53,400	57,000	82,900	89,100
Suborbital program.....	79.100	73,100	44,700	45.100
Total.....	554,000	542.800	610,800	791,600

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
		(Thousands of Dollars)			
Distribution of Program Amount by Installation					
Johnson Space Center	9.810	16.781	13.260	12.677	
Kennedy Space Center	4.217	5.490	7.239	a.087	
Marshall Space Flight Center	248.079	247.568	253.677	307.696	
Goddard Space Flight Center	179.545	172.105	229.924	343.411	
Jet Propulsion Laboratory	13.995	14.453	15.510	15.005	
Ames Research Center	32.588	35.673	12.985	15.542	
Langley Research Center	100	---	150	150	
Lewis Research Center	100	---	---	---	
Headquarters	65.566	50.730	78.055	89.032	
Total	554.000	542.a00	610.800	791.600	

RESEARCH AND DEVELOPMENT

FISCAL YEAR 1989 ESTIMATES

OFFICE OF SPACE SCIENCE AND APPLICATIONS **PHYSICS AND ASTRONOMY PROGRAM**

PROGRAM OBJECTIVES AND JUSTIFICATION

The objectives of the Physics and Astronomy program are to increase our understanding of the origin and evolution of the universe, the fundamental laws of physics, and the formation of stars and planets. Objects studied by the Astrophysics program include distant galaxies and galactic clusters, as well as stars and other structures in nearby galaxies and the interstellar medium in our galaxy. Unusual and exotic phenomena -- such as quasars, neutron stars, pulsars and black holes -- are of particular interest to the Astrophysics program, and are the target of many ground-based and and space-based research programs.

Intensive study of our own Sun, with its multitude of time-varying phenomena, provides key answers to a vast range of questions requiring comprehensive research into solar-terrestrial processes and the physics and coupling between the solar wind, magnetosphere, ionosphere, and atmosphere.

The objectives of the Physics and Astronomy program are accomplished with a mixture of large, complex free-flying space missions, less complex Explorer spacecraft, Shuttle/Spacelab flights and suborbital opportunities. In the future, the Space Station will act as a platform for attached payloads and as a servicing point for major free-flying observatories which require assembly, maintenance and refurbishment in orbit. Space-based research allows observations in wavelength regions such as the infrared or the ultraviolet which cannot be carried out on the ground due to the obscuring effects of the atmosphere. Also, observations in the visible light region are vastly improved when conducted above the atmosphere. The entire program rests on a solid basis of supporting research and technology, data analysis, and theory.

Research teams involved in this program are located at universities, industrial laboratories, NASA field centers, and other government laboratories. The scientific information obtained and the technology developed in this program are made available to the scientific communities and the general public for application to the advancement of scientific knowledge, education and technology.

The first nearby Supernova since the invention of the telescope appeared in the southern skies last year. A broad campaign of observations using the Deep Space Network, aircraft, balloons, rockets, and existing spacecraft was rapidly assembled to take advantage of the unique scientific opportunity provided by this exciting event.

The Physics and Astronomy missions undertaken to date have been extraordinarily successful. Recently, these include the High Energy Astronomical Observatories (HEAO, 1977-1979), the International Ultraviolet Explorer (IUE, 1978), the Solar Maximum Mission (SMM, 1980) the Active Magnetospheric Particle Trace Explorer (AMPTE, 1984), the Dynamics Explorer (DE, 1981), the Interplanetary Monitoring Platform (IMP-8, 1972), International Sun-Earth Explorers (ISEE 1 & 2 and ICE, 1977-78), and the Infrared Astronomy Satellite (IRAS, 1983). The IUE, SMM, AMPTE, IMP, DE and ICE are still operating, and new scientific results are continually emerging from these, as well as from the high quality data sets archived from the HEAOs, ISEE 1 & 2 and IRAS.

The Hubble Space Telescope, to be launched by the Space Shuttle in 1989, will provide an international spaceborne astronomical observatory capable of measuring objects appreciably fainter and more distant than those accessible from the ground, since it will be above the turbulent and absorbent atmosphere. This telescope will be able to resolve spatial features by a factor of ten better than the typical ground-based optical telescope, and will observe the universe at approximately seven times the distances now possible. This means some 350 times the volume of the present universe will be available for study. This increased capability will allow us to address basic questions concerning the origin, evolution, and disposition of galaxies, quasars, clusters, and stars, thus allowing us to significantly increase our understanding of both the early and present universe--its beginning and end.

The Gamma Ray Observatory (GRO) mission will be launched by the Space Shuttle in 1990. This mission will measure gamma rays, which are produced by the most energetic and exotic fundamental physical processes occurring in nature. Instruments on this mission will provide unique information on phenomena occurring in quasars, active galaxies, black holes, neutron stars, supernova, and the nature of the mysterious cosmic gamma-ray bursts.

The Global Geospace Science (GGS) program was approved as an FY 1988 new start. It is a complementary science mission to the Collaborative Solar-Terrestrial Research (COSTR) project and enables the U.S. to move from a supporting to a leadership role in solar-terrestrial physics. Both projects are being conducted in cooperation with the European Space Agency (ESA) and the Japanese Institute of Space and Aeronautical Science (ISAS). GGS will make the first coordinated geospace measurements in the key plasma source and storage regions, with emphasis on the cause-effect relations of energy flow. Together with

Definition studies of advanced technology will continue on the Advanced X-ray Astrophysics Facility (AXAF), which is proposed as an FY 1989 new initiative. AXAF will be a major national observatory for x-ray astronomy. The 1.2m class grazing incidence telescope will provide a factor of 100 increase in sensitivity, a factor of 10 increase in angular resolution and double the energy coverage which was provided by the Einstein observatory (HEAO-2). It will provide new observations and insights in studies of stellar structure and evolution, large-scale galactic phenomena, active galaxies, clusters of galaxies and cosmology. It will restore U.S. leadership in a field pioneered by the U.S. astronomers.

Definition studies of the advanced technology necessary for a Space Infrared Telescope Facility (SIRTF) will continue. SIRTF is intended to measure phenomena associated with the beginning of an evolutionary cycle. This includes cosmic dust, cool interstellar material, star formation, and proto-planetary nebulae in both our galaxy and others.

Since the inception of the U.S. space program, the Explorer program has been the means for fast-turnaround scientific space missions. The Physics and Astronomy Explorers have been extremely successful. The IUE, a U.S./ESA endeavor, has recently shown that our galaxy has a halo of gas with a temperature of over a million degrees, while the IRAS, a joint U.S./U.K./Netherlands project, has detected and cataloged over 300,000 infrared sources and has shown star formation in other galaxies to be more prevalent than previously thought. IRAS has also demonstrated that at least one quasar has its dominant energy release in the infrared spectral region. Since IRAS completed operations in late 1983, these discoveries have come from analysis of archival data and many more such results are expected.

ICE, which was designed to provide solar wind data, was redirected in 1985 for the first successful encounter with a comet when it passed through the tail of Comet Giacobini-Zinner, and made Halley's Comet observations in 1986. In March-May 1986, the Polar Region and Outer Magnetosphere International Study (PROMIS) coordinated six satellites (ISEE 1 & 2, ICE, Active Magnetospheric Particle Explorer (AMPTE), Interplanetary Monitoring Platform (IMP-8), Dynamics Explorer (DE-1) and the Swedish Viking satellite to provide unique data on magnetospheric processes.

Two major Explorer missions are now under development: the Cosmic Background Explorer (COBE) and the Extreme Ultraviolet Explorer (EUVE). A third mission, the X-ray Timing Explorer (XTE), is under definition. In addition, a U.S. instrument is being developed for inclusion on the Roentgen Satellite (ROSAT), being built by the Federal Republic of Germany. A Cosmic Ray Isotope Experiment (CRIE) is also being developed, along with a DoD experiment, for flight aboard the Combine Released and Radiation

Effects Satellite (CRRES) scheduled for launch in 1990 on a Department of Defense spacecraft. Finally, we are developing an instrument for flight on the Japanese Solar-A mission (previously called the High Energy Solar Physics Mission, HESP). Solar-A will be launched in 1991 to study the Sun during the upcoming solar maximum.

The Astrophysics program continues its involvement in the Shuttle/Spacelab program with Astro-1, a set of ultra-violet and soft x-ray telescopes and spectrometers, scheduled for a launch in 1989. Astro-1 will investigate the interstellar medium by following up on discoveries made with the IUE. Mission management activities will continue with increasing emphasis on major life sciences and microgravity research missions such as the Spacelab-Life Sciences (SLS) and International Microgravity Laboratories (IML) series.

Payload and instrument development activities provide the data necessary to conduct basic research projects as well as to provide correlative and developmental feasibility information for major free-flying spacecraft. Instrument activities include Shuttle payloads such as the Shuttle experiment to test the theory of relativity and the Tethered Satellite System (TSS). Also included are Space Plasma Physics flight of opportunity instruments such as those for the Japanese Geotail Spacecraft and the European Solar Heliospheric Observer (SOHO) and Cluster spacecraft. The Collaborative Solar Terrestrial Research (COSTR) instrumentation provides the U.S. complement for the European Solar Terrestrial Science Programme (STSP).

During the Shuttle recovery period, suborbital observation from balloons, sounding rockets, and high-flying aircraft has taken on increased significance. This enhanced effort will provide observations and instrument development opportunities for research groups. Furthermore, increased emphasis will also continue in the Research and Analysis (R&A) and the Mission Operations and Data Analysis (MO&DA) areas in order to maintain a vital research base in Physics and Astronomy.

BASIS OF FY *1989* FUNDING REOUIREMENT

HUBBLE SPACE TELESCOPE DEVELOPMENT

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Spacecraft	82,700	85,000	80,000	90,300
Experiments	13,300	13,100	13.100	11.900
Total	96.000	98.100	93.100	102.200
Mission operations and data analysis	(97,300)	(93,700)	(91,600)	(111,300)
Space transportation system operations	(11,800)	(60,800)	(49,300)	(51,600)

OBJECTIVES AND STATUS

The Hubble Space Telescope will make a major contribution to understanding the stars and galaxies, the nature and behavior of the gas and dust between them, and the broad question of the origin and scale of the universe. The Hubble Space Telescope will operate in space above the atmospheric veil surrounding the Earth, increasing dramatically the volume of space accessible for observations. With its significant improvements in resolution and precision in light sensitivity and in wavelength coverage, the Hubble Space Telescope will permit scientists to conduct investigations that could never be carried out with ground-based observatories limited by the obscuring and distorting effects of the Earth's atmosphere.

The Hubble Space Telescope will enhance the ability of astronomers to study radiation in the visible and ultraviolet regions of the spectrum. It will be more sensitive than ground-based telescopes and will allow the objects under study to be recorded in greater detail. It will make possible unique observations of objects so remote that the light will have taken many billions of years to reach the Earth. As a result, we will be able to look farther into the distant past of our universe than ever

before. The Hubble Space Telescope will also contribute significantly to the study of the early state of stars and the formation of solar systems, as well as the observation of such highly-evolved objects as supernova remnants and white dwarf stars. With the Hubble Space Telescope, we may be able to determine the nature of quasars and the processes by which they emit such enormous amounts of energy; it may also be possible to determine whether some nearby stars have planetary systems.

The Hubble Space Telescope will be an automated observatory, delivered into orbit by the Space Shuttle in June 1989. Data from its scientific instruments will be transmitted to Earth via the Tracking and Data Relay Satellite System. The Hubble Space Telescope is designed for on-orbit maintenance and repair.

During FY 1987, the Hubble Space Telescope Program continued at a reduced level of activity. The schedule for launch and operations was further adjusted, as a result of the post-Challenger changes in the Space Transportation System (STS). Hubble Space Telescope program activity focused on corrections to a few cases of off-nominal systems performance observed in the intensive period of testing in late FY 1986. This included rework of some components and instruments, improvements to the power system, and adjustments to the thermal control system. In addition to this work on the Hubble Space Telescope spacecraft, the planned tests of the ground system continued, building toward final operational capability on the stretched-out launch schedule. Work also continued on preparing for the future on-orbit maintenance of the Hubble Space Telescope spacecraft. A logistics system was put in place, and development was underway on advanced scientific instruments and other components for orbital replacement. Astronauts conducted realistic training with the replacement components, using specially developed tools. Finally, the Failure Modes and Effects Analysis/Critical Items List/Hazard Analysis of the Hubble Space Telescope system, required for STS safety, was successfully completed.

Planning for FY 1988 reflects the added delays in the STS launch schedule. After a pre-ship functional test verifies the readiness of the Hubble Space Telescope spacecraft for shipment, it will enter a period of inactive storage. In FY 1989, approximately three months before the launch date, the spacecraft will be shipped to Kennedy Space Center for final launch preparations. Ground system verification and buildup to full operational capability will continue, consistent with the extended launch schedule.

CHANGES FROM FY 1988 REVISED BUDGET

The HST development budget was reduced by $5 million as directed by Congress

BASIS OF FY 1989 ESTIMATE

The FY 1989 funding level is required to complete those program activities that were planned for the previous year, but delayed because of further adjustments to the STS launch schedule. These activities include pre-ship preparation of the spacecraft, shipment to the Kennedy Space Center, launch preparations and launch operations at Kennedy, and the initial phase of orbital operations. In addition, the requested funding level will support the buildup of the HST ground system to the level required for sustained science operations.

BASIS OF FY 1989 FUNDING REQUIREMENT

GAMMA RAY OBSERVATORY DEVELOPMENT

	1987 Actual	1988 Revised Budeet	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Spacecraft.....	38,900	33,600	38,600	29,900
Experiments and ground operations.....	11.600	14,800	14.800	12.000
Total.....	50.500	48,400	53.400	41.900
Space transportation system operations	(···)	(23,400)	(24,700)	(51,600)

OBJECTIVES AND STATUS

The Gamma Ray Observatory (GRO) will study the highest energy electromagnetic radiation emitted from sources in the cosmos. This spectral region represents one of the last frontiers in astronomy to be studied at high sensitivity. Because of their extreme energy, gamma-rays are produced by the most energetic and intriguing phenomena occurring in the universe: phenomena occurring in the central energy source region of quasars, in supernovae, near black holes, and on the surface of neutron stars. Gamma-rays provide the unique direct signature of all nuclear processes which occur in astrophysics: the synthesis of elements, cosmic rays interacting in the interstellar medium, and transformations involving the fundamental particles of physics. GRO will provide new information on phenomena ranging from the enigmatic, and yet unidentified, cosmic gamma-ray bursts, to the diffuse gamma-ray sky background, whose origin must have cosmological significance.

The GRO science and instrumentation rests on a foundation of exploratory investigations and developments from previous spacecraft, such as the Small Astronomy Satellite-2 (SAS-2, 1972), the High Energy Astronomical Observatories (HEAO's 1 and 3, 1977 and 1979), and the European COS-B (1975). A

community of astronomers and physicists has built up both the data analysis experience and developed the theoretical concepts to complete the infrastructure required for a successful space mission. Participation in the **GRO** mission includes the university science community as well as government and industry. International involvement, with a complete Principal Investigator team based in Europe, is extensive.

The low flux of cosmic gamma-rays, their penetrating nature, and the high background produced by cosmic-ray interactions all dictate large and massive instruments to be flown in space for extended periods of time. The four complementary instruments selected for the **GRO** represent a quantum jump in sensitivity, spectral range, and spectral, spatial, and temporal resolution over any previous missions or instruments in these energy ranges. **GRO**, scheduled for launch on the Space Shuttle in 1990, is designed to be pointed at fixed directions in space for hours or weeks to obtain the long exposures required.

In FY 1987, instrument calibration and testing and electronic manufacturing continued and the spacecraft structure assembly was completed. In FY 1988, the modal survey and static load tests will be completed and all government-furnished-property spacecraft subsystems for **GRO** will be delivered. Observatory subsystem integration is scheduled to begin late in the year, after the completion of spacecraft attitude control and power systems electronics. The development of the **GRO** mission operations and data systems will continue, and the implementation of the Payload Operations Control Center (POCC) for **GRO** will be completed. Funding is also required for final testing, calibration and shipment of all four science instruments to the spacecraft contractor for the beginning of spacecraft integration and testing.

CHANGES FROM **FY 1988** REVISED BUDGET

FY 1988 funding has been increased by $5.0 million to ensure completion of spacecraft assembly and test in an effort to retain the capability to launch as early as January 1990. This would minimize the marginal costs of a launch delay and would maintain flexibility within the program in the event an earlier launch slot becomes available.

BASIS OF FY 1989 ESTIMATE

FY 1989 funding is required to complete observatory integration and environmental testing and to complete preparations for shipping the spacecraft from TRW to Kennedy Space Center.

BASIC OF FY 1989 FUNDING REQUIREMENT

GLOBAL GEOSPACE SCIENCE

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
*Global geospace science.....	(---)	(25,000)	20,000	101,400
STS operations.....	(---)	(---)	(---)	(13,000)

*Funding transferred from Environmental Observatories under Office of Space Science and Applications reorganization.

OBJECTIVES AND STATUS

Global Geospace Science (GGS) will be part of the United States' contribution to the International Solar Terrestrial Physics (ISTP) program. This program is an international, multi-spacecraft, collaborative science mission designed to provide the measurements necessary for a new and comprehensive understanding of the interaction between the Sun and the Earth.

GGS is a complementary science mission to the Collaborative Solar Terrestrial Research (COSTR) program to provide instruments and launch support and to gain science return in a cooperative effort with the European Space Agency (ESA) and the Japanese Institute of Space and Aeronautical Science (ISAS). The scientific value of this effort will be greatly enhanced by the addition of the two spacecraft proposed in the GGS program. The combined program will include five spacecreft missions: two U.S. spacecraft, WIND and POLAR; two ESA spacecraft, SOHO and Cluster; and one ISAS spacecraft, GEOTAIL, most of which are to be launched by NASA.

The GGS mission will measure and model the effects of the Sun on the Earth's space system to enhance our understanding of the processes and flow of energy and matter in the solar energy chain from outer geospace to atmospheric deposition. GGS will also enhance our ability to assess the importance of variations in atmospheric energy deposition from the geospace system to the terrestrial environment. GGS consists of two fully-instrumented U.S. spacecraft, WIND and POLAR, making simultaneous measurements in

key geospace regions. Instruments and theory investigations were selected through an Announcement of Opportunity to U.S. and foreign investigators. GGS provides the first coordinated geospace measurements in key plasma source and storage regions, multi-spectral global auroral imaging, and multi-point study of magnetospheric response to solar wind.

Essentially all commitments by the foreign governments are in place and their development activities have commenced. GGS will allow the United States to become a full partner in the ISTP program, reinforcing our commitments to international cooperation and is essential to maintaining continued leadership in solar terrestrial physics.

CHANGES FROM THE FY 1988 REVISED BUDGET

Consistent with the OSSA reorganization, the GGS program which was previously budgeted under Environmental Observations, is now budgeted under Physics and Astronomy. Funding has been reduced by $5.0 million consistent with Congressional direction.

BASIS OF FY 1989 ESTIMATE

Definition studies are complete and FY 1989 funds are required to initiate development of GGS spacecraft, instruments and ground system. FY 1989 funding will allow continuation of these early development efforts in order to take advantage of simultaneous measurements provided by the Collaborative Solar Terrestrial Research (COSTR) program and other solar-terrestrial research efforts.

BASIS OF FY 1989 FUNDING REQUIREMENT

ADVANCED X-RAY ASTROPHYSICS FACILITY DEVELOPMENT

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
Spacecraft	---	---	---	23,000
Experiments	---	---	---	4,000
Total	---	---	---	27,000

OBJECTIVES AND STATUS

Our nation is poised for an accomplishment unique in the history of humankind - to observe the universe with unprecedented completeness and resolution. We have the demonstrated capability to construct high technology orbiting telescopes that can observe the universe in all the forms of electromagnetic radiation, and we have the unique capability with the Shuttle, and eventually the Space Station, to maintain these telescopes on orbit. The key to realizing this amibition is the start in FY 1989 of a telescope facility designed to observe the universe in the x-ray region of the electromagnetic spectrum. This telescope, known as AXAF - the Advanced X-ray Astrophysics Facility, is 100 times more sensitive, and has 1000 times more capability for spectroscopy, than any previous or planned x-ray mission. AXAF needs to be undertaken immediately in order to fly in concert with the Hubble Space Telescope, which will observe the universe in visible and ultraviolet radiation, and the Gamma Ray Observatory, which will observe in gamma rays. The scientific return of these "Great Observatories" will be enhanced enormously if flown together to observe the whole range of phenomena in the cosmos, from the most tranquil to the most violent, and provide a complete physical picture of the universe's most engimatic objects. Moreover, immediate initiation of AXAF will provide a scientific opportunity that is unlikely to be repeated for many generations. The closest supernova to occur near Earth since the invention of the telescope, 400 years ago, was seen last year, and can be studied by AXAF provided that it is launched by 1995, before the x-rays fade. Supernovae are responsible for the origin of all the heavier elements in the universe including those essential for life.

The AXAF, with its 1.2m class grazing incidence telescope will double the energy coverage which was provided by the Einstein Observatory (HEAO-2). AXAF will be launched in 1995 using the Space Transportation System (STS). It will be a long-lived observatory designed for on-orbit instrument replacement and servicing. With the Shuttle, and eventually the Space Station, the U.S. has the unique capability to maintain this telescope in orbit.

An extensive preparatory program has been completed for AXAF, including completion of 32 months of observatory definition in January 1987, which included the fabrication of the finest x-ray mirror ever built. NASA and industrial teams are in place and ready to proceed with AXAF.

In this era in which United States leadership in space is being challenged, a new start for AXAF will provide a bold statement that in the premier scientific discipline of astrophysics, we will be second to none.

BASIS OF FY 1989 ESTIMATE

FY 1989 funding will initiate AXAF. During the first year, work will focus on development of the High Resolution Mirror Assembly and the science instruments.

BASIS OF FY 1989 FUNDING REQUIREMENT

PAYLOAD AND INSTRUMENT DEVELOPMENT

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Collaborative solar terrestrial research.	(5,000)*	(14,900)*	14,900	43,900
Tether satellite systems.....	(5,500)*	(3,100)*	3,400	3,700
Shuttle test of relativity experiment....	(---)**	(10,300)**	10,300	22,000
Astrophysics payloads.....	(5,000)***	(5,200)***	5,200	5,500
Space physics payloads.....	(4,600)***	(4,900)***	9.900	2,000
Total.....	(---)	(---)	43,700	77.100

* Funded under Environmental Observations
** Funded under Physics and Astronomy Research and Analysis
*** Funded under Physics and Astronomy Spacelab Payloads and Mission Management

OBJECTIVES AND STATUS

Instrument development activities support a wide range of instrumentation - from early test, checkout and design of instruments for long-duration free-flying missions to international flights of opportunity

The Collaborative Solar Terrestrial Research Program (COSTR) will provide state-of-the-art instrumentation for flight opportunities on international spacecraft and various U.S. spacecraft of opportunity. Emphasis is on developing scientific instruments conceived through the Space Physics Research and Analysis and Sounding Rocket programs. Most instruments to be developed in the near term will provide a U.S. contribution to an international thrust in space physics research in the 1989-1995 timeframe, principally, the European Solar Terrestrial Science Programme (STSP) and the Japanese Geotail Mission.

The Tethered Satellite System (TSS) will provide a facility for conducting experiments weighing 500 kg or less from distances of 100 km above or below the Space Shuttle. The objective of the initial TSS mission is to verify the controlled deployment, retrieval and on-station stabilization of a satellite tethered from the orbiter, and to carry out an electrodynamics experiment using a conducting tether extended 20 km above the orbiter. TSS is an international cooperative project with the Italian government. The U.S. is responsible for overall project management, system integration, developing the tether deployment and retrieval system, developing and integrating U.S. provided instruments, and flight on the Shuttle. Italy is developing the satellite and is responsible for development and integration of Italian provided instruments.

The Shuttle experiment to test the theory of relativity will develop a multigyroscope experimentation package to fly as an attached payload on the Shuttle in 1993, as an integral part of the study of relativity.

Astrophysics and Space Physics Payloads include a number of instruments designed for flight on the Space Transportation System. Emphasis will be on technology definition for the High Resolution Solar Observatory (HRSO) as well as instrument development for study of the complex relationships of solar irradiance and the near-Earth plasma environment (Atmospheric Laboratory for Applications and Science - ATLAS), and the diffuse x-ray background and spectra of point and extended sources (Shuttle High Energy Astrophysics Lab - SHEAL).

CHANGES FROM THE FY 1988 REVISED BUDGET

Payload and Instrument Development activities under the responsibility of the recently created Space Physics Division (COSTR and TSS) have been transferred to Physics and Astronomy. Also, Imaging Spectrometic Observatory (ISO) development activities previously funded under Shuttle/Spacelab Payload and Mission Management line have been transferred to the Environment Observations Payloads line. Activities on Gravity Probe-B, which follow the completion of advanced technology definition in early FY 1988, have been transferred to Physics and Astronomy Payload and Instrument Development. A $5.0 million Congressional increase has also been included in Payloads and Instrument Development for continued definition for Shuttle/Spacelab payloads. Tether payloads has increased as a result of a prior-year accounting adjustment within the Environmental Observations payloads line.

BASIS FOR FY 1989 ESTIMATE

In FY 1989, the COSTR program will continue development of U.S. provided instruments for the ISAS/NASA Geotail mission which will explore the Earth's magnetosphere and deep geotail region. NASA will also be developing U.S.-provided instruments and mission support equipment for the ESA/NASA joint Cluster and SOHO missions, which will provide unique capabilities for measurement of solar oscillations and solar corona. Funding is also required to continue development of U.S. provided instruments on TSS-1 and for core equipment development and integration. Funding will be used to support the First Integrated System Test in which a full scale prototype of the Shuttle experiment to test the theory of relativity will undergo developmental testing.

BASIS OF FY 1989 FUNDING REQUIREMENT

SHUTTLE/SPACELAB/PAYLOAD MISSION MANAGEMENT AND INTEGRATION

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Shuttle/Spacelab payload mission management and integration....	72,800	68,300	54,200	61,500
	(9,600)*	(10,100)*	(---)	(---)

* Funding transferred to Physics and Astronomy Payload and Instrument Development included in totals.

OBJECTIVES AND STATUS

The primary objective of the Spacelab Payload Mission Management program is to manage the mission planning, integration, and execution of all NASA Spacelab and attached Shuttle payloads. This includes system management and engineering development of flight support equipment and software; development of certain interface hardware; payload specialist training and support; integration of the science payloads with the Spacelab system; payload flight operations; and, data dissemination to experimenters.

Mission management activities are continuing for Physics and Astronomy missions including the ASTRO-1 mission and the Shuttle High Energy Astrophysics Lab (SHEAL). ASTRO-1 is scheduled for flight in 1989, SHEAL, is currently planned for flight in 1992. The primary instrument on SHEAL, a broad-band X-ray Telescope is also under consideration for an early flight on the Astro mission, in order to make timely observations of the Supernova 1987a.

Mission management activities are continuing on several other space science and applications missions, such as the Atmospheric Laboratory for Applications and Science (ATLAS). The first of this series is planned for flight in 1991. The mission will incorporate a large number of instruments designed to study the complex relationships of solar irradiance, atmospheric composition and changes, and the near-earth plasma environment. Other examples include flight of an imaging radar in the early 1990's; a series of Spacelab Life Sciences missions (SLS), the first scheduled for launch in December 1989; a joint

microgravity mission with the Japanese (SL-J); a series of cooperative International Microgravity Laboratories (IML's); and flight of the on-going series of Materials Science Laboratories (MSL's). Mission management activities also support other (non-OSSA) payloads. For example, the Space Station heat pipe advanced radiator element experiment payload will test a heat rejection system with high potential for future spaceborne applications.

CHANGES FROM FY 1988 REVISED BUDGET

The recent reorganization of the Office of Space Science and Applications established a new Space Physics Division and placed budget responsibility for all payload development in the appropriate discipline divisions of OSSA. Consequently, funds for development of Physics and Astronomy payloads have been transferred to the newly created Payload and Instrument Development budget line. In addition, funding for reflight of the Imaging Spectrometric Observatory (a Spacelab-3 atmospheric physics experiment), on ATLAS-1 has been transferred to the Environmental Observations Payload and Instrument Development. Spartan funding has also been transferred to the Physics and Astronomy Research and Analysis line to provide additional funding for the Supernova campaign.

BASIS **OF FY 1989 ESTIMATE**

Mission management activities will intensify in FY 1989 as Spacelab missions resume with the flight of ASTRO-1. Besides final preparation for flight of ASTRO-1, mission management will continue for the major Shuttle/Spacelab missions including SHEAL, the ATLAS series, the Spacelab Life Sciences Missions (SLS) the International Microgravity Laboratories (IML), and flight of an imaging radar. Mission management support for non-OSSA payloads will also continue.

BASIS OF FY 1989 FUNDING REQUIREMENT

SPACE STATION INTEGRATION PLANNING AND ATTACHED PAYLOADS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Integration planning.....	8,000	11,100	11,100	---
Attached payloads.....	7,500	7.800	7,800	8.000
Space station integration planning and attached payloads.....	15.500	18,900	18.900	8.000

OBJECTIVES AND STATUS

The primary objective of the Space Station Integration Planning and Attached Payloads program is to initiate the necessary planning, definition and development of payloads and missions as the Office of Space Science and Applications begins its preparations as a future major user of the Space Station complex. This includes the definition of attached payloads suitable for deployment on the early Space Station, as well as the definition of integration and operational requirements, in anticipation of the new, integrated methods of conducting scientific research which the Space Station will offer.

Studies continue to define the end-to-end science operations requirement for the Space Station era (i.e., the cycle from identification of science requirements, through mission planning and operations to dissemination, analysis and archiving of data). Studies also continue to determine the best use of Space Station resources (e.g., power, crew time, volume, data handling capabilities, pointing capabilities) vis-a-vis science requirements. Potential attached payloads have been identified for further feasibility and definition and appropriate studies are under way.

BASIS OF FY 1989 ESTIMATE

The two-year study phase for Space Station Integration Planning activities will be completed in FY 1988. In FY 1989, definition and development will continue on those attached payloads selected for early flight on the Space Station. Additionally, Space Station payload development activities are augmented in FY 1989 in the cognizant science disciplines where the payloads, hardware and support equipment will be defined and developed through a judicious program of Spacelab test flights. They include facilities and instrumentation for microgravity experiments, as well as Life Sciences hardware, support equipment and studies, and Advanced Technology Development for the polar platform payload (Earth Observing System). The total augmentation for Space Station-related payload activities included in the OSSA FY 1989 budget is approximately $50 million.

BASIS OF FY 1989 FUNDING REOUIREMENT

EXPLORER DEVELOPMENT

	1987 Actual	1988 Revised Budaet	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Cosmic background explorer.....	31,500	14,600	14,600	5,500
Extreme ultraviolet explorer.....	13,600	29,600	29,600	40,400
Roentgen satellite experiments.....	2,700	2,400	2,400	3,300
Combined release and radiation effects satellite experiments.....	2,200	2,200	2,200	2,200
Solar-A.....	3,000	4,700	7,600	4,600
Other explorers.....	2.700	4.400	11,500	26.100
Total.....	55.700	57.900	67,900	82,100

OBJECTIVES AND STATUS

Investigations selected for Explorers are usually of an exploratory or survey nature, or have specific objectives not requiring the capabilities of a major observatory. Past Explorers have discovered radiation trapped within the Earth's magnetic field, investigated the solar wind and its interaction with the Earth, studied upper atmosphere dynamics and chemistry, mapped our galaxy in radio waves and gamma-rays, and determined the properties of the interstellar medium through ultra-violet observations.

Recent Explorers have performed active plasma experiments on the magnetosphere, made in-situ measurements of the comet Giacobini-Zinner, and completed the first high sensitivity, all sky survey in the infrared, discovering over 300,000 sources.

Explorers under development will study the properties of the cosmic microwave background, which is important for understanding the early universe and cosmology, survey the sky in the extreme-ultraviolet for the first time, and measure time variable phenomena in x-ray sources. The Explorer program also provides a means of developing instruments for "payload-of-opportunity" missions, such as those involving other Federal agencies or international collaboration.

The San Marco-D mission, a cooperative project with Italy, is scheduled for launch in 1988 on a Scout expendable launch vehicle. This project will include a group of U.S. experiments to study the relationship between solar activity and meteorological phenomena on the Earth. The Cosmic-Ray Isotope Experiment (CRIE) will be included in the Combined Release and Radiation Effects Satellite (CRRES), an Air Force Mission now scheduled for launch in 1990. The CRRES will also release trace chemicals, whose transport in the magnetosphere can be observed from ground and airborne-based instruments.

In FY 1986, a new cooperative mission called Solar-A was initiated with the Japanese. Solar-A will be launched in 1991 to study the Sun during the upcoming solar maximum. The U.S. has selected an instrument for this spacecraft, which will relate energetic solar phenomena and dynamic coronal structures seen in hard and soft x-rays to the topology of evolving solar magnetic fields. This will allow the first simultaneous observations of these phenomena from space.

In FY 1988, development continues on the Cosmic Background Explorer (COBE), the Extreme Ultraviolet Explorer (EWE), and on the x-ray imaging instrument to be flown on the German Roentgen Satellite (ROSAT). COBE will carry out a definitive, all-sky exploration of the infrared background radiation of the universe between the wavelengths of a micrometer and 9.6 millimeters. Because COBE requires a polar orbit, and the opening of the West Coast Shuttle launch facility has been postponed, the decision was made to launch the COBE spacecraft on a Delta expendable launch vehicle in early 1989. Funding in FY 1988 will be used for integration and testing of the three COBE instruments and the COBE spacecraft vehicle. Design and development also continues on EWE, which will carry out the first detailed all-sky survey of extreme ultraviolet radiation between 100 and 900 angstroms.

ROSAT, a cooperative project between the Federal Republic of Germany (FRG) and the United States will perform a high resolution imaging survey of the x-ray sky and provide indepth studies on selected objects. The U.S. will provide one of the ROSAT instruments and the launch services; Germany will provide the spacecraft, telescope, and other instruments. The U.S. x-ray imaging instrument will be delivered in the second quarter of N 1987. Current plans call for ROSAT to be launched on a Delta expendable launch vehicle in early 1990.

Definition and design will continue in FY 1988 on the X-ray Timing Explorer (XTE). This mission, the last currently planned major effort in the Explorer line, can be ready for launch as early as 1993. During FY 1986, a "Dear Colleague" letter was issued to obtain proposals for future Explorers. Over 43 were received and are currently being evaluated for further definition.

In addition to our efforts in the traditional "Delta-class" Explorer area, current plans call for issuance of an Announcement of Opportunity for Scout-class Explorer missions in early 1988. While subject to more stringent constraints than Delta-class missions (weight, telemetry, power, etc.), it is anticipated that a significant number of scientifically exciting missions can utilize this capability and be developed on a short time-scale. Following a peer review of proposals, it is anticipated that several Scout missions will be selected for development with the initial one being launched as early as 1991.

CHANGES IN **FY 1988** REVISED BUDGET

The $10.0 million Congressional addition to the Explorer budget will accelerate development of smaller Scout-class payloads program and will be used to maintain the tight instrument development schedule for the cooperative Japanese-American mission, Solar-A.

BASIS **OF FY 1989** ESTIMATE

During FY 1989, the final testing of the COBE spacecraft will be completed in preparation for a mid-year launch. Development activity will continue on EWE, and in the instruments scheduled to fly on CRRES, ROSAT and Solar-A. Development activities will begin on the XTE and will increase on the Scout-class payloads.

BASIS OF FY 1989 FUNDING REQUIREMENT

MISSION OPERATIONS AND DATA ANALYSIS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Hubble space telescope operations.....	41,700	50,800	50,800	59,100
Hubble space telescope maintenance and refurbishment.....	55,600	40,800	40,800	52,200
Astrophysics mission operations and data analysis.....	25,200	21,800	21,800	29,300
Space physics mission operations and data analysis.....	8,500	7,700	18,600	15,600
	(14,100)*	(10,900)*	---	---
Total.....	131,000	121,100	132,000	156,200

* Previously funded under Environmental Observations MO&DA

OBJECTIVES AND STATUS

The purpose of the mission operations and data analysis effort is to conduct operations and analyze data received from physics and astronomy spacecraft after launch. The program also supports the operation of a number of spacecraft after their originally planned objectives have been achieved, for purposes of conducting specific investigations that have continuing high scientific significance. The funding supports the data analysis activities of the many investigators at universities and other research organizations associated with astrophysics and space physics operational satellite projects. Actual satellite operations, including control centers and related data reduction and engineering support activities, are typically carried out under a variety of mission support or center support contracts.

Space Physics research activities rely on data received from the Interplanetary Monitoring Platform (IMP), the Active Magnetospheric Particle Trace Explorer (AMPTE), the Dynamics Explorers which are still operational, and the International Sun Earth Explorers (ISEE-1&2), which re-entered in October 1987. IMP continues to provide the only available source of solar wind input measurements to the Earth. IMP, along with ISEE-1&2, DE, AMPTE, and the Swedish Viking satellite successfully conducted a multisatellite campaign called Polar Regions and Outer Magnetospheric International Study (PROMIS) in 1986. The ISEE-3 spacecraft, renamed the International Cometery Explorer (ICE), provided complementary solar wind measurements upstream of Comet Halley in 1986, and was retargeted for a return to Earth orbit in 2014 for retrieval and presentation to the National Air and Space Museum (NASM).

In addition to the normal support required for mission operations, the Hubble Space Telescope program encompasses several unique aspects which must be provided for in advance of the launch. The Hubble Space Telescope is designed to operate for more than a decade, using the Space Shuttle/Orbital Maneuvering Vehicle combination and/or Space Station for on-orbit maintenance of the spacecraft and in-orbit changeout or repair of the scientific instruments.

The Hubble Space Telescope will be used primarily by observers selected on the basis of proposals submitted in response to periodic solicitations. Science operations will be carried out through an independent Hubble Space Telescope Science Institute. The Institute will operate under a long-term contract with NASA. While NASA will retain operational responsibility for the observatory, the Institute will implement NASA policies in the area of planning, management, and scheduling of the scientific operations of the Hubble Space Telescope.

Initiation of the definition and implementation of a unified data system which will ensure the fullest access and exploitation of the various mission data sets, with emphasis on the wealth of data to be returned by the Great Observatories, will be undertaken. An initial definition process involving extensive inputs from the astrophysical community has now been completed, and FY 1989 funding in the Mission Operations and Data Analysis (MO&DA) area will enable the principal elements of this essential system to be put in place.

CHANGES FROM FY 1988 REVISED BUDGET

In line with the recent OSSA reorganization, Space Physics MO&DA activity previously budgeted in the Environmental Observations program has been transferred to Physics and Astronomy. This includes support for IMP, AMPTE, DE, ICE and ISEE 1&2. The remaining MO&DA activity carried out by the Astrophysics program has been consolidated in a single Astrophysics MO&DA line.

Although total funding remains unchanged, several substantial additions to the Hubble Space Telescope program have been initiated. In order to reduce the likely servicing requirements of the Hubble Space Telescope, development has been initiated on Nickel-Hydrogen Batteries and Back Surface Field Reflecting Solar arrays to improve the power lifetime of the spacecraft. Attempts are being made fund the new requirements within the baseline program.

BASIS OF FY 1989 ESTIMATE

The FY 1989 funding level is required to maintain critical skills for the operation and maintenance of the Hubble Space Telescope, and to prepare for launch activities in the fourth quarter of FY 1989.

Mission operations, data analysis, and guest investigator programs will continue for the Solar Maximum Mission (SMM), the Interplanetary Monitoring Platform (IMP), the Dynamics Explorer (DE), the Active Magnetospheric Particle Trace Explorer (AMPTE), and the International Ultraviolet Explorer (IUE). The High Energy Astronomical Observatories (HEAO 1-3), International Sun-Earth Explorers 1 and 2 (ISEE-1 & 2), International Cometary Explorer (ICE) and the Infrared Astronomy Satellite (IRAS) data analysis will also continue. These programs have produced valuable data sets which are used by a wide segment of the physics and astronomy community. FY 1989 funds will also be used to begin development of the unified Astrophysics data system.

BASIS OF FY 1989 FUNDING REQUIREMENT

RESEARCH AND ANALYSIS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Supporting research and technology.....	30,800	30,800	67,000	84,800
	(20,800)**	(20,600)**	---	---
Gravity probe-B definition.....	9,000	2,700	2,700	---
Shuttle test of relativity.....	---	10,300	(---)*	(---)*
Advanced technology development.....	13.600	13.200	13.200	4.300
Total.....	53.400	57,000	82.900	89.100

* Transferred to Payload and Instrument Development
** Previously funded under Environmental Observations Research and Analysis

OBJECTIVES AND STATUS

This program provides for the preliminary studies required to define missions and/or payload requirements, as well as providing a research and technology base necessary to define, plan and support flight projects.

- Supporting Research and Technology (SR&T): The objectives of supporting research and technology are to: (1) optimize the return expected from future missions through scientific problem definition, development of advanced instrumentation and concepts, and sound definition of proposed new missions; (2) enhance the value of current space missions by carrying out complementary and supplementary ground-based observations and laboratory experiments; (3) develop theories to explain observed phenomena and predict new ones; (4) strengthen the technological base for sensor and instrumentation development and conduct the basic research necessary to understand astrophysics phenomena and solar-terrestrial relationships; and, (5) continue the acquisition, analysis and evaluation of data from laboratories, balloons, rocket and spacecraft activities.

Research is supported in the disciplines of astronomy, astrophysics, gravitational physics, and space physics. Research in astronomy and astrophysics involves the study of stars, galaxies, interstellar and intergalactic matter, and cosmic rays. Space physics research and analysis is a broadly structured effort to enhance our understanding of the characteristics and behavior of plasmas in the solar corona, the interplanetary medium and in the vicinity of the Earth and other planets. The theory activities are related to all the Physics and Astronomy disciplines and are critical to the correlation of available information. The development of new instruments, laboratory and theoretical studies of basic physical processes, and observations by ground-based and balloon-borne instruments will also be continued. Results achieved in the SR&T program will have a direct bearing on future flight programs. For example, the development of advanced x-ray, ultraviolet, and infrared astronomy imaging devices under this program may enable spacecraft to carry instruments for astronomical observations which have increased orders of magnitude in sensitivity and improved resolution over currently available detectors.

One major thrust of the space physics program is directed at studies of the near-Earth geospace environment, from the flow of the solar wind past the magnetosphere, to manifestations of variations of the plasma environment detectable near the surface of the Earth. Not only are these studies of great interest for basic plasma physics but there are also many practical ramifications, such as ionospheric influences on communication, global circulation of the atmosphere driven by magnetospheric input, the charging of spacecraft immersed in plasma, and the behavior of antennas and their signals in the magnetosphere.

The SR&T program carries out its objectives through universities, nonprofit and industrial research institutions, NASA centers and other government agencies. Current emphasis is being placed on studies of advanced instrumentation with increased sensitivity and resolution.

- Advanced Technological Development (ATD): The advanced technological development activities support detailed planning and definition of potential new physics and astronomy missions. ATD activities assure that future missions address the scientific questions most important to the evolution of knowledge in the field, and that those missions use the appropriate technology and techniques. Funding is applied to the definition and preliminary design for specific missions or subsystems/elements critical to eventual mission development in order that technical readiness and resources requirements may be adequately defined before the missions are proposed for implementation.

Candidate missions for the 1980's and early 1990's that require ATD activities include the Advanced X-Ray Astrophysics Facility (AXAF) and the Space Infrared Telesope Facility (SIRTF). The AXAF mission, which is an FY 1989 new initiative, will study stellar structure and evolution, active galaxies, clusters of galaxies and cosmology. The AXAF's imaging x-ray telescope is planned to have a sensitivity approximately 100 times that of HEAO-2, a resolution increase of nearly a factor of twenty and an increase in wavelength range by a factor of two. The SIRTF will observe faint, cool infrared sources in the universe and will significantly build on the IRAS science foundation. Major Spacelab payloads being considered for future missions and requiring advanced technological development support include the Pinhole/Occulter Facility, a detector for imaging hard x-rays from solar and cosmic sources. During FY 1988, AXAF definition will be completed and a down selection between prime contractor candidates will be performed through a Source Evaluation Board process. Work will continue toward deepening the technological and system understanding of science instruments selected for definition. Technological preparation for SIRTF will also continue.

CHANGES FROM FY **1988** REVISED BUDGET

All program elements under the responsibility of the recently created Space Physics Division have been consolidated within Physics and Astronomy. Space Physics research and analysis activites previously funded in the Environmental Observations program have been transferred to Physics and Astronomy SR&T. Astrophysics rocket science activity previously funded in the Sounding Rocket program has been transferred to Physics and Astronomy SR&T. Funding for Supernova support has been transferred to Physics and Astronomy SR&T from both the sounding rockets and payloads programs. Activities on Gravity Probe-B following the completion of advanced technology definition in early FY 1988 have been transferred to Physics and Astronomy Payload and Instrument Development.

BASIS OF FY **1989** ESTIMATE

During FY 1989, the supporting research and technology program will support those tasks which contribute to maintaining a firm base for viable physics and astronomy and space physics programs. Support will be provided for study of Supernova 1987a to take advantage of the unique scientific opportunity provided by this exciting event. FY 1989 funding will also support continued studies on potential future missions. In the data analysis activities to be carried out at university and government research centers in N 1989, emphasis will be placed on correlative studies involving data acquired from several sources (spacecraft, balloons, sounding rockets, research aircraft and ground observatories).

BASIS OF FY 1989 FUNDING REQUIREMENT

SUBORBITAL PROGRAM

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Sounding rockets.....	30,900	31,300	24,900	25,700
Airborne science and applications.....	35,600	29,200	7,300	7,a00
	(27,600)*	(21,900)*	---	---
Balloon program.....	7,900	8,100	9,900	a,600
Spartan.....	4.700	4.500	2.600	3.000
Total.....	79.100	73.100	44.700	45,100

* Transferred to Environmental Observations Airborne Science and Applications

OBJECTIVES AND STATUS

The suborbital program uses balloons, aircraft, and sounding rockets to conduct versatile, relatively low cost research of the Earth's ionosphere and magnetosphere, space plasma physics, stellar astronomy, solar astronomy, and high energy astrophysics. Activities are conducted on both a national and on an international cooperative basis.

- Sounding Rockets:

  A major objective of the sounding rocket program is to support a coordinated research effort. Sounding rockets are uniquely suited for performing low altitude measurements (between balloon and spacecraft altitude)-and for measuring vertical variations of many atmospheric parameters. Special areas of study supported by the sounding rocket program include the nature, characteristics, and composition of the magnetosphere and near space; the effects of incoming energetic particles and solar radiation on the magnetosphere, including the production of aurorae and the coupling of energy into the atmosphere; and the nature, characteristics, and spectra of radiation of the Sun, stars and other celestial objects.

Additionally, the sounding rocket program provides the physics and astronomy program with the means for flight testing instruments and experiments being developed for later flight on the Shuttle/Spacelab and space probes and for calibrating and obtaining vertical profiles in concert with current orbiting spacecraft. Forty-four rockets are currently scheduled for launch in FY 1988. Included in this number are eight NASA launches in Greenland as a follow-up to the FY 1985 effort,

- Airborne Science and Applications:

Research with instrumented jet aircraft has been an integral part of the NASA physics and astronomy program since 1965. For astronomy research, the airborne science and applications program operates the Kuiper Airborne Observatory. This full-scale manned facility consists of a *C-141* equipped with a 91-centimeter infrared telescope. The *C-141* aircraft, able to fly for several hours at altitudes approaching 13 kilometers, provides a cloud-free site for astronomical observations. The ability to carry out observations at this altitude, above most of the infrared-absorbing water vapor in the Earth's atmosphere, has been essential in expanding astronomical observations into the infrared region of the electromagnetic spectrum from one micrometer to hundreds of micrometers.

In FY 1987, the *C-141* responded rapidly to the discovery of the SN 1987a Supernova, making observations during the crucial expansion phase of the event. Other observations included the exploration of the star-forming regions and of other areas in our own galaxy and solar system. In FY 1988, 72 missions are planned, including support of the SN 1987a campaign with additional flights in the southern hemisphere. FY 1988 activities continue the study of a Stratospheric Observatory For Infrared Astronomy (SOFIA) as a potential follow-on for the *C-141* in the 1990's. SOFIA would incorporate a 3-meter class infrared telescope mounted in a suitable aircraft.

- Balloon Program:

The Balloon Program provides a cost-effective means to test flight instrumentation in the space radiation environment and for making observations at altitudes which are above most of the water vapor in the atmosphere. Balloon experimentation is particularly useful when studying infrared,

gamma-ray, and cosmic-ray astronomy. In many instances it is necessary, because of size, weight, cost, or lack of other opportunities, to fly primary scientific experiments on balloons. In addition to the level-of-effort science observations program, significant emphasis has been and will be placed on development of a balloon capable of lifting more than 3,500 pounds, and to support missions lasting several days.

The Balloon Program funding is required for purchase of balloons, helium, launch services, tracking and recovery, as well as for maintenance and operations of the National Scientific Balloon Facility (NSBF) at Palestine, Texas. This facility supports the launch of about 80 percent of NASA's balloon payloads, and it is the nation's primary means for carrying out large scientific balloon operations. Funding for the experiments flown on balloons is provided from other research and technology programs supporting the various scientific disciplines.

- Spartan Program:

The Spartan missions involve low-cost Shuttle payloads flown as autonomous sub-satellites which are deployed and retrieved by the Space Shuttle. Spartans allow the accomplishment of single, specific scientific objectives with efficiency and simplicity. The first Spartan flew successfully in 1985. It obtained valuable, new x-ray data on the nuclear region of our own galaxy and on the vast cluster of galaxies in the constellation Perseus. Detailed analysis of this data is continuing. The second Spartan, Spartan Halley, was lost with the Challenger. A third Spartan mission, Spartan 201, consisting of a 17-inch diameter solar telescope with an ultraviolet coronagraph and a white light coronagraph to measure the intensity and scattering properties of solar light, is being developed for a future Shuttle mission.

CHANGES FROM FY 1988 REVISED BUDGET

Astrophysics rocket science activity previously funded in the Sounding Rocket program has been transferred to Physics and Astronomy SR&T in accordance with the Office of Space Science and Applications reorganization. This has also led to the transfer of the majority of airborne activity previously funded in Physics and Astronomy to the Environmental Observations program, which funds a majority of the users of these airborne capabilities. The balloon program has been augmented to accommodate improvements in operational and long duration capabilities and for increased demands on the program due to Shuttle delays and the Supernova 1987a effort. The Spartan program has been revised to support development of Spartan 201 as well as the FY 1988 Supernova 1987a effort. This is reflected in the transfer of some Spartan funds to Research and Analysis.

BASIS OF FY 1989 ESTIMATE

FY 1989 funds will provide for continuation of the sounding rocket, Spartan, and balloon programs including management and operation of the NSBF. This funding is also required to continue definition activities for balloon improvement and long-duration balloon flights. In FY 1989, the Airborne Science and Applications funding will be used to continue flights of the Kuiper Airborne Observatory.

LIFE SCIENCES

RESEARCH AND DEVELOPMENT

FISCAL YEAR 1989 ESTIMATES

BUDGET SUMMARY

OFFICE OF SPACE SCIENCE AND APPLICATIONS **LIFE SCIENCES PROGRAM**

SUMMARY OF RESOURCES REQUIREMENTS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
		(Thousands of Dollars)			
Life sciences flight experiments.....	30,000	30,900	30,900	54,500	RD 4-3
Research and analysis.....	41,800	39,100	38,600	47,200	RD 4-5
Total.....	71,800	70,000	69,500	101,700	
Distribution of Program Amount By Installation					
Johnson Space Center.....	23,600	23,200	23,000	32,300	
Kennedy Space Center.....	3,000	3,000	2,900	4,200	
Goddard Space Flight Center.....	200	200	200	300	
Jet Propulsion Laboratory.....	1,700	1,700	1,700	3,700	
Ames Research Center.....	30,200	29,700	29,500	44,300	
National Space Technology Laboratories	100	100	100	100	
Langley Research Center.....	500	500	500	600	
Marshall Space Flight Center.....	100	100	100	200	
Headquarters.....	12,400	11,500	11,500	16,000	
Total.....	71,800	70,000	69,500	101,700	

RESEARCH AND DEVELOPMENT

FISCAL YEAR 1989 ESTIMATES

BUDGET SUMMARY

OFFICE OF SPACE SCIENCE AND APPLICATIONS **LIFE SCIENCES PROGRAM**

PROGRAM OBJECTIVE AND JUSTIFICATION

The goals of the Life Sciences program are to advance knowledge in all areas of space life sciences and to develop medical and biological systems which enable human habitation in space. Results from the research program are applied to: the immediate needs of maintaining astronaut health and productivity; understanding the response of biological mechanisms to weightlessness; the design of controlled ecological life support systems; understanding the origin, evolution and distribution of life in the universe; and, understanding the biosphere of the planet Earth.

Continuing support of the Life Sciences program is essential to: understand the basic biological mechanisms of gravitational responsivity; evolve the critical technologies necessary to enable long-term piloted space flight; and, develop the capability to sustain a permanent manned presence in space. The research program includes ground-based and space research efforts which are mutually supportive and integrated, and studies fundamental biological processes and space-related medical problems through a variety of disciplines and techniques.

The Life Sciences research and analysis program includes five major elements: 1) space medicine, which addresses the health and well-being of space crews by seeking to understand and prevent adverse physiological changes which occur in space flight and upon return to Earth; 2) space biology, an integrated basic science research program that studies the fundamental mechanisms of gravitational interaction with all orders of plants and animals in flight and ground experiments; 3) controlled ecological life support systems, a program of research and critical technology development for life support systems necessary to maintain life in space autonomously for long periods of time; 4) exobiology research, which is directed toward understanding the origin and distribution of life and life-related molecules on Earth and throughout the universe; and, 5) biospheric research, which explores the interaction between life on Earth and its physical and chemical environment.

The Life Sciences Flight Experiment program supports the research and analysis program with the selection, definition, in-flight execution, data analysis and reporting on medical and biological investigations in space involving humans, animals and plants. Experiments are currently conducted on the Shuttle and Spacelab, and are being readied for conduct on the Space Station. An international cooperative program, the U.S./U.S.S.R. working group in space biology and medicine, pursues investigations of joint interest.

BASIS OF FY 1989 FUNDING REOUIREMENT

LIFE SCIENCES FLIGHT EXPERIMENTS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Life sciences flight experiments.....	30,000	30,900	30,900	54,500

OBJECTIVES AND STATUS

The objective of the Life Sciences Flight Experiment program is to assimilate information and scientific questions from various life sciences disciplines and develop payloads designed to expand the understanding of the basic physiological mechanisms involved in adaptation of weightlessness. The program includes selection, definition, in-flight execution, data analysis and reporting on medical and biological investigations involving humans, animals and plants. Past experience indicates that humans clearly undergo physiological changes during weightlessness. Many of the observed changes are physiologically significant and are not well understood. Shuttle/Spacelab and Space Station missions are suitable for gaining a greater understanding of the basic mechanisms underlying this response to weightlessness. Flight experiments that lead to a firmer comprehension of the underlying mechanisms of gravitational adaptation enhance our basic science knowledge, make it possible to improve the management of several existing problems, and increase the confidence with which we can estimate the physiological consequences of more sustained weightless exposure and design corresponding countermeasures.

BASIS OF FY 1989 ESTIMATE

FY 1989 funding is required for the final preparation and flight of approved experiments on the first dedicated Life Science mission (Spacelab Life Sciences-1 (SLS-1)) which is scheduled to be launched in FY 1991 and will concentrate on studies of human and animal biomedical responses, with emphasis on cardiovascular, bone metabolism and vestibular functions. SLS-1 will be unique in several respects: it will be the first Shuttle/Spacelab mission dedicated entirely to life sciences, and it will involve highly skilled scientists as payload specialists, thus permitting the use of numerous experimental techniques and procedures never before utilized in space. Many of the experiments and associated flight hardware flown on earlier Shuttle flights will support and enhance preparations for SLS-1 and subsequent missions.

Final preparations are also underway to support the flight of the first International Microgravity Laboratory (IML-1) mission in 1990. Approximately 50 percent of the payload relates to space life sciences, with the U.S. focus on plants, neurovestibular studies, human performance, radiation and cellular differentiation.

Efforts will continue on definition and development of new experiments (selected through the Announcement of Opportunity (AO) process) and hardware that will be flown on future Spacelab/Shuttle missions - i.e., Shuttle mid-decks, the Japanese SL-J mission, the second dedicated life sciences mission (SLS-2), the German D-2 mission, IML-2, SLS-3, and the Department of Defense Starlab mission. Collaboration with the Soviet Union on its COSMOS biosatellite program will continue with joint research on the next COSMOS flight in 1989.

To ensure that the Space Station will serve life sciences research objectives, studies will be conducted in FY 1989 to determine how space biology research will be accommodated on the Space Station, as well as to define instrument and facility requirements. Studies will identify unique scientific and hardware transition requirements from continuing Spacelab flights to Space Station operations. In addition, technology assessment, advanced technology development, and experiment definition and planning will be conducted.

In FY 1989, research efforts will be increased on the feasibility of extending operational tours of duty of flight crews on the Space Station in order to achieve greater cost-effectiveness. The program will decrease transportation costs by helping to reduce yearly Shuttle flights needed to support crew rotations on the Space Station from eight to an estimated four to five. It will also allow more effective use of human resources by maintaining crew health and productivity with countermeasures that minimize impact on in-flight crew time. Crew debility and rehabilitation time following long duration space flight will also be reduced. Spacelab opportunities will be used to conduct supporting experiments and fly associated payloads. Preparation for the Space Station will commence with investigation planning, technology assessment for flight equipment, and critical technology and hardware development.

In FY 1989, development will begin on an integrated centrifuge facility that will support a broad spectrum of life sciences research using small animals and plants. For the first time, it will provide continuous on-board 1-G control that can separate influences of weightlessness from other effects of space flight. It will allow scientists to test the response of living organisms to operational forces at various stages of adaptation to weightlessness. Two units will be developed. The initial unit will be deployed on Spacelab where in-flight engineering verifications for the centrifuge, associated equipment and logistical support will be performed. The second unit will be deployed on the Space Station. This facility represents a marked enhancement of basic research capability to the Life Sciences program.

BASIS OF FY 1989 FUNDING REQUIREMENT

RESEARCH AND ANALYSIS

	1987 Actual	1988 Revised Budaet	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Life sciences research and analysis.....	41,800	39,100	38,600	47,200

OBJECTIVES AND STATUS

The research and analysis activity supports Life Sciences program goals of: advancing knowledge in all areas of space life sciences and developing medical and biological systems which enable human habitation in space. The program is composed of five elements: 1) space medicine; 2) space biology; 3) controlled ecological life support systems research; 4) exobiology; and, 5) biospheric research.

The Life Sciences Space Medicine program is responsible for assuring the physical welfare, performance and adequate treatment of in-flight illness or injuries of spaceflight crews. Such conditions as space motion sickness, spatial disorientation, fluid shifts and endocrine changes, can decrease performance and cardiovascular tolerance and possibly aggravate latent disease. These conditions must be carefully evaluated to determine preventative measures. To this end, careful medical selection, periodic evaluation of health status, and in-flight monitoring of the adaptation to space and success of physiological countermeasures will be continually undertaken. In addition, long-term monitoring of space flight crews will be performed in a standardized fashion in order to identify risk factors and establish the long-term clinical significance associated with repeated exposure to the space environment. Biomedical research will investigate the fundamental physiological basis for problems encountered in manned spaceflight. Research areas include: neuroscience; cardiovascular, musculoskeletal, and regulatory physiology; cell and developmental biology; human behavior and performance; and, environmental health sciences.

The Space Biology program explores the role of gravity in life processes and uses gravity variations as an environmental tool to investigate fundamental biological questions. Specific objectives are to perform the basic science research required to identify and investigate: 1) the role of gravity in plant and animal behavior, morphology, development and physiology; 2) the mechanisms of gravity sensing and the transmission of this information within both plants and animals; 3) the interactive effects of gravity and other stimuli (e.g., light) and stresses (e.g., vibration and disorientation) on the physiology of organisms; 4) the uses of gravity to study the normal nature and properties of living organisms; and, 5) the effects of microgravity to facilitate plant and animal growth, long-term survival and reproduction in space.

The Controlled Ecological Life Support Systems program seeks to provide air, water and food to support life through bioregenerative closed systems which receive only energy from the external environment. Development of such systems is a critical path element for long duration manned spaceflight and lunar colonization.

The Exobiology program is directed toward understanding the origin and evolution of life, and life-related molecules, on Earth and throughout the universe. Research seeks to trace the pathways leading from the origin of the universe through the major epochs in the evolution of living systems. Research encompasses: the cosmic evolution of the biogenic compounds, prebiotic evolution, early evolution of life, and evolution of advanced life. Emphasis is placed on understanding these processes in the context of the planetary and astrophysical environments in which they occurred. Flight experiments in Earth orbit and on planetary missions are important program elements. Theoretical and laboratory investigations are also included in this program to develop a better understanding of the conditions on Earth as related to early chemical and biological evolution.

The Biospheric Research program explores the interaction between global biological and planetary processes to develop an understanding of global biogeochemical cycles. Laboratory and field investigations are correlated with remote sensing data to characterize the influence of biological processes in global dynamics. Biospheric modeling efforts integrate biological data with atmospheric, climate, oceanic, terrestrial, and biogeochemical cycling data to reflect the state of the biosphere as a function of both natural and anthropogenic perturbations.

CHANGES FROM THE FY 1988 REVISED BUDGET

The reduction of $.5 million will be reallocated to Physics and Astronomy Research and Analyses in order to support Supernova activities.

BASIS OF THE FY 1989 ESTIMATE

The Space Medicine program will resume collecting information on occupational exposure in microgravity on each Shuttle flight and conduct in-flight clinical testing of countermeasures, especially in the area of vestibular dysfunction, cardiovascular deconditioning and muscular atrophy. Resolving problems associated with the initial adaptation to weightlessness such as space motion sickness and fluid shifts will continue to be of high priority. Research emphasis will be placed on operational management of space adaptation syndrome. Approaches such as autogenic (biofeedback) techniques will be evaluated in flight to provide a basis for development of specific countermeasures. Research will commence in the field of biomechanics. Understanding the dynamics of bodily adaptation to physical forces and being able to measure stress on the human body is crucial to designing countermeasures to maintain astronaut health and productivity. Research in the fields of psychology and the ergonomics of man/machine interface will be supported for their importance in improving the performance and efficiency of flight crews. Research

in radiation biology will continue because it is necessary to precisely measure dosages and the effects of cosmic and solar radiation in order to determine the optimum radiation shielding required for humans in space. Research is in progress to develop pressurized space suits for quick reaction situations and to develop corresponding pressurized suit gloves.

In conjuction with NASA's development of the Space Station, the Space Medicine program will support extended duration crew operations in space with extensive research in the physiological changes associated with longer exposure to weightlessness. Bone demineralization, muscle atrophy and cardiovascular deconditioning will be studied in ground-based simulation so appropriate countermeasures can be designed. This accelerated program of directed research, bed rest studies and protocol development and evaluation will allow more effective use of human resources in space by developing physiological countermeasures that minimize impact on in-flight crew time. Critical technology requirements will be addressed and research on implementation initiated.

In FY 1989, the Office of Space Science and Applications will collaborate with the Office of Aeronautics and Space Technology on the Agency's proposed new initiative: Project Pathfinder. The Project will research critical path elements for long-term manned missions in order to inform policy makers of the requirements (as well as uncertainties, risks and technological issues) involved in such efforts as a lunar base or manned Mars mission. Life science research will be directed to the Humans in Space element of Project Pathfinder and focus on the areas of human performance, extravehicular activity and life support. Critical areas of investigation in human performance include: biomedical requirements for artificial gravity; advanced medical care technology for remote locations; radiation protection; and psychological and habitability factors affecting crew behavior and performance on long duration missions. Research in extravehicular activity will focus on: developing requirements for portable life support systems and habitability of space suits; and gathering the anthropometric and bioengineering data needed to develop pressurized suit gloves that allow adequate manual dexterity. The life support program will develop and test technologies that will provide the capability for closed-loop life support. Important factors include waste processing, food production, air revitalization, and water purification.

The Space Biology program will concentrate ground research on: developing working models of functioning gravity-sensing neural (information) networks to understand neurosensory processing in microgravity; understanding the physiological side effects of centrifugation in preparation for use of the Shuttle/Space Station centrifuge as a research tool; and identifying the cellular events of the gravity perception mechanism in plants. Research in preparation for flight opportunities on the Shuttle and the Soviet biosatellite COSMOS will focus on genetic, cytological, developmental and metabolic effects of gravity on plants and animals. Fundamental research in gravitational response mechanisms in plant and animal development will be developed in preparation for future biosatellite and Space Station experiments.

The Controlled Ecological Life Support Systems program will continue to investigate basic biological processes and physical methods to control the interior environment of manned spacecraft. In developing such a life support system, the near term emphasis will be on system definition and development of design concepts and critical technologies for flight, and supporting research in the areas of controlled-environment plant production, waste processing and human nutrition.

The Exobiology program will emphasize the development of new flight experiment concepts to investigate models of early Solar System evolution and mechanisms for the synthesis of biologically significant molecules in space. The program will further develop analytic capabilities to utilize an expanding extraterrestrial sample base, participate in the retrieval of samples and focus science on emerging opportunities in planetary exploration. In FY 1989, definition and design phases will be completed in the program's microwave observing project which will analyze microwave signals in space for evidence of advanced life elsewhere in the galaxy. Funds will be used to begin the development phase of signal processing systems which will be used with existing radio astronomy facilities and NASA's Deep Space Network antennas.

The Biospheric Research program will place emphasis on improving estimation techniques for determining the structural state of the terrestrial biomass by combining ground-based measurements at tropical, temperate, and wetland sites with remote sensing data and biogeochemical modeling of the interactions of ecosystems on a global scale. Information gathered through remote sensing will also be used to help nations prepare for outbreaks of vector-borne disease (malaria) by allowing predictive modeling of the occurrence of the disease vector (mosquitos).

PLANETARY
EXPLORATION

RESEARCH AND DEVELOPMENT

FISCAL YEAR 1989 ESTIMATES

BUDGET SUMMARY

OFFICE OF SPACE SCIENCE AND APPLICATIONS **PLANETARY EXPLORATION PROGRAM**

SUMMARY OF RESOURCES REQUIREMENTS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
		(Thousands of Dollars)			
Galileo development	71,200	54,700	51,900	61,300	RD 5-5
Magellan	97,300	59,300	73,000	33,900	RD 5-7
Ulysses	10,300	10,800	7,800	10,300	RD 5-9
Mars observer	35,800	28,900	53,900	102,200	RD 5-11
Mission operations and data analysis	75,100	76,300	74,700	112,700	RD 5-13
Research and analysis	69,500	74,300	67,900	83,600	RD 5-15
Total	359.200	304,300	329,200	404.000	

Distribution of Program Amount by Installation

Johnson Space Center	12,029	10,678	10,825	10,855
Marshall Space Flight Center	394	75	237	245
Goddard Space Flight Center	10,579	8,190	9,284	9,710
Jet Propulsion Laboratory	274,391	225,966	251,887	325,300
Ames Research Center	19,318	15,740	15,555	15,795
Lewis Research Center	195	--	--	--
Langley Research Center	29	25	13	15
Headquarters	42.265	43.626	41,399	42,080
Total	359.200	304,300	329.200	404,000

OFFICE OF SPACE SCIENCE AND APPLICATIONS **PLANETARY EXPLORATION PROGRAM**

PROGRAM OBJECTIVES AND JUSTIFICATION

The Planetary Exploration program encompasses the scientific exploration of the solar system including the planets and their satellites, comets and asteroids, and the interplanetary medium. The program objectives are: (1) to determine the nature of planets, comets, and asteroids as a means for understanding the origin and evolution of the solar system; (2) to understand the Earth better through comparative studies with the other planets; (3) to understand how the appearance of life in the solar system is related to the chemical history of the solar system; and, (4) to provide a scientific basis for the future use of resources available in near-Earth space. Projects undertaken in the past have been highly successful. The strategy that has been adopted calls for a balanced emphasis on the Earth-like inner planets, the giant gaseous outer planets, and the small bodies (comets and asteroids). Missions to these bodies start at the level of reconnaissance to achieve a fundamental characterization of the bodies, and then proceed to levels of more detailed study.

The reconnaissance phase of inner planet exploration, which began in the 1960's, is now virtually completed, although we still know little about the nature of the planet Venus' surface, Mars has provided program focus because of its potential as a site of biological activity. The Viking landings in 1976 carried the exploration of Mars forward to a high level of scientific and technological achievement, thereby setting the stage for the next step of detailed study. Analyses of meteorites and the lunar rock samples returned by Apollo continue to be highly productive, producing new insights into the early history of the inner solar system and thus leading to revision of our theoretical concepts. The Pioneer Venus mission is continuing to carry the study of the Earth's nearest planetary neighbor and closest planetary analog beyond the reconnaissance stage to the point where we have now obtained a basic characterization of Venus' thick, massive atmosphere, as well as fundamental data about the formation of the planet.

The exploration of the giant outer planets began more recently. The Pioneer-10 missions to Jupiter in 1973 and 1974 were followed by the Voyager-1 and 2 spacecraft encounters in 1979. Voyager-1 then encountered Saturn in November 1980, and Voyager-2 in August 1981. The Voyager data on these planets, their satellites, and their rings have revolutionized our concepts about the formation and evolution of the solar system. Voyager-2 encountered Uranus in January 1986 and has provided our first look at this giant outer planet. Its trajectory is now carrying it to an encounter with the planet

Neptune in 1989. The Pioneer-10 and 11 and Voyager-1 spacecraft are on trajectories heading out of the solar system, as they continue to return scientific data about the outer reaches of the solar system.

Galileo will be launched on a Shuttle/Inertial Upper Stage (IUS) combination in 1989 on a trajectory using gravity assists at Venus and Earth. The comprehensive science payload will extend our knowledge of Jupiter and its system of satellites well beyond the profound discoveries of the preceding Voyager and Pioneer missions. During twenty-two months of operation in the Jovian system, Galileo will inject an instrumented probe into Jupiter's atmosphere to make direct analyses, while the orbiter will have the capability to make as many as ten close encounters with the Galilean satellites.

Ulysses is a joint NASA and European Space Agency activity. The mission will carry a package of experiments to investigate the Sun at high solar latitudes that cannot be studied from the Earth's orbit. Ulysses will be launched in 1990 using the Shuttle and IUS/PAM-S launch stages.

Magellan will provide global maps of the cloud-shrouded surface of Venus, including its land forms and geological features. Using a synthetic aperture radar to penetrate the planet's opaque atmosphere, Magellan will achieve a resolution sufficient to identify small-scale features and to address fundamental questions about the origin and evolution of the planet, Magellan will also obtain altimetry and gravity data to accurately determine the planet's gravity field as well as internal stresses and density variations. With these data, the evolutionary history of Venus can be compared with that of the Earth. Magellan is scheduled for launch in April 1989 from the Shuttle with an IUS.

Mars Observer will follow up on the earlier discoveries of Mariner 9 and Viking and will emphasize the geologic and climatic evolution of this complex planet. The mission will utilize a modified Earth-orbiting spacecraft, thereby benefiting from the previously developed technology.

Beginning in late 1985, we entered an exciting new phase of exploration by making our first close-up studies of the solar system's mysterious small bodies -- comets and asteroids. These objects may represent unaltered original solar system material, preserved from the geological and chemical changes that have taken place in even small planetary bodies. By sampling and studying comets and asteroids, we can begin to make vigorous inquiries into the origin of the solar system itself. These efforts began with the encounter of Comet Giacohini-Zinner by the International Comet Explorer (ICE) Spacecraft in September 1985 and continued through our involvement with the 1986 encounters and observations of Comet Halley by U.S. and foreign spacecraft and by intensive studies of the comet from ground-based observatories coordinated through the International Halley Watch. Studies of results obtained by these missions and observations and the archiving of these dntn are continuing. In addition, we arc conducting preliminary design for development of a new class of spacecraft, Mariner Mark (MM II).

The Planetary Exploration program is also founded on a coordinated ground-based research and analysis effort. Research and analysis activities will continue to maximize the scientific return from both ongoing and future missions and from such Earth-based activities as lunar sample and meteorite analysis, telescope observations, theoretical and laboratory studies, and instrument definition. This program strives for interdisciplinary coordination among various research groups and for the wide dissemination of scientific results. A close coupling is also maintained between the research programs and planning activities that are undertaken to define the scientific rationale and technology needed for future missions. The program also supports the growing involvement of U.S. scientists as participants on foreign-sponsored missions.

BASIS OF FY 1989 FUNDING REQUIREMENT

GALILEO DEVELOPMENT

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Spacecraft	45,715	19,700	26,000	25,100
Experiments	11,383	12,600	11,000	10,100
Ground operations	14.102	22.400	14.900	26.100
Total	71.200	54,700	51,900	61,300
Space transportation system operations	(11,800)	(23,400)	(30,800)	(83,900)

OBJECTIVES AND STATUS

The objective of the Galileo program is to conduct a comprehensive exploration of Jupiter, its atmosphere, magnetosphere, and satellites through the use of both remote sensing by an orbiter and *in situ* measurements by an atmospheric probe. The scientific objectives of the mission are based on recommendations by the National Academy of Sciences to provide continuity, balance, and orderly progression of the exploration of the solar system.

The orbiter and probe will be launched together in October 1989 as a single combined payload using a Shuttle/Inertial Upper Stage (IUS) combination on an initial trajectory toward Venus, followed by two Earth swingbys. The three gravitational assists will provide the energy required for a trajectory to Jupiter not otherwise obtainable with this launch vehicle. When the orbiter arrives at Jupiter it will provide remote sensing of the probe entry site and provide the link for relaying the probe data back to Earth. Twenty-two months of orbital operations will follow during which both Jupiter's major satellites and the dynamic magnetosphere will be extensively mapped. During this time ten close flybys of Jupiter's four major satellites are targeted.

The Galileo flight system will be powered by two general purpose heat-source Radioisotope Thermoelectric Generators (RTG's) developed by the Department of Energy. The orbiter will carry approximately 100 kg of scientific instruments and the probe will carry approximately 25 kg of scientific instruments.

During FY 1988, activities will continue in completing assembly, integration and initial testing of the modified spacecraft system. In addition, several critical parts changeouts will be completed, which will improve the reliability of the spacecraft computers and science instruments. Modification of the flight software and mission operations systems required to accommodate the new trajectory will continue.

CHANGES FROM FY 1988 AMENDED BUDGET

The net decrease of $2.8 million results from the deferral of selected ground operations development activities to subsequent years. These funds will be used to offset additional funding requirements for Magellan. Funds have also been reallocated internally in order to accomplish required spacecraft orbiter modifications made necessary by the new trajectory.

BASIS OF FY 1989 ESTIMATE

FY 1989 funds will provide for completion of spacecraft system testing and for preparing the spacecraft to be shipped to Kennedy Space Center for initiation of integration with the IUS and Shuttle. Mission operations software development and testing will also continue in preparation for a launch in October 1989.

BASIS OF FY 1989 FUNDING REQUIREMENTS

MAGELLAN

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Spacecraft	54,525	38,000	43,000	14,300
Experiments	29,170	7,900	15,200	5,400
Ground operations	13,605	13,400	14.800	14.200
Total	97,300	59.300	73,000	33.900
Space transportation system operations	(11,800)	(37,400)	(49,300)	(51,600)

OBJECTIVES AND STATUS

The objective of the Magellan mission is to address fundamental questions regarding the origin and evolution of Venus through global radar imagery of the planet. Magellan will also obtain altimetry and gravity data to accurately determine the planet's gravity field as well as internal stresses and density variations. The detailed surface morphology of Venus will be analyzed to compare the evolutionary history of Venus with that of the Earth.

The Magellan spacecraft will carry a single major scientific instrument, a synthetic aperture radar, which will be used to obtain high resolution (120 to 200 meter) images of the planetary surface as well as altimetric data. Gravity data will be obtained by processing radio signals from the spacecraft, Spacecraft development is making extensive use of existing designs, technology, and residual hardware. For example, the spacecraft will use an existing spacecraft structure, large antenna, and propulsion components from the Voyager program.

In April 1989, the Magellan spacecraft will be launched by the Shuttle/Inertial Upper Stage (IUS) on a direct trajectory to Venus. Arriving at Venus in July 1990, the spacecraft will perform a retro-propulsive maneuver and enter a near-polar elliptical orbit. After an initial check-out period, the spacecraft will map a major portion of the planet over a 243 day period (one Venus year) with a ground resolution of about 150 meters.

During FY 1988, spacecraft structural testing will be initiated, the flight model of the radar instrument will be delivered for integration with the spacecraft, the spacecraft assembly will be completed and environmental testing will be initiated for the entire spacecraft flight system. Integration of the mission operations system will be completed to be followed by initiation of operations testing and training preparatory for launch.

CHANGES FROM FY **1988** REVISED BUDGET

The FY 1988 Revised Budget assumed an adequate level of funding to support the then recently revised mission plan, based on a one year launch delay with a new trajectory and a new upper stage. Since that time, formal contractor proposals and updated estimates supporting the new mission, together with newly identified technical problems, such as radar development and several major parts failures will require additional funding of $13.7 million in order to reduce programmatic and schedule risks.

BASIS OF FY **1989** ESTIMATE

In FY 1989, the spacecraft will be shipped to Kennedy Space Center following final testing. Upon arrival, the spacecraft will be integrated with the IUS and Shuttle and undergo final preparation prior to launch in April 1989.

BASIS OF FY 1989 FUNDING REQUIREMENT

ULYSSES

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Spacecraft	1,950	3,300	3,100	2,800
Experiments	7,135	5,900	3,900	5,600
Ground operations	1,215	1.600	200	1.900
Total	10,300	10,800	7,200	10.300
Space transportation system operations	(---)	(9,400)	(12,300)	(32,300)

OBJECTIVES AND STATUS

Ulysses is a joint mission of NASA and the European Space Agency (ESA). ESA is providing the spacecraft and some scientific instrumentation. The U.S. is providing the remaining scientific instrumentation, the launch, tracking support, and the Radioisotope Thermoelectric Generator (RTG). The mission is designed to obtain the first view of the Sun above and below the plane in which the planets orbit the Sun. The mission will study the relationship between the Sun and its magnetic field and particle emissions (solar wind and cosmic rays) as a function of solar latitude, to provide a better understanding of solar activity on the Earth's weather and climate.

Ulysses was restructured in FY 1981 from a two-spacecraft mission--one provided by the United States and one provided by ESA--to a single ESA spacecraft mission. However, the United States' participation in the program remains substantial. NASA is responsible for five of the nine principal investigator instruments, and three of the four European investigations have U.S. co-investigators.

The Ulysses launch is planned for October 1990, using the Shuttle and IUS/PAM-S launch stages. During 1988, documentation of the spacecraft/launch vehicle interface will be completed while support to ESA will continue in order to make the spacecraft compatible with the new upper stage configuration. Launch approval activities involving the RTG, and support for retesting the spacecraft and the science instruments will also be continued.

CHANGES FROM FY 1988 REVISED BUDGET

The reduction of $3.0 million will be accomplished by the deferral of planned activities into subsequent years. These funds will be used to help cover additional funding requirements for Magellan.

BASIS OF FY 1989 ESTIMATE

FY 1989 funding will support launch approval activities for the Radioisotope Thermoelectric Generators (RTGs). Periodic testing of the spacecraft and science instruments will also continue.

BASIS OF FY 1989 FUNDING REQUIREMENT

MARS OBSERVER MISSION

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Spacecraft development.....	15,715	7,800	21,200	39,400
Experiments.....	16,392	17,700	28,600	56,700
Ground operations.....	3.693	3.400	4,100	6.100
Total.....	35,800	28,900	53,900	102.200
Space transporation system operations	(---)	(---)	(---)	(5,000)

OBJECTIVES AND STATUS

The Mars Observer mission is the first in a series of planetary observer missions utilizing a lower cost approach to inner solar system exploration. This approach, which was recommended by NASA's Solar System Exploration Committee, starts with a well defined and focused set of science objectives and uses modified production-line Earth-orbital spacecraft and instruments with previous space flight heritage. The objectives of the Mars Observer mission are to extend and complement the data acquired by the Mariner and Viking missions by mapping the global surface composition, atmospheric structure and circulation, topography, figure, gravity and magnetic fields of Mars to determine the location of volatile reservoirs and observe their interaction with the Martian environment over all four seasons of a full Martian year.

The limitation on the number of launch opportunities through 1990 and the further restrictions placed on scheduling by timing requirements for planetary launches have necessitated delaying the planned launch of Mars Observer from 1990 until the following planetary opportunity 25 months later. The current plan is to launch the mission in 1992 with a Transfer Orbit Stage (TOS). The spacecraft will be inserted into a near-polar Martian orbit in 1993, from which it will carry out geochemical, geophysical, and climatological mapping of the planet over a period of a full Martian year, which is about two Earth-years,

In FY 1988, it is planned to continue detailed design of the instrument hardware and system design of the overall mission and to complete design of the Payload Data Subsystem. Detail design of the spncecrnft and parts and subassembly procurements will be continued.

CHANGES FROM FY 1988 REVISED BUDGET

The $25.0 million increase in FY 1988 is consistent with Congressional direction and will provide for adequate levels of spacecraft and instrument spares in support of Mars Observer mission requirements. Residual hardware will be made available for use on future observer class missions.

BASIS OF FY 1989 ESTIMATE

FY 1989 funding will support the completion of spacecraft and instrument designs. Initial hardware fabrication for both the spacecraft and instruments will also begin. Funding is also included for the procurement of additional spacecraft and instrument spares.

BASIS OF FY 1989 FUNDING REQUIREMENT

MISSION OPERATIONS AND DATA ANALYSIS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Magellan operations.....	---	...	...	17,100
Voyager extended mission.....	2,800	2,716	2,716	3,300
Pioneer programs.....	a,300	7,894	7,894	9,300
Voyager/Neptune mission.....	26,105	26,090	22,912	40,300
Planetary flight support.....	37.a95	39.600	41.178	42,700
Total.....	75,100	76,300	74,700	112.700

OBJECTIVES AND STATUS

The objectives of the mission operations and data analysis activities are in-flight operation of planetary spacecraft and the analysis of data from these missions. Currently, two major classes of planetary spacecraft are operating--the Pioneer and the Voyager spacecraft. The planetary flight support activities are those associated with the design and development of planetary flight operation systems, and other activities that support the mission control, tracking, telemetry, and command functions for all planetary spacecraft.

The two Voyager spacecraft are now exploring the outer solar system on trajectories that will take them into interstellar space. Voyager 1 continues to provide data on the interplanetary medium in that distant part of the solar system. In January 1986, Voyager 2 made a close flyby of the planet Uranus, the first time this planet has ever been visited by a spacecraft. During this flyby, it made detailed observations of the planet, its rings, and moons. Upon completion of the Uranus encounter, the spacecraft began its path to the planet Neptune, where, in 1989, it will provide us with our first close look at this distant planet.

Pioneers 10 and 11 continue to explore the outermost solar system. Pioneer 10 will soon enter the unexplored region beyond Pluto where the Sun's influence is secondary to those of true interstellar space. These spacecraft will continue the search for gravitational evidence of a tenth planet. Pioneers 6-9 are still collecting information on the interplanetary magnetic field and solar wind as they orbit the Sun.

The Pioneer Venus orbiter continues to obtain data on Venus' atmosphere and magnetosphere and its interaction with the Solar Wind. In late 1985, the spacecraft's spin axis was adjusted to allow ultraviolet observations of Comet Halley. The Pioneer Venus was the only spacecraft able to observe the Comet at its closest approach to the Sun, thus providing critical enhancements to the data gathered by foreign spacecraft.

The planetary flight support activities include the procurement, operation and maintenance of mission operations and general purpose scientific and engineering computing capabilities at the Jet Propulsion Laboratory (JPL). In addition, the activity supports the development of the Space Flight Operations Center (SFOC) at JPL. This facility will be a versatile, cost-effective means for carrying out multimission data acquisition, telemetry, image processing, and for commanding of planetary and orbital spacecraft.

FY 1988 funding is providing for operational support for the Voyager and Pioneer operations, for analysis of scientific data returned by the missions, and for the extension of the Voyager 2 mission to a 1989 encounter with the planet Neptune. Activities are also continuing in multimission support development and software designs for activities.

CHANGES FROM FY 1988 REVISED BUDGET

The net decrease of $1.6 million is the result of a reduction of $3.2 million in the Voyager Neptune mission due to lower than planned requirements, partially offset by an increase of $1.6 million in Planetary Flight Support for the development of the Space Flight Operations Center (SFOC). This net reduction will be used to offset additional funding requirements for Magellan.

BASIS OF FY 1989 ESTIMATE

FY 1989 funding is required for the continued operation and data analysis activities in support of the Pioneer missions as well as the August 1989 Voyager/Neptune encounter. Operations activities will also begin for the Magellan mission, which will be launched in April 1989. Development activities will also continue on the Space Flight Operations Center (SFOC) at the Jet Propulsion Laboratory.

BASIS OF FY 1989 FUNDING REQUIREMENT

RESEARCH AND ANALYSIS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Supporting research and technology.....	46,061	46,976	45,576	50,500
Advanced programs.....	16,600	20,642	15,642	26,600
Mars data analysis.....	2,868	3,687	3,687	4,500
Halley's comet co-investigations and watch.....	3.971	2.995	2.995	2.000
Total.....	69.500	74,300	67.900	83.600

OBJECTIVES AND STATUS

The research and analysis program consists of four elements required to: (1) assure that data and samples returned from flight missions are fully exploited; (2) undertake complementary laboratory and theoretical efforts; (3) define science rationale and develop required technology to undertake future planetary missions; and (4) coordinate an International Halley's Comet Watch and provide co-investigator support to the European Space Agency's Giotto mission which encountered Halley's Comet in 1986.

The supporting research and technology activity includes planetary astronomy, planetary atmospheres, planetary geology/geophysics, planetary materials/geochemistry, instrument definition, and U.S. scientist participation on foreign missions.

The planetary astronomy activity includes all observations made by ground-based telescopes of solar system bodies, excluding the Sun. Emphasis is on the outermost planets, comets and asteroids. Observations are made at a wide range of wavelengths from ultraviolet to radio. The rate of new discoveries continues to be high, and the data acquired is used both for basic research in support of planetary program objectives and for direct support of specific flight missions. The planetary astronomy funding also provides for the continued operation of the Infrared Telescope Facility in Hawaii.

The planetary atmospheres activity includes data analysis, laboratory, and theoretical efforts. The properties of other planetary atmospheres are amenable to measurement with planetary spacecraft and can aid us in better understanding our own weather and climate. Observations of the atmospheres of Venus, Jupiter and Saturn, acquired by Pioneer Venus and Voyager, have laid the basic observational groundwork for major advances in this field.

The planetary geology/geophysics activity is a broadly scoped program that includes the study of surface processes, structure, and history of solid components (including rings) of the solar system and investigation of the interior properties and processes of all solar system bodies, both solid and gaseous, This program emphasizes comparative studies to gain a fundamental understanding of the physical processes and laws which control the development and evolution of all planetary bodies, including the Earth. In this respect, data from the Magellan mission will be of crucial importance.

The planetary materials/geochemistry activity supports an active scientific effort to determine the chemistry, mineral composition, age, physical properties and other characteristics of solid material in the solar system through the study of returned lunar samples and meteorites and through laboratory and theoretical studies of appropriate geochemical problems. Extraterrestrial dust grains, collected for analysis, continue to yield new and otherwise unobtainable information about the solar system, and its early history. This program is coordinated with the lunar sample and meteorite research, which'is supported by other agencies, such as the National Science Foundation. The operation of the Lunar Curatorial Facility is also supported by the planetary materials/geochemical funding.

The instrument definition activity is directed toward ensuring maximum scientific return from future missions by the definition and development of state-of-the-art scientific instrumentation, which are optimized for such missions.

The support for U.S. science investigators on foreign missions currently is being provided for U.S. participation on the USSR Phobos missions.

The objective of the advanced program activity is to provide planning and preparation for the systematic exploration of the solar system on a scientifically and technically sound basis. Prospective planetary missions are identified and defined through long-range studies; the technological and fiscal feasibility is evaluated, and the scientific merit is determined through interaction with the scientific community. The strategy for future solar system exploration has been developed by the Solar System Exploration Committee (SSEC), an advisory group, which has recommended a comprehensive program of missions to the inner and outer solar system.

The Mars Data Analysis program continues to support analysis of data obtained by Viking and earlier missions so that we are scientifically prepared for the next phase of Mars exploration. It also supports the establishment of a Planetary Data System which will permit the archiving of these and all other data products in a manner which will promote and facilitate their use.

The International Halley's Comet Co-Investigations and Watch program is part of an international program of cooperative astronomical observations of Halley's Comet. During 1986, support was provided to nearly three dozen U.S. co-investigators on the European Space Agency's (ESA) Giotto mission, and to conducting complementary remote sensing investigations carried out with ground based telescopes, aircraft, rockets, and distant spacecraft. Concurrently, an observation program called the International Halley Watch, coordinated by the United States, conducted world-wide scientific observations of the Comet Halley. The objectives of the Watch are: (1) to coordinate scientific observations of Comet Halley through its 1985-1986 apparition; (2) to promote the use of standardized instrumentation and observing techniques; (3) to help insure that data are properly documented and archived; and (4) to receive and distribute data to participating scientists. Activities in FY 1987 were directed to analyzing and archiving data. These activities will continue in 1988 at a reduced level of support.

CHANGES TO FY 1988 REVISED BUDGET

Funding in advanced programs will be decreased by $5.0 million as a result of deferring a limited amount of preliminary design and advanced technology associated with the Mariner Mark II class of spacecraft. In addition, $1.4 million will be reduced from various supporting research and technology activities to offset Magellan funding requirements.

BASIS OF FY 1989 ESTIMATE

During FY 1989, research efforts will continue in the areas of planetary astronomy, planetary atmospheres, planetary geology/geophysics, planetary materials/geochemistry, instrument definition, Mars data analysis, and in the development of required technology to undertake future missions. Ground telescope observations will provide data complementary to that obtained from the flight missions, with emphasis on the outermost planets, comets and asteroids. A variety of efforts will be pursued to improve our understanding of planetary atmospheres, including laboratory studies of reactions in deep planetary and tenuous cometary atmospheres. Geology/geophysics research will be directed at specific problems in understanding the various processes that have shaped planetary surfaces, as well as geological analyses and a cartography effort based on the Galilean, Saturnian and Uranian satellite imaging data acquired by Voyager. Analysis of lunar samples, meteorites, and extraterrestrial dust particles will be continued in FY 1989 to determine their chemical and physical properties and thereby derive their origin and evolutionary history, Instrument definition activities will continue to support development of new

state-of-the-art instruments with emphasis on those supporting a future mission to Saturn and its moon Titan and for a Cosmic Dust Collection Facility planned as an attached payload for the Space Station, The Mars Data Analysis Program will support continued analysis of Mars data in preparation for new Mars missions, and for continued development of the Planetary Data System to archive all planetary data for enhanced accessability for all users. Within Advanced Programs, advanced technology development for potential future missions will be also be continued with emphasis on the Mariner Mark II spacecraft.

The FY 1989 Halley's Comet Co-Investigations and Watch funding is required to continue support of U.S. co-investigators involved in the European Space Agency's Giotto mission who will be analyzing and archiving the data acquired during the encounter with Halley's Comet. International Halley Watch funding will support the archiving and distribution of ground-based observations.

The FY 1989 funding will also provide for continued operations of both the Infrared Telescope Facility and the Lunar Curatorial Facility.

SOLID EARTH
OBSERVATIONS

RESEARCH AND DEVELOPMENT

FISCAL YEAR 1989 ESTIMATES

BUDGET SUMMARY

OFFICE OF SPACE SCIENCE AND APPLICATIONS — SOLID EARTH OBSERVATIONS PROGRAM

SUMMARY OF RESOURCE REQUIREMENTS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
		(Thousands of Dollars)			
Payload and instrument development.....	21,400	20,800	20,800	25,300	RD 6-4
Geodynamics.....	31,600	32,400	32,400	33,900	RD 6-6
Research and analysis.....	19,400	21,100	21,100	22,900	RD 6-9
Total.....	72,400	74,300	74,300	82,100	
Distribution of Program Amount by Installation					
Johnson Space Center.....	36	---	---	---	
Marshall Space Flight Center.....	360	400	400	400	
Goddard Space Flight Center.....	35,728	39,000	39,000	41,300	
Jet Propulsion Laboratory.....	25,672	25,700	25,700	30,500	
Ames Research Center.....	812	900	900	1,000	
National Space Technology Laboratories.....	647	800	800	800	
Headquarters.....	9,145	7,500	7,500	8,100	
Total.....	72,400	74,300	74,300	82,100	

OFFICE OF SPACE SCIENCE AND APPLICATIONS **SOLID EARTH OBSERVATIONS PROGRAM**

PROGRAM OBJECTIVES AND JUSTIFICATION

The objectives of the Solid Earth Observations program are to understand the processes controlling the state of the land surface and the interior of the Earth as well as the interaction of the solid Earth with the atmosphere and the oceans. The Solid Earth Observations Program is an integral part of the overall NASA Earth Science and Applications effort to increase understanding of the planet Earth through the study of its dynamics, the physical processes which affect habitability, and solar-terrestrial environment.

The major objectives of the Solid Earth Research and Analysis program are to characterize the current state of the terrestrial landscape, including the biosphere and the hydrosphere, and the changes and change mechanisms that are occurring within that landscape. Studies of the cycling of key biogeochemical elements, interactions between the biosphere and the climate system, the composition and evolution of the Earth's crust and the processes that shape the Earth's crust are essential to these objectives.

The geodynamics research objectives include determination of the movements and deformation of the Earth's crust, the processes which drive tectonic plates, the rotational dynamics of the Earth and its interactions with the atmosphere and oceans, the Earth's gravity and magnetic fields, and the interior structure and composition of the Earth. These objectives require precise measurements of crustal movements and Earth orientation over an extended period along with accurate knowledge of the Earth's geopotential fields and their variability.

The objective of the Shuttle/Spacelab payload development program is to develop, test and evaluate Earth-viewing remote sensing instruments and systems to obtain data for solid earth observations research. The Shuttle Imaging Radar-B (SIR-B), which was flown on the Shuttle in October 1984, has demonstrated the utility of spaceborne imaging radar for geologic exploration. The Large Format Camera (LFC), required for high resolution mapping applications, was flown successfully on the Shuttle in 1984 and is presently under consideration for commercialization. The next generation Shuttle Imaging Radar (SIR-C), which involves the use of SIR-B components, is a multi-polarized, dual frequency instrument under development for flight in 1991. The imaging spectrometer and solid-state sensor research efforts will continue to focus on the development of such features as electronic scan, inherent geometric and spectral registration and programmable high spatial and spectral resolution.

BASIS OF FY 1989 FUNDING REQUIREMENT

PAYLOAD AND INSTRUMENT DEVELOPMENT

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Imaging radar program.....	13,000	13,700	13,700	16,700
Advanced spectrometer.....	8,400	7,100	7,100	8,600
Total.....	21,400	20,800	20,800	25,300

OBJECTIVES AND STATUS

The objective of this program is to develop, test, and evaluate Earth-viewing remote sensing instruments and systems to obtain data for and develop the techniques for land remote sensing research.

Components of the Shuttle Imaging Radar-B (SIR-B) will be used in building the next generation Imaging Radar instrument, SIR-C. The SIR-C will use multi-polarized, dual frequency sensor technology. SIR-C is in the development phase; System Requirements Review, Antenna Preliminary Design Review and System Preliminary Design Review are complete. In October 1987, NASA signed a Memorandum of Understanding with the Federal Republic of West Germany agreeing to joint missions of SIR-C with an X-band imaging radar to be provided by a joint German/Italian project (X-SAR). Preparations continue for commercialization of the Large Format Camera (LFC).

Advanced spectrometer technology development activities include fundamental research in remote sensing involving airborne and spaceborne imaging spectrometer instruments. The imaging spectrometer and linear array solid-state sensor research focuses on the development of such features as inherent geometric and spectral registration and programmable high spatial and spectral resolution. The critical technology development and supporting research on the Shuttle Imaging Spectrometer Experiment (SISEX) and the linear array focal plan will continue.

BASIS OF FY 1989 ESTIMATE

FY 1989 funding is required for continued development of SIR-C technology, and for advanced spectrometer activities including the development of the Shuttle Imaging Spectrometer Experiment

BASIS OF FY 1989 FUNDING REOUIREMENTS

GEODYNAMICS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Crustal dynamics project.....	17,500	17,900	17,900	18,600
Laser network operations.....	8,400	8,800	8,800	9,200
Research and technique development.....	5.700	5,700	5.700	6.100
Total.....	31,600	32,400	32,400	33.900

OBJECTIVES AND STATUS

The objective of the Geodynamics program is to understand the origin, evolution, and current state of the solid Earth by measuring the movement and deformation of the tectonic plates and by measuring its rotational dynamics and potential fields. Laser ranging to satellites and the moon, microwave interferometry using astronomical radio sources and transmissions from the Global Positioning Satellite System (GPS) are used to determine precise position locations. The global gravity and magnetic fields are determined from satellite observations.

Measurements over the past years have provided experimental determination of the velocities of several of the major tectonic plates. Measurements of regional deformation across the San Andreas Fault continue to indicate a relative movement of the Pacific and North American Plate of about 6 cm per year. In addition, measurements indicate that about 4 cm of this movement is occurring in Southern California. Measurements of polar motion and changes in the length of day have been correlated, to a high degree, with variations in the angular momentum and the inertial balance of the Earth's atmosphere due to high altitude winds. The Earth's rotation was found to have slowed by five milliseconds due to the El Nino effect. The Earth's rotational dynamics are also influenced by motions of the Earth's core and the oceans. Models of the Earth's gravity field, derived from Laser Geodynamics Satellite (LAGEOS-1) data

have provided the first evidence of gravity field variations. These variations are believed to be caused by continued relaxation of the crust following the last ice age and have confirmed estimates of the viscosity of the Earth's mantle layer. Analysis of the magnetic field, using data from Magsat has confirmed the diameter of the Earth's outer core and has provided new data on secular variations of the magnetic field.

The United States and a consortium of eight European and middle East countries continue measurements of crustal deformation in Greece, Turkey, and Italy. In 1988, a mobile Laser Ranging Station operated by the Federal Republic of Germany will join similar U.S. stations in deformation studies in the U.S.

Development of instrumentation and techniques for use of the DOD GPS system for rapid crustal motion measurements has continued. The geodetic techniques developed by NASA for measurement of polar motion and Earth rotation have been adopted by the International Union of Geodesy and Geophysics (IUGG) as the basis of the new International Earth Rotation Service. Within the U.S., NOAA and the U.S. Naval Observatory (USNO) have adopted Very Long Baseline Interferometry as the basis for the National Earth Orientation Service.

Studies continued to confirm the need €or improved gravity and magnetic field measurements. While considerable advances have been made in modeling the gravity field, new data are needed to achieve the resolution and accuracies required for solid Earth research. Laboratory development of a supercooled gravity gradiometer are continuing, and plans are being made for a Shuttle test of this technology. Joint studies are underway with the French on a cooperative Magnolia/Magnetic Field Satellite for extensive, long-duration studies of secular and temporal changes of the main magnetic field.

BASIS OF FY 1989 ESTIMATE

In FY 1989, measurements of plate motion between North America and Europe will be continued in cooperation with countries in Europe, the Middle East, Far East, South and Central America. Measurements of the motions of the Pacific Plate will be continued in cooperation with Japan and China. Regional crustal deformation measurements in western North America will continue in cooperation with NOAA, Canada and Mexico. The Caribbean studies will be continued and include more sites along the plate boundary and on the plate itself.

LAGEOS-1 and other satellites will continue to be used for studies of plate motion. NASA systems in the U.S., Pacific, South America, and Australia will be operated in cooperation with laser systems in 12 other countries. The LAGEOS-2, a joint mission with Italy, is presently under development by Italy and will be launched by the U.S.

Theoretical studies of crustal motion, internal Earth structure and composition, and the modeling and interpretation of geopotential fields will be continued in FY 1989. In addition, system studies of a second magnetic field satellite for long-term measurements of the Earth's field (Magnolia/MFE), studies of geopotential research, and laboratory development of room-temperature and cryogenic gravity gradiometer instrumentation will continue.

BASIS OF FY 1989 FUNDING REQUIREMENT

RESEARCH AND ANALYSIS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Biogeochemical processes.....	3,900	4,400	4,400	5,600
Geological processes.....	6,000	6,800	6,800	6,900
Hydrologic processes.....	5,600	6,000	6,000	6,400
Remote sensing science.....	3,900	3,900	3,900	4,000
Total.....	19,400	21,100	21,100	22,900

OBJECTIVES AND STATUS

The broad goal of the Biogeochemical Processes program is to achieve an improved understanding of the role of terrestrial biota in processes of global significance through the use of airborne and spaceborne sensors. Specific objectives are to understand biogeochemical processes and cycles, biotic contributions to the global energy balance, and change in vegetation state and dynamics.

The goals of the Hydrology program are to use remote sensing to achieve a better understanding of the regional and global storages and fluxes of the land component of the Earth's hydrologic cycle, to investigate the role of the hydrologic cycle in regional and global biogeochemistry, and to examine the interactions between land surface processes and regional and global climate.

The goal of the Geology program element is to derive a better understanding of the Earth's geology, geologic history, and the processes that have shaped the surface of the Earth over geologic time using spaceborne sensors. Specific objectives are: to investigate the history and evolution of the continents from early formation through accretionary, depositional, tectonic, deformational, and presently active erosional processes, to investigate quaternary geologic history and processes in order to unravel the course of recent geomorphic, volcanic and climatic processes for a better understanding of the evolution of land surfaces and climate over the last million years.

The Remote Sensing Science program is a cross cutting activity which supports the three other disciplinary program elements through theoretical modeling and field measurements of land surface properties. At this time the focus is on obtaining a firm understanding of the physical and biological factors which control the interaction of electromagnetic radiation with the Earth's surface. The aim is to develop the capability to determine surface properties with remote sensing using only a minimum reliance on empirical or statistical techniques.

BASIS FOR FY 1989 ESTIMATE

In FY 1989 emphasis will be on investigations using multiple sensors operating in the visible, near-infrared, shortwave infrared, thermal infrared, and the microwave. Advanced airborne instruments which are prototypes for the future Earth Observing System (EOS) will be used in a variety of geologic, ecological and hydrological experiments. The theoretical basis for the use of combined sensors will be developed within the Remote Sensing Science program element. Current theoretical models will be used in the design of these experiments which will be designed to meet specific scientific goals in the other program elements.

As a part of NASA's program for the study of Global Change, there will be a series of multitemporal ecosystems studies using the airborne prototypes of EOS instruments. Vegetation is dynamic over a growing season, and remote sensing coverage at an instant in time only captures on stage of the annual cycle. Repetitive coverage of selected sites offers the opportunity to study dynamic, and not just static, properties of ecosystems. We plan to select a small number of sites to be scheduled for multiple data acquisitions spanning the growing season and to encourage several investigators to conduct investigations at any one site.

The two broad goals of the Geology program expressed above will be addressed through focused efforts which will be identified in workshops to be held during 1988. These are expected in the fields of volcanism (volcanic processes, monitoring, and hazard identification/prevention), quaternary land climatologic history, and neotectonics of actively faulting areas.

Operational satellite systems will be used in conjunction with the advanced airborne sensors. Multiyear data sets from the Landsat Multispectral Scanner, the Advanced Very High Resolution Radiometer (AVHRR) and the Scanning Multifrequency Microwave Radiometer (SMMR) will be used to study global change on the decadal scale. Global data sets will be maintained using the AVHRR and the Special Sensor Microwave Imager (SSMI), which replaces the SMMR.

The initial phase of the International Satellite Land Surface Climatology Project's (ISLSCP) First ISLSCP Field Experiment (FIFE), will be completed. Guest investigators will be supported to broaden the base of users of this comprehensive data set, and mechanisms will be established to make the data available to other investigators.

ENVIRONMENTAL OBSERVATIONS

RESEARCH AND DEVELOPMENT

FISCAL YEAR 1989 ESTIMATES

BUDGET SUMMARY

OFFICE OF SPACE SCIENCE AND APPLICATIONS **ENVIRONMENTAL OBSERVATIONS PROGRAM**

SUMMARY OF RESOURCES REQUIREMENTS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
		(Thousands of Dollars)			
Upper atmosphere research and analysis	32,700	32,700	32,700	34,000	RD 7-6
Atmospheric dynamics and radiation research and analysis.....	31,300	*31,400*	31,400	32,800	RD 7-8
Oceanic processes research and analysis.....	18,000	20,200	20,200	21,600	RD 7-12
Space physics research and analysis.....	20,800	20,600	---*	---*	---
Payload and instrument development.....	9,700	18,900	4,100	19,700	RD 7-14
Mission operations and data analysis.....	33,600	25,700	14,800	18,500	RD 7-17
Interdisciplinary research and analysis.....	1,100	1,100	1,100	1,200	RD 7-20
Tethered satellite payloads.....	5,500	3,100	---*	---*	RD 7-21
Scatterometer.....	32,900	22,700	22,700	15,800	RD 7-23
Upper atmosphere research satellite mission.....	113,800	94,600	89,600	103,900	RD 7-25
Ocean topography experiment.....	18,900	89,900	75,000	97,800	RD 7-27
Global geospace science.....	---	25,000	---*	---*	---
Airborne science and applications	(27,600)**	(21,900)**	21,900	23,000	RD 7-29
Total.....	318,300	385,900	313,500	368,300	

* Transferred to Physics and Astronomy as a result of reorganization
** Previously funded under Physics and Astronomy Suborbital Program

RESEARCH AND DEVELOPMENT

FISCAL YEAR 1989 ESTIMATES

BUDGET SUMMARY

OFFICE OF SPACE SCIENCE AND APPLICATIONS — ENVIRONMENTAL OBSERVATIONS PROGRAM

SUMMARY OF RESOURCES REQUIREMENTS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
Distribution of Program Amount by Installation					
Johnson Space Center	77	100	100	---	
Marshall Space Flight Center	12,025	10,700	6,400	6,800	
Goddard Space Flight Center	177,139	203,900	139,600	176,100	
Jet Propulsion Laboratory	64,441	108,900	95,600	107,900	
Ames Research Center	5,241	5,300	27,100	28,100	
Langley Research Center	21,061	18,600	17,400	19,800	
National Space Technology Laboratories	50	100	100	100	
Headquarters	38,266	38,300	27,200	29,500	
Total	318,300	385,900	313,500	368,300	

OFFICE OF SPACE SCIENCE AND APPLICATIONS **ENVIRONMENTAL OBSERVATIONS PROGRAM**

PROGRAM OBJECTIVES AND JUSTIFICATION

The objectives of the Environmental Observations program are to improve our understanding of the processes in the atmosphere and the oceans; to provide space observations of parameters involved in these processes; and, to extend the national capabilities to predict environmental phenomena, both short and long term, and their interaction with human activities. Because many of these phenomena are global or regional, they can be most effectively, and sometimes only, observed from space. NASA's programs include scientific research efforts plus the development of new technology for global and synoptic measurements. NASA's research satellites provide a unique view of the radiative, chemical, and dynamic processes occurring in the atmosphere and oceans.

To achieve these goals, a number of significant objectives have been established for the next decade. These include advancing the understanding of the upper atmosphere through the determination of the spatial and temporal distribution of ozone and select nitrogen, hydrogen, and chlorine species in the upper atmosphere and their sources in the lower atmosphere; optimizing the use of space-derived measurements in understanding large scale weather patterns; advancing our knowledge of severe storms and forecasting capabilities, ocean productivity, circulation, and air-sea interactions; and improving the knowledge of seasonal climate variability leading to a long-term strategy for climate observation and prediction.

Effective utilization of remote sensing requires a balanced set of activities including: analytical modeling and simulation; laboratory research of fundamental processes; development of instrumentation, flight of the instruments on the Space Shuttle, dedicated spacecraft and flights of opportunity; collection of in situ ancillary or validation data; and, scientific analysis of data. The approach is to develop a technological capability with a strong scientific base and then to collect appropriate data, through remote and in situ means, which will address specific program objectives.

The Upper Atmospheric Research Satellite (UARS) will place a set of instruments in Earth orbit which will make comprehensive measurements of the state of the stratosphere, providing data about the Earth's upper atmosphere in spatial and temporal dimensions which are presently unattainable.

Detailed definition studies of the instruments have been completed, and the design and development activities are well underway. Development of the UARS observatory will continue in FY 1989, consistent with a planned launch in 1991.

The Earth Radiation Budget Satellite (ERBS) was successfully launched in 1984, and data continues to be collected from the satellite. NOAA-F was launched December 12, 1984 and NOAA-G was launched September 17, 1986, both equipped with ERBE instrumentation. NASA is also continuing to support the National Oceanic and Atmospheric Administration (NOAA) by managing the implementation of the polar orbiting NOAA and Geostationary Operational Environmental Satellites (GOES) series on a reimbursable basis.

Design and development activities are being continued in FY 1989 on the NASA Scatterometer (NSCAT), the objective of which is to acquire global ocean data for operational and research use by both military and civil sectors. While the U.S. Navy reviews the possible continuation of the Navy Remote Ocean Sensing System (N-ROSS) program, Scatterometer instrument development continues along with planning for alternative spacecraft flight opportunities.

Development of the Ocean Topography Experiment (TOPEX) began in FY 1987 and will continue in FY 1989; its objective is to acquire precise observations of the surface topography of the oceans. These data, in conjunction with those from NSCAT, will enable the first determination of the wind forcing and ocean-current response of the global oceans. Spacecraft development efforts have begun at Fairchild, while the Johns Hopkins Applied Physics Laboratory continues work on TOPEX Altimeter development.

The Nimbus spacecraft continues to collect unique data which is being used in the study of long term trends of the Earth's atmosphere, oceans and polar ice, and provides near real time data. Collection and analysis of Solar Mesosphere Explorer (SME) data, the only mesosphere data currently available, continues.

Shuttle payload and instrument development activities provide the airborne and spaceborne data necessary to conduct basic research projects as well as provide correlative and developmental feasibility information for major free-flying spacecraft. Instrument activities include Shuttle payloads such as Atmosphere Trace Molecules Observed by Spectroscopy (ATMOS), Active Cavity Radiometer (ACR), and Light Detection and Ranging (LIDAR).

Along with the Solid Earth Observations program, the Environmental Observations activities compose an integral part of NASA's total Earth sciences and applications efforts, with emphasis on understanding the Earth as a planet, studying its dynamics, processes, habitability, and solar-terrestrial environment.

Elements of the Mission Operations and Data Analysis Program and the Payload and Instrument Development Program as well as the entire Tether Satellite Payloads, Space Physics Research and Analysis, and Global Geospace Science programs have been transferred to Physics and Astronomy in the recent Office of Space Science and Applications reorganization and creation of the Space Physics Division.

BASIS OF FY 1989 FUNDING REOUIREMENT

UPPER ATMOSPHERE RESEARCH AND ANALYSIS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Upper atmospheric research.....	19,701	19,800	19,800	20,700
Stratospheric processes.....	6,720	6,800	6,800	7,000
Tropospheric chemistry.....	6.279	6.100	6,100	6.300
Total.....	32.700	32.700	32.700	34.000

OBJECTIVES AND STATUS

The upper atmosphere research program is a comprehensive research and technology effort designed to investigate and monitor the phenomena of the upper atmosphere and related phenomena in the lower atmosphere. It is aimed at improving our basic scientific understanding of the global atmosphere and the methods needed to assess its susceptibility to significant chemical and physical change. The program's three major thrusts are in the areas of upper atmospheric research, stratospheric processes research, and tropospheric chemistry research.

In particular, the goal of the upper atmosphere research program is to understand the physics, chemistry and transport processes in the stratosphere on a global scale, and to assess as accurately as possible the perturbations to the atmosphere caused by man's activities. In order to accomplish this, efforts are underway to: (1) improve upper atmosphere and global troposphere models, validate them, and assess their uncertainties; (2) measure important trace chemical constituents, temperature, and radiation fields throughout the atmosphere; (3) develop sensors capable of making chemical and physical measurements of the upper atmosphere and the global troposphere both directly and remotely from space; (4) assemble and maintain the existing long-term data base of stratospheric and tropospheric ozone measurements to aid in the detection of long-timescale natural variations and man- made ozone changes; (5) determine the effects of global tropospheric chemistry on the atmosphere; (6) conduct theoretical and field studies of tropospheric/stratospheric exchange; and (7) carry out laboratory kinetics and spectroscopy investigations to support these activities.

A variety of in situ and remote sensing techniques are needed to meet the objectives of determining and understanding the distribution of ozone and other trace species in the atmosphere. Data sets from a limited number of satellites are now generally available to the scientific community, including a record of the global distribution of ozone extending back over a decade, and simultaneous observations of a number of trace constituents. This data is being exploited to determine if trends in the ozone amount can be detected and to understand those processes which are directly involved with these trends.

BASIS OF FY 1989 ESTIMATE

Recent developments in our understanding of the ozone layer have revealed a possible non-linear dependence of ozone depletion on the amount of fluorocarbon released to the atmosphere. These findings place increased urgency on the need to verify the completeness and accuracy of the theoretical stratospheric models. In FY 1989, tests of the models will be continued by means of field measurements, model calculations, and interpretation of satellite data. The development of more realistic two- and three-dimensional models will be continued. The global data sets from past and present satellites will be further analyzed in FY 1989 to aid in the understanding of large-scale atmospheric processes.

The comparison of balloon, aircraft, and ground-based measurements will be continued in FY 1989 to ensure the validity of the different techniques that have been developed and to observe chemical species in the stratosphere and troposphere to determine the exchange of gases between the lower and upper atmosphere. These balloon and aircraft measurement programs are the only way to measure many of the localized phenomena of the atmosphere; they also help to validate satellite observations. Studies of potential new instruments for use on future satellites and suborbital measurement platforms will also be conducted in FY 1989 to ensure that new technologies are put to use in improving the capability and cost efficiency of tropospheric composition and upper atmosphere measurements.

The recent observations of a depletion in the amount of ozone over Antarctica in the austral spring have attracted a great deal of attention. In order to understand the chemical and dynamic processes that are causing this phenomena, a major aircraft mission conducted in late FY 1987 - early FY 1988 using the NASA ER-2 and DC-8. Analysis and interpretation of the results of this mission will be a critical effort in FY 1988. An Arctic and/or return Antarctic mission is planned for FY 1989 based on the results of the 1987 campaign.

BASIS OF FY 1989 FUNDING REQUIREMENT

ATMOSPHERIC DYNAMICS AND RADIATION RESEARCH AND ANALYSIS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Global-scale atmospheric processes research and analysis.....	14,046	14,200	14,200	14,600
Mesoscale atmospheric processes research and analysis.....	8,500	8,300	8,300	8,800
Climate research and analysis.....	8.754	8,900	8.900	9,400
Total.....	31,300	31.400	31.400	32,800

OBJECTIVES AND STATUS

The research and analysis activities within the Atmospheric Dynamics and Radiation program combine a core effort which is essential in order to use space technology to address problems in atmospheric science. The three main thrusts in the program are in the areas of Global-Scale Processes, Mesoscale Processes and Climate Research.

The objectives of the global scale research program are to improve our understanding of large-scale atmospheric behavior and to develop improved capabilities to observe the atmosphere from space. The program involves the development of advanced remote sensing instrumentation to observe the atmosphere, the development of advanced analysis techniques to better utilize existing meteorological satellite data, and development of advanced numerical models which use satellite observations to describe the state of the atmosphere both diagnostically and predictively. Recent accomplishments include the development and application of techniques which more fully utilize passive multispectral data (IR and microwave) from the NOAA operational satellites to provide global maps of a number of key atmospheric and surface parameters. The first year of a ten year data set of these Earth science parameters has been completed and made

available to the scientific community. Additionally, special attention has been devoted to developing active lidar techniques to provide detailed profiles of atmospheric wind, temperature, pressure, and moisture data from future spaceborne platforms. Simulations of these advanced techniques indicate their increased potential in greatly improving meteorological prediction capability.

The objectives of the mesoscale processes research program are to improve our understanding of the behavior of the atmosphere on short (minutes to hours) time scales and local to regional scales (severe weather, such as tornadoes and hurricanes). Since all of the characteristic parameters of these mesoscale processes cannot be measured directly, new techniques are under study to derive the information from other observations which can be directly measured. Such an activity requires advanced data handling and analysis techniques which rely upon man-computer interactive display and manipulation. In the area of remote sensor development, initial feasibility studies of instrumentation to observe lightning from space have been completed under the guidance of a joint NASA/NOAA working group. This group continues to study the practical value of lightning mapping from geostationary orbit and the possibility of incorporating experimental lightning mapping observations on a GOES spacecraft. A Memorandum of Agreement with NOAA is being written to fly a research version of the lightning mapper on GOES-M.

The Climate Research Program seeks to develop a space capability for global observations of climate parameters to increase our understanding of the processes that influence climate and its predictability. in accordance with the National Climate Program priority, research in solar and Earth radiation is led by NASA. Future thrusts will be aligned with programs of solar irradiance monitoring, Earth radiation budget monitoring and analysis, stratospheric aerosols on the radiation budget, and on selected process studies which relate to monitoring of climate change. Selected process studies related to monitoring climate change are also included. The first results of the data phase of the International Satellite Cloud Climatology Project (ISCCP) have been successfully archived and two field experiments of the First ISCCP Regional Experiment (FIRE) have been completed. Data from ISCCP and FIRE are being analyzed in conjunction with the Earth Radiation Budget Experiment (ERBE) data to improve our knowledge of cloud-radiation interactions which affect our climate. In addition, measurements of the solar irradiance will continue through the repaired Solar Maximum Mission (SMM) spacecraft, Nimbus 7 and reflights of the Active Cavity Radiometer flown on Spacelab-1.

A significant research effort to develop the capability for observing rainfall from space continues. Studies of instruments, sampling requirements, algorithm development, and modeling indicate the feasibility of sensing rainfall from space for climatic purposes. Under a bilateral agreement with the Science and Technology Agency of Japan, NASA is cooperating in a joint study of a special mission to measure tropical rainfall. Studies to accommodate a rainfall measurement experiment on the Space Station have been initiated and will be continued.

BASIS OF FY 1989 ESTIMATE

FY 1989 funding is required for support of the Global Backscatter experiment (GLOBE). Two field campaigns are scheduled in GLOBE using the NASA DC-8. These airborne observations and the auxilliary observations to be made from ground-based and satellite observatories will be used to determine the seasonal and geographic variations in the backscatter of laser radiation due to atmospheric aerosols. In addition to increasing our understanding of the optical properties of the atmosphere, these data are needed in the system design of the Laser Atmospheric Wind Sounder (LAWS), a facility instrument for the future Earth Observing System (EOS).

An initiative in Radiative Gas Effects is being planned as a potential new focus for the Climate Research program during FY 1989. In particular, plans for the detection of greenhouse effect on climate from space observations will be pursued. The plans call for: (1) the identification of the required spaceborne measurements, process studies, and modeling improvements needed for early detection of the climatic effects of changing atmospheric composition; and, (2) the development of a NASA interdisciplinary research strategy for acquiring the technology and knowledge needed for understanding the regional and global climatic implications of projected greenhouse changes.

FY 1989 funding is required to provide instruments and support for aircraft flights to study the detail of flows around thunderstorms and weather fronts, continue development and comparison of numerical models, study atmospheric scale interactions, and develop techniques to display model outputs in four-dimensions. Continued analysis of the data collected in interagency field experiments during FY 1986 and 1987 will be performed. These data include the results of the Genesis of Atlantic Lows Experiment (GALE), the Cooperative Huntsville Meteorological Experiment (COHMEX) and the First International Satellite Cloud Climatology Project (ISCCP) Regional Experiment (FIRE). In addition, experimental, theoretical, and computational work will be done to better define the capabilities and requirements for the remote measurement of rainfall. Other activities will involve continued retrieval and archiving of global International Satellite Cloud Climatology Project data sets, analysis of data from the Earth Radiation

Budget Experiment and the Stratospheric Aerosol and Gas Experiment, and continued ground-based and rocket flight support for solar irradiance monitoring. Technology development of active temperature, pressure, and moisture sounders as well as basic lidar technology development will also be continued in FY 1987. Preliminary planning, experiment design, and technology development will begin for the large, multi-Agency STORM program to evaluate the research and operations potential of new meteorological remote sensors such as the sounder on GOES-NEXT, NEXRAD, AWIPS-90, ASOS, SSM/I, AVHRR-3 and high-altitude active and passive sensors to estimate precipitation.

BASIS OF FY 1989 FUNDING REQUIREMENT

OCEANIC PROCESSES RESEARCH AND ANALYSIS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Research and analysis.....	18,000	20,200	20,200	21,600

OBJECTIVES AND STATUS

The Oceanic Processes Research and Analysis (R&A) program emphasizes the development and application of spaceborne observing techniques to advance our understanding of the fundamental behavior of the oceans, as well as to assist users with the implementation of operational systems.

The Oceanic Processes R&A program is organized into three discipline areas: (1) physical, (2) biological, and (3) polar oceanography. In physical oceanography, satellite scatterometers and altimeters are used to observe surface roughness and topography, from which surface winds and ocean current response can be estimated. In biological oceanography, color scanners are used to observe chlorophyll concentration, from which primary productivity can be estimated. In polar oceanography, microwave radiometers and synthetic aperture radars are used to estimate the characteristics of sea-ice cover and the details of its motion.

The Oceanic Process R&A program operates in concert with other federal agencies (Navy, NOAA, and NSF) and foreign countries (Canada, European, Japan), for the World Climate Research Program (WCRP). Component WCRP efforts include the Tropical Ocean/Global Atmosphere (TOGA) and World Ocean Circulation Experiments (WOCE), a Global Ocean Flux Study (GOFS) and a Program for International Polar Oceans Research (PIPOR).

BASIS OF FY 1989 ESTIMATE

In FY 1989, the physical oceanography research activities will include implementation planning for WOCE and TOGA, as well as the development of assimilation techniques to incorporate altimeter and Scatterometer data into numerical models for use in determining the general circulation of the oceans. In biological oceanography, global ocean productivity will be assessed based on analyses of Nimbus-7 Coastal Zone Color Scanner (CZCS) data, in order to help with the conceptual design of the Global Ocean Flux Study. In addition, implementation studies will be performed with EOSAT for potential flight of an ocean-oriented color scanner (Sea-WIFS) aboard the Landsat-6 spacecraft. In polar oceanography, emphasis will be placed on the experimental design for the Program for International Polar Oceans Research, which is planned to involve direct reception at the Alaska Synthetic Aperture Radar (SAR) Facility in Fairbanks of SAR data from the European Space Agency's ERS-1 (Earth Resources Satellite) and from the Japanese Earth Resources Satellite (JERS)-1 spacecraft, due for launch in 1990 and 1992, respectively.

Significant work on the NASA Ocean Data System will be performed in order to optimize its use as a scientific support facility for the ocean research community. NASA's activities are being coordinated with the Office of Naval Research, NSF, and NOAA in order to assure that appropriate computing facilities, data archives, and communication networks will be available for the utilization of spaceborne observations from missions planned within the next decade.

Advanced technology development activities will also be continued on prospective future sensors for flight aboard both the Shuttle and free-flying spacecraft.

BASIS OF FY 1989 FUNDING REOUIREMENT

PAYLOAD AND INSTRUMENT DEVELOPMENT

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Imaging spectrometric observatory	(400)*	(400)*	400	600
Measurement of air pollution from satellites (MAPS).....	700	600	600	600
Atmosphere trace molecules observed by spectroscopy (ATMOS).....	1,200	1,500	1,200	2,600
Active cavity radiometer (ACR, ACRIM)....	400	1,000	1,000	1,100
Light detection and ranging (LIDAR).....	2,400	900	900	300
Collaborative solar terrestrial research (COSTR).....	5,000	14,900	---***	---***
EOS advanced technology development	(3,500)**	(3,500)**	(3,500)**	14,500
Total.....	9,700	18,900	4,100	19,700

* Previously funded under Spacelab Payloads Mission Management and Integration, transferred in accordance with reorganization.

** Previously funded under Earth Science Research and Analysis

***Funding transferred to Physics and Astronomy due to Office of Space Science and Applications reorganization

OBJECTIVES AND STATUS

The Space Transportation System offers the unique opportunity for short-duration flights of instruments. The Environmental Observations program has incorporated this capability into the Shuttle/Spacelab payload development activities in these important aspects: early test, checkout and design of remote sensing instruments for long duration free-flying missions; and short-term atmospheric and environmental data gathering for basic research and analysis where long-term observations are impractical. Instrument development activities support a wide range of instrumentation - from airborne to international flights of opportunity.

The objective of the Atmosphere Trace Molecules Observed by Spectroscopy (ATMOS) experiment is to make detailed measurements of gaseous constituents (e.g., hydrogen chloride, water, ammonia, methane) in the Earth's atmosphere by using the technique of infrared absorption spectroscopy. The data will help determine the compositional structure of the upper atmosphere, including the ozone layer and its spatial variability on a global scale. The instrument was launched in 1985 on Spacelab-3 and data analysis continues. It will be reflown on the ATLAS (formerly EOM) series. The science results from the first flight of ATMOS were of exceptional value, and the basic capability of ATMOS to measure very low concentrations of trace species in the Earth's atmosphere was clearly demonstrated. In FY 1987, ATMOS commenced a ground observation program at Table Mountain Observatory which will continue until the instrument is readied for shipment to KSC for the ATLAS-1 mission.

The Measurement of Air Pollution from Satellites (MAPS) experiment is a gas-filter correlation radiometer designed to measure the levels of troposphere carbon monoxide and the extent of interhemispheric mass transport in the lower atmosphere. The instrument was flown successfully on two Shuttle flights, and data analysis continues. It is planned for four STS flights, one for each season of the year, to provide the first observations of the global seasonal variation of carbon monoxide in the Earth's atmosphere. Reflight of MAPS is also planned on the ATLAS series.

The Active Cavity Radiometer-1 (ACR-1) is designed to aid in the study of the Earth's climate and the physical behavior of the Sun. Reflights of ACR-1 on the ATLAS series are planned. Other experiments have also been selected for reflight, including some instruments which were flown on the Shuttle orbital flight tests, and Spacelabs-1 and -2.

CHANGES FROM FY **1988** REVISED BUDGET

The changes are due to the Office of Space Science and Applications reorganization. The Space Physics effort has been transferred to Physics and Astronomy. The Imaging Spectrometric Observatory development activities have been transferred into this line from Physics and Astronomy Spacelab Payloads Mission Management. The minor change in the ATMOS funding represents a prior year accounting adjustment.

BASIS OF FY **1989** ESTIMATE

FY 1989 funds will be used to support the Measurement of Air Pollution from Satellites (MAPS) science team activities including data reduction, refurbishment for reflight and upgrading of the ground service equipment. The FY 1989 funding for ATMOS is required to support the ground observation program as well as continued science team activities, data processing and analysis, and limited refurbishments. FY 1989 funding is also required to continue the Active Cavity Radiometer (ACR) data processing, science team activities, and refurbishment for reflight on future Shuttle ATLAS flights, and development of a free-flyer version of ACR.

Preliminary definition of the advanced instrumentation and data facilities associated with the future Earth Observing System (EOS) will be continued in FY 1989. The EOS is the intended payload on the Space Station's polar platform. Instrument definition and feasibility studies will be continued along with related system engineering and payload accommodation studies. Release of an Announcement of Opportunity to the Scientific Community is presently planned for FY 1988. Further detailed review of those proposals will be conducted in FY 1989.

Development activities will continue on the international (U.S. and France) Light Detection and Ranging (LIDAR) airborne instrumentation following completion of critical design reviews in preparation for the integration, ground test and first flight in FY 1989 of this multi-phase user program. In this program, both NASA and the French are supplying science knowledge and hardware to demonstrate first-time detail measurements of the atmosphere to aid in forecasting.

BASIS OF FY 1989 FUNDING REQUIREMENT

MISSION OPERATIONS AND DATA ANALYSIS

	1987 Actual	1988 Revised Budnet	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Operations for the extended mission of:				
Nimbus 7	4,900	4,500	4,500	3,600
Solar mesosphere explorer (SME)	800	700	700	---
Correlative measurement/solar backscatter ultraviolet instrument	1,800	2,200	2,200	2,300
Earth radiation budget experiment extended operations	8,300	7,000	7,000	10,200
Active magnetospheric particle tracer explorer extended operations	3,300	2,300	---*	---*
International sun-earth explorers	4,100	3,000	---*	---*
Interplanetary monitoring platform	700	700	---*	---*
Dynamics explorer extended operations	6,000	4,700	---*	---*
Shuttle imaging radar-B	3,700	400	400	2,400
San Marco extended operations	---	200	---*	---*
Total	33,600	25,700	14,800	18,500

* Funding transferred to Physics and Astronomy MO&DA under Office of Space Science and Applications reoganization.

OBJECTIVES AND STATUS

The objective of the extended mission operations program is to provide for the operations, data processing, validation and data analysis of missions which have completed basic operations funded by approved project support.

Launched in 1978, the Nimbus-7 spacecraft continues to provide significant quantities of both atmosphere and solid earth global data for multi-discipline investigations and applications. These include atmospheric dynamics and chemistry resulting in global ozone measurements that are helping to understand the complicated heat exchanges of the atmosphere-ocean system, and, for the first time, global ocean data and sea ice concentration as well as properties of both polar caps. NASA supplies this unique sea ice concentration data in near real-time to the joint U.S. Navy-NOAA Ice Center. The ocean color measurements provide the only data on open ocean and coastal areas chlorophyll concentration, which relates to abundance of phytoplankton, the basic element of the ocean food chain. Current studies of complete ocean basins are expanding the understanding of global productivity. Nimbus-7 operations and data reduction/validation activities will continue in FY 1989 to support the strong demand for data.

The Solar Mesosphere Explorer (SME), launched in October 1981, continues to provide solar irradiance data. SME data analysis results allows us to better understand the complex chemical processes taking place in the mesosphere through scrutiny of data measurements of ozone, atomic oxygen, nitric oxide and solar irradiance. Data results indicate greater short-term variations and magnitude than was expected of many of the mesospheric properties. SME data is providing excellent information on the effect of volcanoes on the Earth's atmosphere.

CHANGES FROM FY 1988 REVISED BUDGET

The changes are due to Office of Space Science and Applications reorganization. Space Physics activities were transferred to Physics and Astronomy.

BASIS OF FY 1989 ESTIMATE

Operation of the Nimbus and SME satellites and processing of the collected data will be continued as will activities to provide ground truth for a NASA-developed ozone instrument to be flown on a NOAA meterological satellite. The **SME** and Nimbus satellites continue to produce extremely valuable data on ozone concentrations which will be used to estimate the occurrence of natural and man-made variations, sea surface temperatures, aerosol measurements, and ocean productivity. Correlative ground truth activities will also be continued in FY 1989; these in situ observations are needed to verify the quality of remote observations and improve our ability to interpret them.

In addition, FY 1989 funding is required for operating the **ERBS** spacecraft, data processing and analysis from the total three-instrument system, and from the **SAGE-I1** instrument on **ERBS.**

BASIS OF FY 1989 FUNDING REOUIREMENT

INTERDISCIPLINARY RESEARCH

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Interdisciplinary research and analysis..	**1,100**	**1,100**	**1,100**	1,200

OBJECTIVES AND STATUS

Interdisciplinary research activities need to be conducted to quantitatively characterize the Earth's chemical, physical, and bioloical processes on the land, along with the interactions between the land, the oceans, and atmosphere, which are of particular importance in assessing the impact of these pheonmena on global, physical, and biogeochemical processes. Such research is essential to investigating and assessing long-term physical, chemical, and biological trends and changes in the Earth's environment. Included in the program activities are joint efforts from a variety of disciplines, including atmospheric science, climatology, biological sciences, geochemistry, and oceanography.

BASIS OF FY 1989 ESTIMATE

In FY 1989, interdisciplinary studies will be continued with emphasis on integrating discipline-specific research activities of Oceanic Processes, Atmospheric Dynamics and Radiation, Upper Atmosphere/Troposphere Chemistry, and Land Processes into a unified program which will help increase our understanding of critical global processes. Emphasis will be placed on specific pilot studies such as those understanding the biogeochemical processes controlling the concentration of atmospheric methane, characterizing changes in properties of the land surface and their effect on climate, and understanding the role of the oceans in the global carbon cycle.

BASIS OF FY 1989 FUNDING REQUIREMENT

TETHERED SATELLITE PAYLOADS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Tethered satellite payloads.....	5,500	3,100	---*	---*

* Funding transferred to Physics and Astronomy under OSSA reorganization

OBJECTIVES AND STATUS

The Tethered Satellite System (TSS) will provide a facility for conducting experiments weighing 500 kr or less from distances of 100 km above or below the Space Shuttle. The TSS will allow unique science to be undertaken such as observations of atmospheric processes occurring within the lower thermosphere (below 180 kn altitude), observations of crustal geomagnetic phenomena, and direct observation of magnetospheric-ionospheric-atmospheric coupling processes in the 125-180 kilometer region. In addition, the satellite, coupled to the conducting tether, can generate large amplitude hydromagnetic waves and electrodynamic waves in the local space plasma, thus enabling active space plasma and magnetospheric physics experiments to be performed. The objective of the initial TSS mission is to verify the controlled deployment, retrieval and on-station stabilization of the satellite tethered from the orbiter, and to carry out an electrodynamics experiment using a conducting tether extended 20 km above the orbiter.

The TSS is an international cooperative project with the Italian government. The United States is developing the tether deployment and retrieval system, is responsible for overall project management and system integration, development and integration of the U.S. provided instruments, and flight on the Shuttle. Italy is developing the satellite and is responsible for development and integration of Italian provided instruments. An Announcement of Opportunity for investigations was issued in April 1984. Selection of investigators was completed in late 1985 and instrument design initiated in 1986.

CHANGES FROM 1988 REVISED BUDGET

In accordance with the Office of Space Science and Applications reorganization, funding has been transferred to Physics and Astronomy-Instrument and Payload Development.

BASIS OF FY 1989 FUNDING REQUIREMENT

SCATTEROMETER

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Scatterometer.....	32.900	22,700	22,700	15,800

OBJECTIVES AND STATUS

The Scatterometer will provide accurate, global measurements of ocean surface winds which will be useful for both oceanography and meteorology. In addition to providing wind field data, Scatterometer data will permit the first global study of the influence of winds on ocean circulation, provide data on the effects of the oceans on the atmosphere, and provide improved marine forecasting (winds and waves). Flight of the instrument in 1992 for three years will provide an overlap of data gathering with the World Ocean Circulation Experiment, Tropical Ocean-Global Atmospheres Experiment planned by the international oceanographic community; and additionally, concurrent flight with the Ocean Topography Experiment (TOPEX) would result in unique measurements of the ocean's driving force (winds) and the resulting ocean response (topography).

The feasibility of using the Scatterometer technique from space to accurately measure winds was demonstrated by Seasat in 1978. Definition studies conducted by NASA during FY 1983 and early FY 1984 resulted in the determination that the performance requirements as stated jointly by the research community and the Navy could be satisfied by utilizing system design concepts similar to those used on the Seasat Scatterometer. The major improvements include the addition of two antennas for improved wind direction determination and the addition of digital filtering to compensate for Earth rotational effects.

The Scatterometer was currently planned to fly on the Navy Remote Ocean Sensing System (N-ROSS) satellite in 1992. The N-ROSS program was cancelled in December 1986 due to financial constraints but a lower cost version of N-ROSS was proposed by Navy for reinstatement in April 1987; this proposal is currently under review with DoD. In the meantime, NASA has been exploring a number of alternatives to N-ROSS, the most cost effective of which will be selected for implementation should N-ROSS not gain full DoD approval to go forward.

BASIS OF FY 1989 ESTIMATE

During FY 1988, the antenna contract will be completed and all six flight antennas will be finished. The Traveling Wave Tube (TWT) contract is scheduled to be completed and the development of the other flight hardware items will be continued. The instrument Critical Design Review, which was delayed due to the N-ROSS cancellation, will be held and delivery of the second computer system for the ground data system will occur. Planned activities in FY 1989 include the continuation of flight hardware development leading to the beginning of flight unit integration and testing at the end of the fiscal year; the completion of software requirements definition, the initiation of detailed software design, both for the ground data and flight systems; conducting the PDR for the mission operation system; and confirmation of the science team which was delayed due to the uncertainly of N-ROSS.

BASIS OF FY 1989 FUNDING REQUIREMENT

UPPER ATMOSPHERE RESEARCH SATELLITE PROGRAM

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Spacecraft	63,100	51,400	49,100	49,100
Experiments	50.700	43.200	40,500	54.800
Total	113.800	94,600	89,600	103.900
STS Operations	(---)	(---)	(---)	(12,900)

OBJECTIVES AND STATUS

The Upper Atmosphere Research Satellite (UARS) program is the next logical step in conducting a comprehensive program of research, technology development and monitoring of the upper atmosphere aimed at improving basic scientific understanding. This mission, scheduled for a STS launch in 1991, is essential for understanding the key radiative, chemical and dynamical processes which couple together to control the composition and structure of the stratosphere. The UARS mission will provide the first integrated global measurements of: ozone concentration; chemical species that affect ozone; energy inputs; temperature; and winds in the stratosphere and mesosphere. These measurements will complement the measurements of ozone and of atmospheric parameters affecting ozone that were made on Nimbus and SAGE. The UARS program is a critical element in overall stratospheric research and monitoring efforts; it will provide the first full data set on stratospheric composition and dynamics which will be required when very difficult decisions must be made in the future regarding production of chlorofluorocarbons. The UARS mission will also contribute to the assessment of the impact of stratospheric changes on our climate and will provide the data needed for a full understanding of the stratosphere. These understandings are essential for subsequent design and implementation of a long-term stratospheric monitoring activity.

A final selection of ten experiments has been made, including infrared and microwave limb sounders which require advances in cryogenics, solid-state devices and microwave antennas beyond earlier capabilities. The instrument design and development activities are underway. A Solar Backscatter Ultraviolet (SBW) instrument will be modified to fly on the Shuttle during the UARS mission and to provide correlative data. In addition, development of the central ground data handling facility, which will permit near-realtime interactive utilization of data by the twenty-one design and theoretical investigator teams, is underway.

CHANGES FROM FY 1988 REVISED BUDGET

The FY 1988 Revised Budget has been reduced by $5.0 million in order to provide additional funds to the Gamma Ray Observatory which is nearing its scheduled launch readiness date. This reduction has been restored to maintain the spacecraft schedule in FY 1989.

BASIS OF FY 1989 ESTIMATE

The FY 1989 funds are required for continuation of the development activities on the ten UARS instruments including flight hardware fabrication, instrument assembly and environmental testing leading to instrument delivery to the spacecraft in 1989. The spacecraft development and hardware fabrication activities will continue including completion of the spacecraft mechanical test model program and the start of spacecraft integration and test in late FY 1988.

The ground data handling facility will enable a higher level of interaction among experimenters and theoreticians than has existed with past programs. Implementation of this concept requires that the system be developed on a timely parallel path with the flight hardware so that individual experiment data processing subsystems, including algorithms and the interactive data base, provide maximum interaction and effectiveness in the design and development phase of the program and are fully verified at launch time. In order to achieve this, FY 1989 funding is required to continue design and development of the ground data handling facility including hardware delivery and checkout, software preliminary and critical design reviews, science team support and science algorithm development.

BASIS OF FY 1989 FUNDING REQUIREMENT

OCEAN TOPOGRAPHY EXPERIMENT

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Ocean topography experiment (TOPEX).....	18,900	89,900	75,000	97,800

OBJECTIVES AND STATUS

The goal of the Ocean Topography Experiment (TOPEX) is to utilize satellite radar altimetry to measure the surface topography of the global oceans over a period of three years with sufficient accuracy and precision to significantly enhance our understanding of the oceans' general circulation and its mesoscale variability, The capability of satellite altimetry to address this goal was demonstrated in 1978 by NASA's highly successful Seasat program. Such information is needed to better understand how the atmosphere drives the circulation of the oceans, how the oceans in turn influence the atmosphere and ultimately, the role of the oceans in climate.

NASA and the French Space Agency (CNES) are collaborating on TOPEX in order to more fully exploit the scientific value of the data. In exchange for this scientific collaboration and the flight of a French altimeter and tracking system, CNES will launch TOPEX in late 1991 using Ariane. TOPEX is also being planned in concert with the World Ocean Circulation Experiment (WOCE), a major international oceanographic field program being planned under the auspices of the World Climate Research Program (WCRP). WOCE will combine satellite observations from TOPEX with traditional *in situ* observations to enable the first comprehensive determination of the three-dimensional current structure of the global oceans, When further combined with ocean surface winds from the NASA Scatterometer (NSCAT), unique measurements of the oceans' driving force (winds) and the resulting ocean response (topography) will have been obtained.

During FY 1988, the recently selected joint NASA/CNES Senior Team will meet for the first time; the definition contract for the satellite contract will be awarded; PDR's for the satellite, sensors, and ground data system will be held all leading to the conduct of an end-to-end system level PDR towards the end of the fiscal year.

CHANGES FROM FY 1988 REVISED BUDGET

The FY 1988 estimate has been reduced by $10.0 million due to Congressional action. An additional reduction by $4.9 million has been made in order to provide funds necessary to prepare and maintain Magellan for launch.

BASIS OF FY 1989 ESTIMATE

In FY 1989, the design of the satellite, sensor, and ground data system will be completed, leading to the initiation of full scale spacecraft system development. Final arrangements are expected to be made by CNES for the French-provided Ariane launch vehicle; the mission design will be refined based on input from and interaction with the Science Team; and the Science Team will be confirmed so that they can begin to refine their post launch research and verification plans.

BASIS OF FY 1989 FUNDING REQUIREMENT

AIRBORNE SCIENCE AND APPLICATIONS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Airborne science and applications.....	(27,600)*	(21,900)*	21,900	23,000

* Previously funded under Physics and Astronomy Suborbital Program

OBJECTIVES AND STATUS

This effort covers operation of an ER-2, two U-2C's, a C-130, and a DC-8 in order to support Earth-sensing and atmospheric research. The DC-8 was acquired to replace the CV-990 research facility, "Galileo II", which was destroyed in 1985. The replacement DC-8 has undergone required upgrades and modifications and carried out initial operations in Antartica in 1987 as part of the Ozone Hole campaign. Acquisition of a second ER-2, to replace the aging U-2C's is underway. These aircraft support other major segments of the Space Science and Applications program dealing with the Earth, the oceans, and the atmosphere. They may serve as test beds for newly developed instrumentation and allow demonstration of new sensor techniques before their flight on satellites or on Shuttle/Spacelab missions. Data obtained from these aircraft are used to refine analytical algorithms, and to develop ground data handling techniques. For example, the ER-2/U-2C's acquire stratospheric air samples and conduct in-situ measurements at altitude ranges above the capability of more conventional aircraft and below those of orbiting satellites. This capability is important in gaining an understanding of stratospheric transport mechanisms.

CHANGES FROM THE FY 1988 REVISED BUDGET

In accordance with the Office of Space Science and Applications reorganization, the majority of the Airborne program has been transferred from Physics and Astronomy (Suborbital program) to Environmental Observations, its primary user.

BASIS OF FY 1989 ESTIMATE

Requested FY 1989 funding will allow operation of the DC-8, two ER-2's, and the C-130. Operation of these aircraft will allow continuation of such projects as the collection and analysis of stratospheric air samples, testing of newly developed instrumentation, the demonstration of new sensor concepts, the investigation of the Ozone Hole phenomena, and participation in numerous other field experiments such as First International Satellite Cloud Climatology Project (ISCCP) Regional Experiment (FIRE). The FY 1989 budget will also provide for NASA's final payment to the U.S. Air Force, thereby completing the purchase of the second ER-2 aircraft.

MATERIALS
PROCESSING IN SPACE

RESEARCH AND DEVELOPMENT

FISCAL YEAR 1989 ESTIMATES

BUDGET SUMMARY

OFFICE OF SPACE SCIENCE AND APPLICATIONS

MATERIALS PROCESSING IN SPACE PROGRAM

SUMMARY OF RESOURCES REQUIREMENTS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
		(Thousands of Dollars)			
Research and analysis	13,900	12,900	12,900	13,600	RD 8-3
Microgravity shuttle/space station payloads	33.400	29,800	49.800	59 800	RD 8-4
Total	47.300	42,700	62,700	73.400	
Distribution of Program Amount by Installation					
Johnson Space Center	2,605	2,400	4,700	6,850	
Marshall Space Flight Center	14,235	11,450	18,000	21,100	
Lewis Research Center	11,710	11,700	15,500	21,450	
Langley Research Center	1,570	1,550	2,500	2,600	
Jet Propulsion Laboratory	11,180	10,300	13,700	13,900	
Headquarters	6.000	5,300	8,300	7.500	
Total	47 300	42,700	62.700	33.400	

OFFICE OF SPACE SCIENCE AND APPLICATIONS **MATERIALS PROCESSING IN SPACE PROGRAM**

PROGRAM OBJECTIVES AND JUSTIFICATION

The mission of the Microgravity Science and Applications Program is to foster the development of near-Earth space as a natural resource by exploiting microgravity and other unique attributes that may be attained in an orbiting spacecraft. In this environment, we can advance knowledge about the fundamental nature of matter, increase understanding of the role of gravity in various industrial processes, and produce limited quantities of certain exotic high-value materials for specialized applications. In FY 1989, ground-based research and payload development will be concentrated in six major areas: metals and alloys, electronic materials, glass and ceramics, biotechnology, combustion, and fluid dynamics and transport phenomena.

During FY 1989, ground-based research will support definition studies for Shuttle and Space Station experiment candidates in areas such as containerless experiments, solidification and crystal growth, and processing of biological materials. Researchers will conduct experiments in drop tubes, towers and aircraft. The ground-based research program also includes support for studies conducted under Technical Exchange Agreements.

The Microgravity Shuttle/Spacelab Payloads program provides a range of experimental capabilities for all participants in the Materials Processing in Space program. The payloads program currently supports a wide variety of hardware development, from unique flight experiments necessary to conduct basic research into the fundamental nature of matter to the modular, multi-user research facilities that will be the cornerstone of microgravity science and applications research on the Space Station. Experiments will be flown on Shuttle and Spacelab, as well as any promising commercial space facility.

BASIS OF FY 1989 FUNDING REQUIREMENT

RESEARCH AND ANALYSIS (MATERIALS PROCESSING)

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Ground-based investigations, analysis and studies.....	13,900	12,900	12,900	13,600

OBJECTIVES AND STATUS

The research and analysis activity provides the scientific foundation for all current and future projects in the Microgravity Science and Applications program. Emphasis is placed on ground-based research which is expected to evolve into space investigations with potential for future applications. This activity also supports technology development for future ground and space capabilities, and applications activities leading toward privately-funded space enterprises. Most research projects are initiated as a result of proposals from the scientific community which have been extensively reviewed by peer groups prior to selection. FY 1988 funding will support ongoing research.

BASIS OF FY 1989 ESTIMATE

Ground-based research and analysis will be continued in FY 1989 in the areas of metals and alloys, electronic materials, glass and ceramics, biotechnology, combustion, and fluid dynamics and transport phenomena. Research will be conducted to define the role of gravity-driven influences in generic processing methods. Effort will continue at the centers for bioprocessing research located at the University of Arizona and the University City Science Center in Philadelphia, PA as well as the Microgravity Materials Science Lab at the Lewis Research Center.

BASIS OF FY 1989 FUNDING REQUIREMENT

MICROGRAVITY SHUTTLE/SPACE STATION PAYMADS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Materials Experiment Operations.....	33,400	29,800	49,800	59,800

OBJECTIVES AND STATUS

The Microgravity Shuttle/Space Station payloads program provides a wide range of opportunities for experiments in microgravity science and applications. NASA currently supports the development of STS mid-deck, Spacelab and cargo-bay experiments. This policy maximizes the effective use of the STS by matching an experiment with the hardware location best suited to meet its scientific and technical requirements. In some cases, the payload program supports an evolutionary program of testing flight experiment concepts in the mid-deck before committing to more complex and ambitious Spacelab or cargo-bay mounted hardware.

The Materials Processing in Space program is preparing to use Space Station as a major platform for conducting microgravity research. During FY 1987, NASA received funds from Congress to begin technical definition of six major multi-user research facilities designed to take advantage of Space Station's unique capabilities. NASA's Microgravity Science and Applications Division (MSAD) is developing a strategy for orderly evolution of microgravity experiments from ground-based research to the Shuttle, and finally to Space Station. During FY 1988 and FY 1989, MSAD will continue Space Station hardware definition, and will initiate equipment development for both the first United States Microgravity Laboratory Spacelab mission, and any promising commercial microgravity facility.

In addition to the planned Space Station Initiative, the Materials Processing in Space program is placing increased emphasis on NASA's Physics and Chemistry Experiments (PACE) program, which uses microgravity research to challenge and improve existing scientific theory about the fundamental nature of matter. As other nations increase their ability to exploit the characteristics of near-Earth space, the "cutting edge" experiments generated by the PACE program will play an increasingly important role in assuring continued U.S. leadership in microgravity research.

CHANGES IN THE FY 1988 BUDGET

A $20.0M Congressional augmentation to the Microgravity Shuttle/Space Station payloads program will be used to initiate design and development of several pieces of advanced hardware that will help facilitate the evolution of the microgravity sciences to Space Station. The augmentation will also be used for continued definition work on the six proposed Space Station microgravity facilities.

BASIS OF FY 1989 ESTIMATE

FY 1989 funding is required to continue basic and applied research activities using STS mid-deck, Spacelab and cargo-bay experiments leading to several flights over the next few years. Investigations are planned in fluid dynamics, glasses, electronic materials, biotechnology, metals and alloys, and combustion. Development will continue on a number of Physics and Chemistry Experiments (PACE) as well as several pieces of advanced equipment in the areas of electronic crystal growth, biotechnology, metallic casting, and levitation. An augmentation has been included, building on the FY 1988 Congressional increase, to develop the advanced second- and third-generation microgravity payloads which will be flown on the STS, Space Station, and any promising commercial space facility.

COMMUNICATIONS

RESEARCH AND DEVELOPMENT

FISCAL YEAR 1989 ESTIMATES

BUDGET SUMMARY

OFFICE OF SPACE SCIENCE AND APPLICATIONS — COMMUNICATIONS PROGRAM

SUMMARY OF RESOURCES REQUIREMENTS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
		(Thousands of Dollars)			
Advanced communications technology satellite (ACTS)	84,600	---	75,600	---	
Advanced communications research	13,384	13,428	14,136	10,486	RD 9-3
Search and rescue	1,385	1,300	1,300	1,350	RD 9-5
Radio science and support studies	3,050	3,404	2,542	2,900	RD 9-6
Communications data analysis	981	1,168	1,322	1,464	RD 9-8
Total	103,400	19,300	94,900	16,200	
Distribution of Program Amount by Installation					
Goddard Space Flight Center	5,289	5,562	6,669	2,615	
Jet Propulsion Laboratory	6,710	6,660	5,765	5,590	
Lewis Research Center	89,018	5,634	78,253	4,412	
Headquarters	2,383	1,444	4,213	3,583	
Total	103,400	19,300	94,900	16,200	

RESEARCH AND DEVELOPMENT

FISCAL YEAR 1989 ESTIMATES

OFFICE OF SPACE SCIENCE AND APPLICATIONS

COMMUNICATIONS PROGRAM

OBJECTIVES AND STATUS

Advanced communications research, formerly communications research and analysis, continues to provide the development of subsystem component technology required by NASA, other government agencies, and U.S. industry for advanced communications satellite systems. Special emphasis is being given to pursuing technologies with high potential for improving spectrum and orbit utilization, satellite antennas, on-board processing inter-satellite links and around terminal designs since these technologies are the key to future growth of the communication satellite and terminal markets. In addition, the mobile communications technology program will continue to address the development of critical enabling technologies needed to insure growth of a commercial mobile satellite service in the U.S. This effort, in cooperation with U.S. industry, Canada, and other government agencies, will help implement a first generation commercial system in the early 1990's.

The search and rescue program is an international cooperative program that demonstrates the use of satellite technology to detect and locate aircraft or vessels in distress. The United States, Canada, France, and the Soviet Union developed the system, in which Norway, the United Kingdom, Bulgaria, Finland and Denmark also participate.

Radio science and support studies, formerly technical consultation services, will provide for studies of radio interference, propagation and special systems required for the growth of existing satellite services and the extension of new satellite applications. Support to the Department of State, the Federal Communications Commission, the National Telecommunications and Information Administration, and other Agencies in the development of frequency and orbit sharing techniques and strategies for upcoming World Administrative Radio Conferences (WARC's) is continuing.

Funding has not been included for continued development of the Advanced Communications Technology Satelitte (ACTS) in FY 1989. It continues to be the Administration's policy that this flight demonstration project is more appropriately and effectively undertaken by the private sector, without subsidies or possible competition by the government.

BASIS OF FY 1989 FUNDING REQUIREMENT

ADVANCED COMMUNICATIONS RESEARCH

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Advanced communications research.....	13,384	13,428	14,136	10,486

OBJECTIVES AND STATUS

The advanced communications research program emphasizes the development of high-risk technology required to maintain U.S. preeminence in the international satellite communications market, to enable new and innovative public services, and to meet the communications needs of NASA and of other government agencies. This program focuses on the "interconnectivity technologies" of on-board switching, inter-satellite links, and antennas, as well as advanced RF technologies. Advanced studies are performed to determine the future satellite communications needs of the country and to define the technology required to meet those needs. The technology is developed and tested through an advanced proof-of-concept (POC) program. The POC devices and components are then integrated into a multiple terminal, satellite communications network in a laboratory where they undergo comprehensive evaluation.

In FY 1988, work is continuing on advanced communications technologies. Laser inter-satellite link communications technologies are being developed that will permit communications between satellites and ground terminals, satellites and low Earth orbiting vehicles, such as the Space Shuttle or Space Station, and between satellites and other geosynchronous orbiting satellites, such as the Tracking and Data Relay Satellite (TDRS). Technology development is also underway in the area of monolithic microwave integrated circuits (MMIC), which have significant potential for applications in multiport spacecraft matrix switches, low noise receivers, and multibeam antenna arrays and beam-forming networks. A number of industry studies are being sponsored to assess new areas of communications technologies required for the 1990's.

The mobile communications technologies activity is aimed at accelerating the introduction of a commercial mobile satellite service in the U.S., and developing and testing power, bandwidth and orbital-slot efficient ground segment technology and networking techniques needed to insure its growth. An innovative NASA offer to industry was signed in FY 1985 by a consortium of U.S. companies which would provide a launch for the first generation commercial satellite in exchange for satellite transponder capacity that would be used by NASA and other government agencies for experimentation and technology validation. The endeavor to commercialize this new service got a recent boost with the allocation of frequencies and the formation of a single consortium that is applying to the FCC for license approval. NASA is planning a major government industry conference in May to exchange information and facilitate the transfer of technology to industry.

CHANGES FROM THE FY 1988 BUDGET ESTIMATE

The change in the FY 1988 Budget Estimate reflects additional requirements for the current laser communication program.

BASIS OF FY 1989 ESTIMATE

The Research and Analysis program will continue to support development of the technologies necessary for future space communications satellite systems. During FY 1989, NASA will continue to work with U.S. industry and other government agencies to complete field testing of advanced communications hardware and help accelerate the introduction of mobile satellite communications service in the U.S. Work in laser communications technologies will continued.

BASIS OF FY 1989 FUNDING REQUIREMENT

SEARCH AND RESCUE

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Search and rescue	1,385	1,300	1,300	1,350

OBJECTIVES AND STATUS

The United States (NASA, NOAA, the Coast Guard, the Air Force, and the FAA), Canada, France, and the Soviet Union developed the search and rescue system, in which Norway, the United Kingdom, Bulgaria, Finland and Denmark also participate. The Search and Rescue (SAR) satellite system was declared operational in July 1985. NOAA maintains operational responsibility for search and rescue, while NASA's role is tightly focused on three research and development aspects of SAR, specifically the development of a low-cost 406 MHz emergency beacon, the next generation satellite-borne SAR equipment, and advanced techniques that will make possible more precise and timely location of downed aircraft and ships in distress.

The Search and Rescue program, developed by NASA and international partners, has demonstrated the feasibility of using satellites to improve significantly the ability to detect and locate general aviation aircraft and marine vessels during emergencies. The system has received world-wide acclaim and has been credited with saving over 1,000 lives to date.

In FY 1988, NASA work is continuing to develop low-cost 406 MHz beacon hardware. In addition, experiments in geostationary orbit to provide nearly instantaneous alerting will be performed. We will continue to support the FAA to minimize the systems false alarm rate.

BASIS OF FY 1989 ESTIMATE

Funding in FY 1989 will continue the NASA-unique research and development role in three areas of SAR, low-cost emergency beacon development, the next generation satellite-borne SAR equipment, and advanced techniques to improve system precision.

BASIS OF FY 1989 FUNDING REQUIREMENT

RADIO SCIENCE AND SUPPORT STUDIES

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Radio science and support studies.....	3,050	3,404	2,542	2,900

OBJECTIVES AND STATUS

Radio science and support studies provide the technical basis for regulatory and policy development to assure the orderly growth of existing and new satellite services. Unique analytical tools are developed and used to solve problems of inter-and intra-satellite/terrestrial system interference. Emphasis is placed on orbit and spectrum utilization studies, which include the development of frequency and orbit sharing techniques and strategies, design standards, and the determination of the effect of propagation phenomena and man-made noise on performance, design, and efficient use of the geostationary satellite orbit and the radio spectrum.

During FY 1988, the radio science and support studies program will continue further development of a geostationary arc allotment concept as part of the U.S. preparations for the FY 1988 Space World Administrative Radio Conference. Also, propagation studies will continue to help minimize radio signals atmospheric interference problems in space communications.

CHANGES FROM THE FY 1988 BUDGET ESTIMATE

The change is a result of the aforementioned funding transfer to the Advanced Communications Research and Communications Data Analysis line.

BASIS OF FY 1989 ESTIMATE

During FY 1989, major emphasis of the radio science and support studies program will be studies to identify and quantify the adverse effects of propagation phenomena on satellite communications as well as remote sensing. Work will continue to identify systems and technologies that make effective use of the frequency spectrum and geostationary orbit.

BASIS OF FY 1989 FUNDING REQUIREMENT

COMMUNICATIONS DATA ANALYSIS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Communications data analysis..... ..	981	1,168	1,322	1,464

OBJECTIVES AND STATUS

The objectives of communications data analysis are to support and to document a wide range of user experiments and demonstrations of the application of satellite communications. Past experiments on experimental satellites, such as the Applications Technology Satellite (ATS) series and the Communications Technology Satellite (CTS), have successfully provided users with the experience necessary to make informed decisions regarding the satellite communications functions. NASA's role to stimulate use of unique space facilities has led to wider application of commercial satellites that better meet the needs of potential users.

The remaining Applications Technology Satellite (ATS) satellite, ATS-3, continues to support the National Science Foundation, the National Oceanic and Atmospheric Administration, the Department of Commerce, the Department of Interior, the Drug Enforcement Administration, several universities, state and local governments, and a number of domestic and international disaster relief organizations. Support is provided through satellite voice and data links for scientific and communications experiments to North and South America, most of the Atlantic Ocean, and a large part of the eastern Pacific, including Hawaii and Antarctica.

CHANGES FROM THE FY 1988 BUDGET ESTIMATE

The change in the FY 1988 Budget Estimate reflects additional requirements for laser communications experiment and analysis.

BASIS OF FY 1989 ESTIMATE

Communications data analysis support of ATS-3 will continue, as will experiment definition and data analysis for laser communications analysis.

Communications data analysis, formerly the experiment coordination and operations support, assists other federal agencies and public sector organizations in the development of experimental satellite communications for emergency, disaster and public service applications. Operation of the Applications Technology Satellite (ATS-3), launched in 1967, will continue.

INFORMATION
SYSTEMS

RESEARCH AND DEVELOPMENT

FISCAL YEAR 1989 ESTIMATES

BUDGET SUMMARY

OFFICE OF SPACE SCIENCE AND APPLICATIONS — INFORMATION SYSTEMS PROGRAM

SUMMARY OF RESOURCES REQUIREMENTS

	1987 Actual	1988 Budget Estimate	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Data systems	10,000	8,776	9,700	11,400
Information systems	11,200	12.124	11.200	10.900
Total	21.200	20.900	20,900	22,300
Distribution of Program Amount by Installation				
Goddard Space Flight Center	14,033	15,103	14,444	14,233
Jet Propulsion Laboratory	4,580	4,496	4,100	4,346
Ames Research Center	810	297	683	724
National Space Technology Laboratories	255	256	---	---
Headquarters	'1.522	748	1.673	2,997
Total	21,200	20,900	20,900	22,300

OFFICE OF SPACE SCIENCE AND APPLICATIONS **INFORMATION SYSTEMS PROGRAM**

PROGRAM OBJECTIVES AND JUSTIFICATION

The objectives of the Information Systems program are to: apply advanced data systems technology to support the data management, scientific computing and information systems needs of NASA scientific research programs; conduct research programs and projects in the area of information systems and related technologies to enhance scientific productivity in the handling and analysis of data acquired from space flight experiments and observations; and, implement information system standards, coordinate data systems requirements, and promote multi-mission sharing to lower information systems costs.

The information systems program provides the focus for integrated information systems planning across OSSA scientific disciplines. This includes definition of an end-to-end architecture or planning model to exploit commonality of requirements as appropriate, and to define interfaces for integrating mission- and discipline-specific portions with common core capabilities. The information systems program also provides leadership in assessing and evaluating advanced techniques, capabilities, and technologies especially as they support the information systems requirements associated with the highly complex sensors, complicated operational scenarios, extended-duration missions and multi-disciplinary requirements anticipated during the Space Station era.

During FY 1988 the information systems program continued to extend access across the OSSA research community to unique resources such as the NASA Space and Earth Sciences Computing Center, the National Space Science Data Center, and the Massively Parallel Processor. Networking is being emphasized as a key element to support scientists' access to computers and data. In addition, significant effort was made in coordinating data system activities across the Earth science and astrophysics disciplines to promote catalog interoperability and the interdisciplinary sharing of data, software tools, and advanced visualization techniques to enhance scientific interpretation.

CHANGES FROM THE FY 1988 BUDGET ESTIMATE

The change in detail is due to increased emphasis on network implementation of pilot data systems

BASIS OF FY 1989 ESTIMATE

The FY 1989 information systems program will continue emphasis on science information systems in support of Space Science and Applications programs, includes the ocean, climate, land processes, and planetary and, astrophysics systems. Emphasis will be placed on the coordinated development of these systems to promote interdisciplinary studies. In addition emphasis will continue on the applications of computer science technologies to support the work of the NASA science disciplines. Funding is included for continued operation of scientific computing resources; such as, the NASA Space and Earth Sciences Computing Center, the Massively Parallel Processor, and the National Space Science Data Center. The information systems program will continue to develop common software to support ongoing research in the space and Earth sciences and continue development of data management and data archiving to support flight projects, science, applications, and research disciplines.

COMMERCIAL
PROGRAMS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FISCAL YEAR 1989 ESTIMATES

RESEARCH AND DEVELOPMENT BUDGET PLAN FOR COMMERCIAL PROGRAMS

Commercial Programs	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
		(Thousands of Dollars)			
Technology utilization	15,700	17,700	17,700	19,100	RD 11-1
Commercial use of space	25,200	35,000	56,000	38,800	RD 12-1
Total	40,900	52,700	73,700	57,900	

TECHNOLOGY
UTILIZATION

RESEARCH AND DEVELOPMENT

FISCAL YEAR 1989 ESTIMATES

BUDGET SUMMARY

OFFICE OF COMMERCIAL PROGRAMS

TECHNOLOGY UTILIZATION PROGRAM

SUMMARY OF RESOURCES REQUIREMENTS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
		(Thousands of Dollars)			
Product development	1,500	2.000	1.400	2.100	RD 11-4
Acquisition. dissemination and network operations	4.100	4.700	4.665	5.400	RD 11-4
Program development. evaluation and coordination	1,700	1.800	2.600	1.500	RD 11-5
Technology applications	6.000	6.600	7.000	7.300	RD 11-5
Industrial outreach	2.400	2.600	2.035	2.800	RD 11-6
Total	15.700	17.700	17.700	19.100	
Distribution of Program Amount by Installation					
Johnson Space Center	335	515	515	500	
Kennedy Space Center	752	492	492	670	
Marshall Space Flight Center	534	640	640	665	
National Space Tech. Labs	940	840	840	865	
Goddard Space Flight Center	1.247	1,275	1.275	1.300	
Jet Propulsion Laboratory	953	1.030	1.030	1.055	
Ames Research Center	474	460	460	500	
Langley Research Center	1.097	622	622	680	
Lewis Research Center	825	355	355	380	
Headquarters	8.543	11.471	11.471	12.485	
Total	15.700	17.700	17,700	19,100	

OFFICE OF COMMERCIAL PROGRAMS **TECHNOLOGY UTILIZATION PROGRAM**

PROGRAM OBJECTIVES AND JUSTIFICATION

The NASA Technology Utilization Program is designed to strengthen the national economy and industrial productivity through the transfer and application of aerospace technology resulting from NASA's R&D programs. To accomplish this objective, NASA has established and operates a number of technology transfer mechanisms to provide timely access of useful technologies to the private and public sectors of the economy. Almost every part of U.S. industry is affected by the technology transfer process, especially in such areas as automation, electronics, materials, and productivity. In the public sector, medicine, rehabilitation, transportation and safety are areas in which aerospace technologies have been especially beneficial. The specific objectives of the program are:

- To accelerate and facilitate the application of new technology into the commercial sector, thus shortening the time between the generation of advanced aeronautics and space technologies and their effective use in the economy;

- To encourage multiple secondary uses of NASA technology in industry, education, and government, where a wide spectrum of technological problems and needs exist;

- To develop applications of NASA's aerospace technology, including its unique facilities, to priority nonaerospace needs of the Nation.

OBJECTIVES AND STATUS

NASA has continued its broad and comprehensive efforts to promote and encourage the effective application and use of new and innovative aerospace technologies throughout the public and private sectors of the U.S. economy. Of particular note is the upward growth of industrial and business subscribers to NASA Tech Briefs which now exceeds 160,000 readers. This 100% increase since January 1985 represents a growth rate averaging over 5,000 new subscribers per month...an effective measure of the importance and value which U.S. industry places on new and emerging technologies.

Moreover, the NASA-sponsored Industrial Applications Center (IAC) network has made significant strides in developing effective linkages with state-sponsored institutions engaged in industrial and economic growth. This broadening and strengthening of the nationwide technology transfer network is continuing to gather momentum with nearly 30 of the 50 states now being linked to transfer products and services

available through the IAC efforts. NASA expects to continue this effort during the balance of FY 1988 and on into FY 1989. An additional milestone was reached in late 1986 when the Federal Laboratory Consortium (FLC) for Technology Transfer (established under P.L. 99-502) and NASA elected to enter into an agreement in early 1987 which establishes formal linkages between the NASA IAC network and the various Federal laboratories. Based on the successful completion of an experimental program between the NASA IAC at the University of Southern California and the FLC Farwest Region, IAC industrial clients will now be able to gain controlled access to Federal laboratories nationwide that are engaged in research and development activities of parallel commercial interest. This effort is spurring the acceleration of technology transfer and application of Federally-sponsored technologies into the mainstream of the U.S. economy. NASA is also seeking to familiarize and involve the private sector to a greater extent. The hiatus in Shuttle flights caused by the Challenger accident has shifted the focus of NASA's commercial programs from in-space experimentation to ground- based opportunities and exploitation of available technology. The IACs are a natural focal point for increasing awareness of available technology and opportunities.

Several important events occurred during the past 18 months in which several NASA-sponsored Technology Applications projects came to fruition. Among these was the first human implant of the Programmable Implantable Medication System (PIMS) at the Johns Hopkins University (JHU) Hospital in November 1986. This successful human application of PIMS culminates several years of an intensive collaborative effort between NASA, JHU Applied Physics Laboratory, and various private sector firms, and initiates a two-year clinical test period in which over 20 implantations will occur. All of these applications during the test period will be for patients with chronic diabetes.

Finally, NASA authorized experimental technology transfer programs involving process and product at the Jet Propulsion Laboratory as a means to enhance access to that laboratory's technology by small and large industrial firms. In May 1986, NASA entered into a cooperative agreement with the non- profit California-based Research Institute for the Management of Technology (RIMTECH) to introduce JPL technology to industrial users in the Southern California area. For an entry fee, RIMTECH clients are offered NASA's technical assistance, information retrieval services, licensing rights and the possibility of cofunding of projects in the development stage. NASA, in turn, fulfills its charter and accrues the benefits of a broadened high-tech base industry, incentives for JPL employee creativity, potential royalities from patent licensing, and reverse technology transfers to NASA/JPL from industry. At present, 15 industrial firms are participating in these programs and another 25 firms are expected to join within the next 12 months.

CHANGES FROM FY 1988 REVISED BUDGET

The distribution of funds was adjusted to reflect programmatic needs.

BASIS FOR FY 1989 ESTIMATE

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
	(Thousands of Dollars)			
Product development.....	1,500	2,000	1,400	2,100

Based on the increasing response to Tech Briefs and expanding IAC network, increases in new technology identification and reporting are anticipated in FY 1989. These resources will provide for evaluation and packaging of these technologies for publication thereby stimulating industrial interest and participation in NASA's Technology Utilization and Commercial Use of Space programs.

Acquisition, dissemination and network operations.....	4,100	4,700	4,665	5,400

In FY 1989, NASA plans continued strengthening of the Technology Counselor network at its field installations to provide for expanded identification of NASA technical capabilities and expertise. This capability and expertise is necessary for matching and cross-correlating NASA technology with industry needs specified by NASA Industrial Applications Centers. To facilitate timely and efficient interaction between Technology Counselors, Industrial Applications Centers and other organizations in the NASA technology transfer network, a coherent, microcomputer-based communications system is planned for functional utilization within the NASA technology utilization infrastructure in FY 1989. Expansion of this capability, increased effective communication, and data storage and retrieval systems will greatly enhance the overall capability of the network to coordinate technology transfer activities, and respond to user needs efficiently with minimum overlap and duplication of effort. Moreover, the system will enable technology transfer managers to maintain appropriate controls over the process to insure overall program effectiveness and management accountability.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Program development, evaluation and coordination.....	1,700	1,800	2,600	1,500

With an expanded role in industrial outreach, additional emphasis will be required in the development of program goals and objectives in terms of long range plans for NASA Technology Utilization (TU). Focused efforts on assessing potential participants in U.S. industry, preparing information guidelines to support cooperative relationships throughout the NASA technology transfer network, as well as satisfying anticipated increased demand for TU publications and responses to increased number of program inquiries are among the many management planning and support requirements. Specific actions are also planned for FY 1989 to strengthen program development, evaluation and coordination on an internal as well as external basis to support the national technology transfer network and emerging commercial use of space outreach efforts.

Technology applications.....	6,000	6,600	7,000	7,300

In FY 1989, a broadening of application team responsibilities is anticipated to assist NASA Industrial Applications Centers in bringing together industrial client problems with existing aerospace technologies leading to project definition and industry-driven cooperative projects. This effort will result in increased tangible and meaningful applications of aerospace technology in the private sector, thus enhancing the productivity and competitive posture of U.S. industry.

	1987 Actual	1988 Amended Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Industrial outreach.....	2,400	2,600	2,035	2,800

In FY 1989, NASA will utilize its existing dissemination center network to contact and acquaint U.S. industrial firms with opportunities to actively interact and participate with NASA in technology transfer and space commercialization. Such contacts are envisioned on a face-to-face basis, with appropriate follow-up including seminars, conferences and workshops to explore more detailed characteristics of the "opportunities" for interaction. The NASA Industrial Applications Centers are in a unique position to serve as NASA's surrogate in aligning U.S. industrial interests in space commercialization as well as opportunities for terrestrial commercialization of advanced technologies derived from NASA's R&D programs. The technological needs of industry, would benefit from this synergistic approach designed to bring engineering resources of both in closer proximity. Successful technology transfer occurs most frequently in an environment where knowledge is shared easily and advantages through cooperative endeavors are explained and understood. It is this role that the NASA dissemination center network can readily fulfill.

COMMERCIAL
USE OF SPACE

RESEARCH AND DEVELOPMENT

FISCAL YEAR 1989 ESTIMATES

BUDGET SUMMARY

OFFICE OF COMMERCIAL PROGRAMS **COMMERCIAL USE OF SPACE**

SUMMARY OF RESOURCES REOUIREMENTS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
		(Thousands of Dollars)			
Commercial applications R&D	22,200	33,600	28,600	36,600	RD 12-4
Commercial development support.....	3,000	1,400	2,400	2,200	RD 12-5
Industrial space facility.....	---	---	25,000	---	
Total.....	25.200	35,000	56.000	38,800	

Distribution of Program Amount by Installation

Johnson Space Center.....	725	100	100	100
Kennedy Space Center.....	68	445	445	460
Marshall Space Flight Center.....	4,819	9,680	9,680	19,700
National Space Technology Laboratories...	738	1,000	1,000	300
Goddard Space Flight Center.....	650	150	150	200
Jet Propulsion Laboratory.....	---	---	---	---
Ames Research Center.....	180	382	382	450
Langley Research Center.....	570	746	746	1,095
Lewis Research Center.....	1,187	1,365	1,365	1,025
Headquarters.....	16.263	21.132	42.132	15,470
Total.....	25,200	35,000	56,000	38,800

OFFICE OF COMMERCIAL PROGRAMS **COMMERCIAL USE OF SPACE PROGRAM**

PROGRAM OBJECTIVES AND JUSTIFICATION

The goal of the Commercial Use of Space Program is to establish a national focus in support of opportunities for the expansion of U.S. private sector investment and involvement in civil space activities. The specific objectives of the program are to:

- Establish close working relations with the private sector and academia to encourage investment in space technology and the use of the in situ attributes of space - vacuum, microgravity, temperature and radiation for commercial purposes.
- Facilitate private sector space activities through improved access to available NASA capabilities and the development of new high technology space ventures and markets.
- Encourage an increase in private sector investment in the commercial use of space independent of NASA funding.
- Develop and implement commercial space policy NASA-wide.

OBJECTIVES AND STATUS

Sixteen Centers for the Commercial Development of Space (CCDS) have been established since the start of the program. The average cost of a CCDS is just under $1 million per year. Several CCDS's have developed strong linkages with the private sector and are developing flight hardware for applied research in space.

The Office of Commercial Programs (OCP) is building multi-user, multi-use government hardware, in cooperation with the Office of Space Sciences and Applications, that will reduce individual entrepenuer experiment costs to a level that can be afforded. This hardware consists of various types of furnaces, materials processing equipment, and experiment carrier supporting structures that private companies may use for space experiments. Use of the hardware provides access to microgravity through flights on the shuttle, on NASA aircraft, and on sounding rockets.

experiment's characteristics and requirements and making provision for the physical placement on-board the shuttle. OCP has two experiments approved for STS flight 26 and two for flight 29. The Space Systems Development Agreement (SSDA) optional services responsibility has been transferred to OCP from the Office of Space Flight. NASA's current SSDA's are with Geostar and Space Industries Incorporated (now Space Industries Partnership).

CHANGES FROM FY 1988 REVISED BUDGET

The current estimate for FY 1988 has increased by a net of $21 million as a result of two Congressional actions. First, the Commercial Use of Space budget was decreased by $4.0 million. This reduction has been absorbed in the Commercial Applications R&D and will result in a reduction of new starts in the R&D Enhancement Program as well as program stretch-out in existing R&D Enhancement projects. In addition, $1.0 million has been transferred from Commercial Applications R&D to Commercial Development Support for on-going activities.

Second, $25 million has been added by Congress with direction to conclude a satisfactory funding arrangement that will lead to a workable leased Industrial Space Facility (ISF) Vehicle in the 1991-1992 timeframe.

BASIS FOR FY 1989 ESTIMATE

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Commercial applications R&D	22,600	33,600	28,600	36,600

In order to maintain momentum in commercial use of space activities, NASA will develop methods to facilitate private sector agreements and commitments to develop commercial opportunities in space. Institutions with strong research capabilities in sciences and engineering, in collaboration with industry and/or industrial associations, will be encouraged to participate in NASA-sponsored workshops and endeavors to accelerate U.S. commercial leadership in the use of space. Resources support and technical assistance will be partially furnished by NASA with the remainder furnished by the Center for the Commercial Development of Space.

NASA's goal of expanding opportunities for U.S. private sector investment and involvement in civil space and space-related activities will be partially achieved by increasing the amount of space-related research conducted by the private sector, the number and type of NASA and private sector facilities available for space use, and the private sector awareness of the opportunity to use NASA's terrestrial and space-based facilities for potential commercial research.

Through coordination with various industrial sectors and NASA program offices, the commercial R&D enhancement efforts will provide generic, multi-use research experimentation equipment. This equipment, as well as ground-based hardware, software and analytical tools, will be developed in order to expand the technical research database on the commercial uses of space required by the private sector to help make economic decisions to commit to research and, potentially, manufacture. Emphasis will be accelerated to build the required technical infrastructure. The main thrust of the effort will be directed by the private sector in coordination with NASA Centers. Resources will also be made available to obtain flight support experimentation hardware required by industrial researchers. This may include across-the-bay carriers, such as Materials Science Laboratories, as well as mid-deck augmentation racks or derivatives thereof, and the possible leasing of private sector hardware developed to exploit commercial research and development in space. Both analytical and physical integration support are required for experiments conducted under Joint Endeavor Agreements (JEA). The NASA support for JEA's is directly proportional to the number of commercial research and development flight experiments scheduled and it is intended to encourage private sector use of space facilities. The use of ground-based research facilities, aircraft and sounding rockets for commercial experimentation will be given emphasis in order to provide limited access to the microgravity environment for certain commercial experiments.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
Commercial development support.....	*3,000*	*1,400*	*2,400*	*2,200*

The support of the Commercial Use of Space Program requires a broad foundation. Ad hoc and continuing studies by experts are required to provide the direction and feedback needed by the program, especially where the economic, commercial and technical circumstances are changing rapidly. Study results assist in the development of short and long range plans and agency policy. Support services, equipment hardware maintenance, and studies and analyses are the other elements of commercial development support.

AERONAUTICS AND
SPACE TECHNOLOGY

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FISCAL YEAR 1989 ESTIMATES

RESEARCH AND DEVELOPMENT PLAN FOR AERONAUTICS AND SPACE TECHNOLOGY

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Aeronautical research and technology	374,000	332,800	336,800	414,200
Transatmospheric research and technology	45,000	65,500	52,500	84,400
Space research and technology	206,000	238,600	223,600	390,900
Total	625,000	636,900	610,900	889,500

AERONAUTICAL
RESEARCHAND
TECHNOLOGY

RESEARCH AND DEVELOPMENT

FISCAL YEAR 1989 ESTIMATES

BUDGET SUMMARY

OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY **AERONAUTICAL RESEARCH AND TECHNOLOGY**

SUMMARY OF RESOURCES REQUIREMENTS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
		(Thousands of Dollars)			
Research and technology base.....	271,111	249,600	251,600	314,200	RD 13–8
Systems technology programs.....	102,889	83,200	83,200	100.000	RD 13–46
Total.....	374,000	332,800	334,800	414.200	
Distribution of Program Amount by Installation					
Marshall Space Flight Center.....	1,586	1,700	1,700	4,100	
Jet Propulsion Laboratory.....	240	200	300	300	
Goddard Space Flight Center.....	273	200	200	200	
Ames Research Center.....	167,087	143,200	142,300	157,900	
Langley Research Center.....	117,885	108,300	108,100	144,300	
Lewis Research Center.....	81,327	72,100	75,100	100,200	
Headquarters.....	5,602	7,100	7.100	7.200	
Total.....	374,000	332,800	334,800	414,200	

OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY **AERONAUTICAL RESEARCH AND TECHNOLOGY**

PROGRAM OBJECTIVES AND JUSTIFICATION

The goal of the NASA aeronautical research and technology program is to conduct research which contributes to a technology base that enables preeminence of U.S. civil and military aviation. This goal is supported by five comprehensive program objectives: (1) emphasize emerging technologies with potential for order-of-magnitude advances in capacity or performance which will enhance the U.S. defense and economic competitiveness; (2) maintain NASA's laboratory strength by repairing and modernizing critical aging national facilities, ensuring that necessary advanced scientific and engineering computational capabilities are available, and enhancing staff technical excellence by selecting highly qualified personnel and providing them with challenging career opportunities; (3) ensure the timely transfer of research results to the U.S. aeronautics community through reports, conferences, workshops, and active participation of industry in cooperative research programs; (4) ensure the strong involvement of universities in NASA's program to broaden the nation's base of technical expertise and innovation; and (5) provide technical expertise and facility support to the Department of Defense (DoD), other government agencies, and U.S. industry for major aeronautical programs. These objectives require a broad program of fundamental research that focuses on critical technologies and accelerates technology readiness for future vehicles. The program is based on a strong commitment to revitalize American competitiveness in the world aviation marketplace, enhance the safety and capacity of the national airspace system, and assure U.S. superiority for national security.

The NASA aeronautical research and technology program is intended to develop and validate emerging technologies for use by the aviation industry well in advance of specific applications through long-term independent research and technology development which is not driven by the development and operational pressures often encountered by the DoD and industry. Fundamental research in the traditional aeronautical disciplines is pursued concurrently with systems research and technology validation.

With the U.S. superiority in aeronautics challenged as never before, the FY 1989 estimate reflects the need to accelerate technologies which are vital to long-term U.S. competitiveness, to continue a strong program in fundamental disciplines and in key areas of systems research, and to revitalize critical NASA wind tunnels. NASA's FY 1989 aeronautics program is focused on achieving the bold objectives established

in the report, "National Aeronautical R&D Goals: Technology for America's Future," by the Office of Science and Technology Policy (OSTP), and by its sequel report, "Agenda for Achievement," which enunciates an eight-point action plan for achieving the goals.

CHANGES FROM FY 1988 REVISED BUDGET ESTIMATE

The aeronautical research and technology program reflects an increase of $2.0 million for rotary engine technology which resulted from Congressional action on the FY 1988 budget request.

BASIS OF FY 1989 ESTIMATE

The FY 1989 research and technology program is committed to developing the technology basis for improving the nation's competitiveness and clear-cut product superiority in the international marketplace, enhancing the safety of aviation, and increasing the margin of the country's preeminence in aviation for national security. Technologies are being pursued that offer an order-of-magnitude increase in vehicle capabilities and substantial positive impact on U.S. competitiveness. Research efforts have been expanded in composite materials, advanced propulsion, and aviation safety. The demands for NASA's unique wind tunnels are growing with the emergence of the national aero-space plane (NASP) program, research on high-speed civil transports, and a new generation of military aircraft. In order to ensure wind tunnel availability to meet these demands, a major revitalization program is required over the next five years to modernize NASA's major wind tunnels for productive use €or the next decade and into the 21st century. This program is included in the FY 1989 construction of facilities budget.

A brief summary of the key elements of the research and technology base and systems technology programs follows.

In fluid and thermal physics, increased research emphasis will be placed on analytical, computational, and experimental studies of turbulence through the focused efforts of a newly formed center for turbulence research. In fundamental fluid physics, investigations using the numerical simulation of the flow instabilities which produce transition from laminar to turbulent flow will be accelerated, leading to an improved understanding of both the mechanisms of transition and the control of transition. This knowledge can enable reductions in aircraft drag and simplification of aircraft thermal management systems. Hybrid laminar flow control for aircraft drag reduction will be validated experimentally through a flight test research program initiated in FY 1989.

In applied aerodynamics, efforts will focus on high angle of attack and separated flow aerodynamics in both ground and flight test. Control of separated flow will be studied to determine cellular formation, control, and wing stall departure and spin resistance. Boundary-layer transition will be investigated for all speed regimes. By utilizing advanced optical and electronic technologies, innovative wind tunnel instrumentation will be developed for infrared boundary-layer transition visualization, micro-encapsulated liquid crystal methods for advanced flow visualization, laser fluorescence for hypersonic flow sensing, and laser velocimetry for supersonic and hypersonic shock propagation measurements. Experimental hardware, which has been under development for the past two years, will be used in an experimental flight investigation program to validate hybrid rotorcraft computational fluid dynamic codes for the prediction of rotor airloads and their resultant effects on aircraft vibration and acoustics.

Propulsion research will continue to emphasize improvement of the fundamental understanding of stationary and rotating component flow fields with the development of unsteady, viscous, computational analysis methods and enhanced experimental verification through three-dimensional nonintrusive measurement capabilities. The focus will be on several specific propulsion technology developments: high-rate fuel injection and adiabatic components for rotary engines, offering a potential for improvement of 40 percent in fuel consumption and 30 percent in power density; axicentrifugal compressor staging arrangements and uncooled radial flow turbines, offering the potential for a 40 percent improvement in efficiency for small gas turbines; powered-lift components (inlets, ducts, augmenting fans, ejectors) and control integration, providing significant improvements for advanced short takeoff and vertical landing vehicles; and the critical component data base needed for hypersonic propulsion. Increased emphasis on advanced propulsion concepts will enhance the technology development of four innovative configurations, offering the potential for high payoff improvements in future propulsion systems: high throughflow turbomachinery, offering a 20 percent range increase for a Mach 3 cruise mission; air turboramjet cycle for extending variable cycle flexibility for the Mach 0 to 6 regime; variable geometry components, providing performance tailoring for multiple operating conditions with a 15 to 25 percent reduction in specific fuel consumption and 10- to 15 percent increase in thrust-to-weight ratio; and an off-axis, high-pressure core, offering the potential for a 20 to 30 percent increase in efficiency.

The materials and structures program will continue to develop advanced materials and innovative structural concepts aimed at reducing aircraft weight and cost. These include high-temperature aluminum alloys for subsonic and moderate supersonic speed aircraft, regenerative cooling of hypersonic aircraft, and deformable wing structures for high-performance aircraft. In addition, increased emphasis will be placed on developing high-temperature composites technology for use at up to 600 degrees Fahrenheit. The composites program will focus on the development of advanced materials, advanced fabrication methods that

are especially tailored to take advantage of composite material characteristics, advanced structural concepts, and design and qualification test methods. Advanced structural concepts and fabrication methods will include filament winding and pultrusion techniques to reduce parts count for major structures and subsystems, while new design and qualification methods will reduce structural design and testing costs. These areas will be supported by continued development of advanced computational methods to reduce structural design time and minimize costly testing. Also during FY 1989, greater emphasis will be placed on analysis of large-scale airframe structures using advanced multiprocessor computers.

Research in information sciences will continue on concurrent processing for highly reliable and high-performance computer architectures which will be more immune to hardware and software failures. A family of parallel processing computers will be used to research novel concepts in parallel processors controlled by new software algorithms. Also, studies will continue to assess the reliability gain from formal specifications, software prototyping, computer-aided software engineering systems, software reuse, and formal verification. Support will be provided to NASA's computer networking system in order to increase the effectiveness and productivity of NASA's distributed computing resources.

In controls and guidance, the advanced transport systems research vehicle (B-737) has returned to flight research status after overhaul and upgrade of its avionics systems, and emphasis will be placed on flight evaluation of takeoff and landing performance monitoring, high-speed rollout and turnoff capacity improvements, and navigation systems for reduced airport congestion and delays. Increased emphasis will be placed on development of automation concepts leading to enhanced safety and productivity in the national airspace system. Adopting state-of-the-art space automation techniques and methods, evaluations will be conducted jointly with the Federal Aviation Administration at the Stapleton Airport in Denver, of an air traffic controller advisor and expert schedule advisor, which offer the promise for allowing reductions in controller workload and more efficient handing of air traffic. In FY 1989, research will continue on the detection, avoidance, and recovery from wind-shear encounters.

Human factors research will emphasize the development of methods for designing pilot decision aids and information transfer improvements in order to increase safety and reduce peak workload. To address the fact that over the last 30 years approximately 70 percent of the world-wide jet fleet accidents were caused by human error, the human factors research will be accelerated in areas directly related to aviation safety and automation. This research will emphasize the development and validation of methodologies for intelligent, error-tolerant systems; improved human/automation interfaces for increased situational awareness; and aircraft/active control technology integration. The goal of this activity is to substantially reduce the risk of human error.

Flight systems research will be directed toward the technology needs of aviation safety, flight test methodologies, and supporting research for high-performance aircraft. Research is being conducted to improve the understanding of the effects of weather and icing conditions on the safe operation of aircraft and rotorcraft and to develop the technologies which will improve the safety of future vehicles. Research will be conducted using the F-18 high angle-of-attack research aircraft to validate emerging experimental and computational methods for the prediction of high angle-of-attack aerodynamics, flight dynamics, and handling qualities.

Systems analvsis research studies will focus on defining the research and technology requirements for advanced high-speed transport aircraft. Emphasis will be placed on assessing the impact of advanced technologies for reducing engine emissions, sonic boom, and airport noise. The goal of this research is to ensure that future high-speed civil transports will be environmentally compatible with respect to concerns about atmospheric ozone depletion and noise. Advanced supermaneuverability fighter configurations will be analyzed to determine the benefits of advanced technologies in aerodynamics, propulsion, materials, structures, and controls.

Advanced rotorcraft technology activities include airloads and active controls development for a potential *80* percent reduction in noise and vibration and high-speed configuration concepts for speeds of *400* knots and above.

High-performance flight research will continue to concentrate on the application of flight/propulsion controls integration for enhanced mission effectiveness, focused technology development of the most promising advanced short takeoff and vertical landing concepts, and the completion of technology validation flights of the X-29A forward swept wing aircraft. Flight tests of the high angle-of-attack research vehicle (HARV) will establish a flight-validated data base for the development and refinement of analytical, simulator, wind tunnel, and flight research design tools and test methods for the prediction of high angle-of-attack aerodynamics. Detailed design, fabrication, and flight qualification of a thrust vectoring control system will enable the HARV to conduct high angle-of-attack research in FY 1990 at the extreme portions of the flight envelope where future highly maneuverable aircraft will operate.

The advanced composite materials research will be directed toward exploiting new organic-composite materials for use up to 600 degrees Fahrenheit and advanced processing and fabrication concepts for low-cost composite structures. These advanced materials incorporated in innovative structures, such as

geodesic fuselage panels and pultruded wing planks, will provide structural weight savings of 40 to 50 percent. Advanced analysis methods, including probabilistic modeling of composites for improved life prediction and analysis of composite failure mechanisms, will provide essential components of the technology required for the full use of composite materials in advanced aircraft,

Advanced turboprop systems technology efforts will continue to develop the underlying base of computational analysis capabilities and the experimental data base for high-speed (Mach 0.65 to 0.90) propellers. Emphasis will be placed on counter-rotating propeller aerodynamics, acoustics and aeroelastics, including aircraft installation interactions. The goal is to obtain cabin noise and vibration levels equivalent to, or less than, that of a modern turbofan-powered aircraft.

The general aviation/commuter engine research program will provide validated analytical data of the flow phenomena and heat transfer in small compressors, combustors, and turbines that offer the promise of a 40 percent increase in fuel efficiency and up to a 10 percent reduction in direct operating cost in small engines.

The advanced high-temperature engine materials program will focus on the development of metal matrix ceramic fibers and ceramic-ceramic composites. This includes the development of new fibers, matrices, and coatings. Chemical vapor deposition will be utilized to develop small-diameter silicon-carbide fibers that are stable to 3000 degrees Fahrenheit, and ceramic matrix composites will be fabricated that are stable to 2500 degrees Fahrenheit in oxygen. Higher temperature fibers and coatings will be developed for intermetallic and refractory metal matrix composites.

The numerical aerodynamic simulation (NAS) system is now operational. During the next year, the pathfinder high-speed processor number two will be integrated into the NAS system, giving a factor of four improvement in performance. This capability will allow for more detailed numerical simulation of complex flows providing, for example, improved aircraft performance through better propulsion/airframe integration optimization.

BASIS OF FY 1989 FUNDING REQUIREMENTS

RESEARCH AMD TECHNOLOGY BASE

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
		(Thousands of Dollars)			
Fluid and thermal physics research and technology	39,141	25,500	24,600	26,500	RD 13-9
Applied aerodynamics research and technology	55,885	48,900	52,800	64,300	RD 13-13
Propulsion and power research and technology	41,365	35,100	45,800	70,100	RD 13-18
Materials and structures research and technology	35,536	39,400	37,200	40,100	RD 13-24
Information sciences research and technology	23,800	20,500	19,000	23,000	RD 13-30
Controls and guidance research and technology	22,789	25,400	21,200	35,700	RD 13-33
Human factors research and technology	23,954	24,300	20,600	19,700	RD 13-36
Flight systems research and technology	23,134	24,200	24,800	28,800	RD 13-39
Systems analysis	5.507	6.300	5,600	6.000	RD 13-42
Total	271.111	249.600	251.600	314.200	

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Fluid and thermal physics research and technology.....	39,141	25,500	24,600	26,500

OBJECTIVES AND STATUS

The objective of the fluid and thermal physics research and technology program is to advance the understanding of fundamental fluid mechanics phenomena and to develop efficient aerodynamic analytical tools. The research is directed primarily at external aerodynamics and includes efforts in fluid physics, computational fluid dynamics (CFD), CFD code validation, experimental aerodynamics, and viscous flow studies, CFD research is performed to increase the speed and efficiency of three-dimensional flow solvers and for the prediction and simulation of complex fluid flows over aircraft. The validation of prediction and simulation methods is accomplished by means of a coordinated experimental test program with particular focus on accurate three-dimensional turbulent models for attached or separated flows. This activity provides improved insight into the fundamentals of flow physics, as well as the detailed flow measurements required for verification of the computations. Experimental aerodynamics uses wind tunnel and flight testing to derive a data base for the evaluation of analysis methods and for the exploration of advanced aerodynamic configurations. Viscous flow research is conducted with emphasis on developing specific devices and design techniques to reduce overall aircraft drag.

Substantial progress has been made in developing new, more efficient, and more accurate solution algorithms for complex viscous flows and in innovative gridding techniques to resolve the added geometrical complexity of realistic three-dimensional configurations. These new algorithms were tested for a variety of applications, including high angle-of-attack forebody flows, hypersonic vehicles, airfoil stall, engine exhaust jets interacting with ground crossflows, and separated flows over wings. The new gridding techniques were tested for three-dimensional geometries, such as civil transports and the Space Shuttle orbiter with solid rocket boosters. To assess the accuracy and reliability of these new techniques and codes, both computational studies and experimental validation activities are in progress.

Significant advances have been made in the enduring problem of understanding, predicting, and modeling the onset and structure of turbulence. First-of-a-kind simulations of late-stage transition to turbulence, turbulent separation, and turbulent heat transfer have generated previously unavailable, high-resolution data bases. To capitalize on the recent advances in supercomputers, experimental techniques and theoretical concepts, NASA and Stanford University jointly created the center for turbulence research (CTR). The CTR provides a synergistic environment for coordinated computational, experimental, and theoretical research on turbulence physics. Visiting participants include outstanding researchers from universities, government laboratories, and industry.

Critical investigations were identified to be conducted to generate the data for turbulence modeling and code validation. A three-dimensional orthogonal laser velocimeter (LV) has been installed for the basic aerodynamics research tunnel at Langley Research Center as part of the CFD validation program. In addition to the LV instrumentation, hot wire and total pressure surveys have been made to compare accuracies of different instrumentation systems. Vortex breakdown, a complex phenomenon which occurs on high-performance aircraft, is being studied to provide the data needed to validate the CFD codes which predict its onset.

Experimental and analytical aerodynamics research is conducted to identify and analyze innovative aerodynamic concepts and configurations. In experimental aerodynamics, Phase I of the Boeing 767 correlation model tests was completed in the National Transonic Facility (NTF). This model was previously tested in a number of NASA and industry conventional transonic wind tunnels so that the NTF experiment could provide calibration data for these facilities. A leading-edge vortex flap was successfully wind-tunnel tested on an F-106 model and demonstrated low-speed and transonic-speed maneuver improvements. Advanced low-speed and medium-speed, low-drag, benign-stall airfoils applicable to commuter and general aviation aircraft have been developed. High angle-of-attack flow separation control was successfully demonstrated through periodic velocity forcing techniques. A low-altitude unmanned research aircraft configuration was developed utilizing advanced airfoil technology. Such reconnaissance aircraft require special airfoil designs to maximize lift-to-drag ratios and range at low Reynolds numbers. An analytical method was derived for the analysis of Gortler instabilities on airfoils with variable curvature, pressure gradients, and Mach number. These instabilities, which are frequently curvature induced, can lead to premature boundary-layer transition. Juncture flow tests were performed in cooperation with the U.S. Navy for design of a submarine hull-appendage juncture.

Because of the high potential drag reduction payoff of laminar flows, viscous flow research efforts have focused on laminar flow control and natural laminar flow concepts which resulted in the completion of two notable flight tests. In the first, laminar flow control leading-edge systems were successfully tested on a Jetstar aircraft which simulated airline flight operations under varying weather conditions and flight scenarios. Additionally, experiments have been completed on a testbed F-14 research aircraft where natural laminar flow wing contours were tested at various sweep angles. The effects of cross-flow instabilities on boundary-layer transition and separation were determined. These tests, along with wind tunnel investigations and analytical techniques, are being performed to minimize the risk of applying laminar flow technology to transport aircraft. The investigation of complex viscous flow phenomena has been improved by the proof-of-concept testing of the holocinematographic velocimeter, which provides global tracking of fluid mechanisms. Passive friction techniques have been developed for flow separation control downstream of shock/boundary-layer interactions. Uncontrolled separation leads to unwanted increases in form drag. Supersonic viscous flow research has been initiated with preliminary flight experiments on determining the extent of natural laminar flow under actual flight conditions on existing aircraft. These tests provided initial data required to begin development of drag reduction concepts based on laminar flow control at supersonic speeds.

CHANGES FROM FY 1988 REVISED BUDGET

The fluid and thermal physics research and technology program reflects a reduction of $0.9 million, which consists of the realignment of $1.4 million for hypersonic research to other disciplines, offset by an increase of $0.5 million for turbulence research.

BASIS OF FY 1989 ESTIMATE

In FY 1989, the CFD program will capitalize on the recent increases in supercomputer memory and speed to investigate unsteady three-dimensional flows. This capability is required for the analysis of unsteady vortex breakdown, tip vortices, unsteady boundary-layer separation, jet impingement, and tail buffet effects. These physical phenomena are critical to the performance of vehicles which utilize thrust vectoring, high angle-of-attack maneuvers, and swept wing tips. Innovative grid techniques will be utilized to resolve complex three-dimensional flows and multiple bodies for use on the National Aero-Space Plane (NASP) configuration, separation of the solid rocket boosters from the space shuttle orbiter, and stores separation. In addition, the renewed emphasis on high-speed flows for supersonic and hypersonic

vehicles, such as the NASP and high-speed civil transport, will be reflected in increased efforts in high-speed flow phenomena such as chemically reacting flows, real gas flows, rarified flows, and compressible transition and turbulence. Benchmark experiments will continue to be conducted for the acquisition of high-quality data bases as required for the validation of CFD codes.

The experimental aerodynamics research program will use wind tunnel, water tunnel, and flight experiments to complement the analytical aerodynamic developments for complex flows over aircraft components and configurations. Wing/airfoil optimization techniques will be extended from subsonic and transonic speeds to the supersonic regime. Panel aerodynamic methods will be tailored to analyze flows over an F-16 aircraft with tip missiles and under-the-wing fuel tanks, and the advanced turboprop. Advanced computational algorithms will be developed for exploring vortex interactions. Vortical flow aerodynamics plays a dominant role in fighter aircraft high angle-of-attack operation and includes some of the most complex phenomena in fluid mechanics. Cellular formation studies will be initiated for the derivation of separated flow control techniques. Laminar flow tests will be completed in the 8-foot transonic pressure tunnel, and this facility will be restored to its original configuration. This "work-horse" wind tunnel has been dedicated to laminar flow research for a number of years, but will now be utilized for other pressing research needs.

In FY 1989, the viscous flow program will emphasize the reduction of drag at supersonic speeds and the flight testing of a hybrid laminar flow system on a transport aircraft. The reduction of drag translates directly to fuel savings and increases aircraft range. Fundamental flow mechanisms investigations will include the study of turbulent-flow coherent structures and supersonic boundary-layer transition physics. Turbulent skin friction reduction devices, such as surface geometry modifiers, will be explored for the supersonic regime. Other supersonic drag reduction efforts will include supersonic laminar flow, utilizing leading-edge suction flow control, and wave drag research. Vorticity control concepts will be investigated for reducing induced drag (drag due to lift) and for preventing flow separation. Hypersonic stability and boundary-layer transition analyses will be performed to derive transition prediction techniques. Predicting the location of boundary-layer transition is vital in the design of hypersonic vehicles such as the NASP. Hybrid laminar flow techniques, which combine wing leading-edge suction and innovative wing profile contouring, will be flight tested on a full-sized transport aircraft near the end of FY 1989. This research is a cooperative effort between NASA, U.S. Air Force, and industry.

	1987 Actual	1988 Revised Budaet	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Applied aerodynamics research and technology.....	55,885	48,900	52,800	64,300

OBJECTIVES AND STATUS

The objective of applied aerodynamics research and technology is to provide new, validated technology applicable to future U.S. military and civil aircraft from subsonic to hypersonic speeds. The approach is to conduct comprehensive ground and flight experiments involving realistic vehicle configurations and key configuration components. Such work is focused on technology areas expected to render major gains in advanced vehicle performance. Examples of potential gains include 40- to 60-percent gains in transport airplane cruise efficiency for subsonic, supersonic and hypersonic vehicles, a doubling of the productivity and agility of rotorcraft, and a doubling of the cruise and maneuver performance of high-performance airplanes. Products include new analytical and experimental methods needed in the design process and new aerodynamic concepts. This work covers the areas of aeroacoustics and the full spectrum of civil and military air vehicles, including rotary-wing and fixed-wing concepts. Recent progress in key program elements is summarized in the following paragraphs.

Test techniques and instrumentation research is performed to provide essential improvements in NASA's wind tunnel and flight testing capability. Classic limitations of wind-tunnel testing, such as wall and sting interference effects, are being eliminated by adaptive wall and magnetic suspension concepts being used and developed at Langley Research Center. Obtaining an accurate description of an unsteady fluid flow field requires the ability to take a "snapshot" of a large portion of the flow field -- such capabilities are being developed and are referred to as global flow-field measurements where a number of parameters can be measured instantaneously over a large extent of the flow field. Another critical requirement in flow measurements used to check prediction methods is to perform the measurements in a nonintrusive manner and to obtain measurements at very high sample rates to describe rapidly changing flow parameters. Measuring turbulent flow fields has required the development of laser holographic sensing

methods for both measurement and visualization; complementary, sophisticated, high-response sensors have been developed for measuring boundary-layer flows that exist very close to the surface of a flight vehicle. Nonintrusive laser velocimeter systems are being developed for in-flight measurement of wing flow fields. Providing accurate, nonintrusive, rapid-response measurement techniques is critical to achieving confident validation of predictive methods and the performance of new concepts.

Subsonic aerodynamic research has emphasized development of technology €or induced drag reduction and separated flow control to reduce aircraft drag and improve stability and control. Novel approaches to achieving lower induced drag are being investigated in the form of unconventional wing planform shapes (crescent, for example) and sheared wingtip shapes. New nonplanar wing theories and wind tunnel tests are showing that these new wing shapes can yield efficiencies higher than originally thought possible, based on classical planar wing theory. Research continues with benchmark wind tunnel tests and radio-controlled model flight tests using sheared wingtip/crescent wing planform configurations to validate the nonplanar wingtip theory and to determine stability and control characteristics. Additional investigations are required to determine if the nonplanar wingtip theory applies to supersonic as well as subsonic flight. Flight tests are also being conducted to support industry applications of spin resistance technology to new aircraft designs.

Significant advancements have been made in recent years in the development of codes for application to the low-disk-loading rotors of conventional (helicopter, tilt rotor) and advanced rotorcraft. The codes include both fully analytical methods for component analysis and comprehensive semi-empirical methodologies for more comprehensive modeling of rotorcraft aerodynamics and dynamics. While the methodologies will continue to evolve, one of the most important needs for the near term is the experimental verification/validation of these methodologies. Preparations for major experimental activities have been completed, and these experiments will be the focus of the rotorcraft program in the next two years. These activities include both flight and wind tunnel programs, with primary emphasis on the investigation and measurement of unsteady airloads and the related acoustics and vibrations. Recent efforts to develop test hardware and instrumentation will come to fruition beginning in FY 1989. The availability of these experimental tools will enable a multipronged attack on the complex aerodynamic and dynamic environment affecting speed and maneuverability of rotorcraft configurations.

The high-performance (fighter/attack) vehicle technology program is focused in three key technology areas: (1) short takeoff and vertical landing (STOVL), (2) high angle-of-attack (post-stall) maneuverability, and (3) supersonic cruise and maneuver. In the STOVL arena, research is emphasizing powered-lift concepts for hovering, methods to predict the complex flow surrounding a hovering vehicle, and investigation of flight dynamics of transition between hover and forward flight. Studies have been

completed to define the most promising STOVL vehicle concepts, and the key technologies needed are being worked. These STOVL technologies will be used to define the payoff of this capability in future supersonic fighter concepts when integrated with the other essential vehicle capabilities. In the area of high angle-of-attack, both new experimental and new analytical methods are being developed for the prediction and control of the separated and vortex flows which dominate this aircraft flight regime. One new concept for aerodynamic control of advanced fighters was successfully demonstrated on a flying model at the Langley Research Center; this concept for control of the airplane forebody flow is being developed further in preparation for potential full-scale flight tests. These new capabilities will be applied to develop new vehicle and control concepts which will allow advanced, superior U.S. vehicles to push beyond the traditional stall barrier by virtue of increased stability and control. In the supersonic cruise arena, new nonlinear prediction and design methods for advanced airfoils and wing planforms are being developed to provide a doubling of cruise efficiency (including laminar flow) and a doubling of the sustained maneuverability of advanced fighters. New techniques have now been developed which allow the designer to rapidly and accurately define the complex shapes of advanced supersonic vehicles in forms needed to calculate the airplane aerodynamics. This technology will meet the current goals of the U.S. to develop more efficient and survivable supersonic vehicles.

In the area of aeroacoustics research, flight tests to verify and quantify the effects of acoustic fatigue loads on the aft structure of an F-15 aircraft were successfully completed at the Dryden Flight Research Facility. Various methods of decoupling the jet plume dynamics, and thus reducing the resonance effects in twin jet configurations, were also successfully demonstrated. Aircraft components with longer life will result from this work.

CHANGES FROM FY 1988 REVISED BUDGET

The applied aerodynamics research and technology program was increased by $3.9 million. This includes $2.8 million for hypersonic research and $1.1 million to support operations of the National Transonic Facility at Langley Research Center.

BASIS OF FY 1989 ESTIMATE

The development of advanced wind tunnel instrumentation will include the exploration of several new sensing techniques for supersonic and hypersonic flows. Emphasis is placed on these high-speed regimes to support the U.S. initiatives on supersonic and hypersonic vehicles. Concepts to be investigated include infrared boundary-layer transition visualization, micro-encapsulated liquid crystal methods for advanced flow visualization, and laser fluorescence for hypersonic flow sensing. Also, the development of laser

velocimetry to obtain high-response measurements in supersonic shock flows will be pursued. Methods will be developed for three-dimensional adaptive-wall testing in the Langley Research Center 0.3-meter transonic cryogenic wind tunnel. A laser molecular velocimetry system capable of simultaneous measurements (essential to define realistic, time-dependent flows) of velocity, density, and temperature will be demonstrated in the supersonic unitary wind tunnel at the Langley Research Center. The capability to extract the hub impedance for rotorcraft configurations in flight and wind tunnel tests will be developed to allow comparison with predicted forces. These enhancements apply to all disciplines and vehicle types, but they are particularly critical for rotorcraft and other vertical/short takeoff and landing (V/STOL) configurations and for very high-speed supersonic/hypersonic vehicles. These configurations have extremely complex flows that must be carefully measured to extract the pertinent information.

In FY 1989, the emphasis of drag reduction technology will shift toward supersonic speeds. Theoretical and experimental investigations will be conducted to determine high angle-of-attack flutter and stability and control characteristics of sheared wingtip/crescent planform wing configurations. Separated flow control research will examine the formation and control of wing stall cells to provide a method to prevent asymmetric stalls and post-stall spins. Boundary-layer transition will be investigated in flight for all speed regimes, including extension to supersonic speeds; transition physics sensors will be developed; and manufacturing tolerances to enhance laminar flow will be determined to facilitate natural laminar flow applications by the aircraft industry. The validation of these new technologies may follow prior achievements such as winglets and supercritical wings into the commercial marketplace, enhancing the U.S. position in the manufacture of subsonic aircraft.

In FY 1989, major full-scale, experimental activities, aimed at verification and validation of advanced rotorcraft codes, will be conducted. Experimental flight and wind tunnel hardware, instrumentation, and data management capability, which have been under development for the past two years, will be available. The primary activity focuses on a joint Ames Research Center/Langley Research Center/Army/industry experimental flight investigation, with a highly instrumented UH-60 Black Hawk helicopter. The primary focus of this program will be on the validation of hybrid rotorcraft codes which combine comprehensive analyses of the entire rotorcraft with CFD codes for critical rotor azimuth positions for predicting rotor airloads and their resultant effects on aircraft vibration and acoustics. The UH-60 program is a comprehensive effort that will form the basis for much of the validation efforts. Model-scale rotor tests will be completed prior to the flight investigations, and full-scale wind tunnel tests of the rotor will be completed following the flight experiments to provide a complete data base. The UH-60 program will be augmented by specialized experiments for specific configurations and codes, including bearingless rotor configurations, tilt rotor airloads, aerodynamic interaction experiments, rotor/fuselage impedance

experiments, and simulation experiments to upgrade mathematical models for piloted simulations. All of these experiments play a key role in the validation of the next generation of codes that will be critical for advanced rotorcraft design. Future commercial and military rotorcraft, optimized for noise, vibration, maneuverability, and performance goals, will result from these new methods.

High-performance research in the STOVL arena will include a technology program between the U.S. and Canada stressing the controls technology for powered lift and flight control integration, as well as wind tunnel tests of a full-scale advanced powered-lift fighter concept to validate the predicted performance. High angle-of-attack research will provide detailed analytical and experimental predictions of post-stall aerodynamics for validation against flight results obtained from the continuing tests of the NASA high angle-of-attack research vehicle (HARV), and new vortex control and vectoring concepts will be developed and explored in piloted simulations to quantify their ability to provide critically needed control power at high angle-of-attack conditions. Supersonic research will include the development of the vehicle mathematical modeling methods needed to apply new nonlinear aerodynamic analysis schemes to realistic, complex airplane configurations and experiments essential to validate the capabilities of these codes. Future fighter design efforts will depend heavily on such methods to accomplish the increasingly complex integrated fighter design process.

Also in FY 1989, the aeroacoustic research efforts will focus on developing and applying numerical techniques for predicting long-range propagation of low-frequency aircraft noise over realistic terrain features. These calculations and predictions will be verified and compared with long-range propagation experiments to be conducted at White Sands; results will lead to techniques for aircraft noise reduction. An additional focus of the FY 1989 aeroacoustics program will be on the coupling of high-frequency aeroacoustic loads with steady flight loads and thermal loads that will provide an integrated loads analysis to assist in verification of the vehicle's life cycle.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Propulsion and power research and technology.....	41,365	35,100	45,800	70,100

OBJECTIVES AND STATUS

The objective of the propulsion and power research and technology program is to provide the understanding of the governing physical phenomena occurring at the disciplinary, component, and subsystem levels that will support and stimulate future improvements in propulsion system performance capability, efficiency, reliability, and durability. Research is being conducted in a wide variety of subsystems with applications ranging from the general aviation class through the hypersonic aerospace plane. Ongoing disciplinary research on instrumentation, controls, internal fluid mechanics, and aerothermodynamic concepts is providing the foundation necessary for continued advancements at the component and subsystem level. These research efforts will lead to high-payoff propulsion system improvements which have historically provided a major share of aircraft performance advances and also enabled new classes of vehicles.

The objectives of general aviation engine research are to achieve a fuel consumption reduction of 40 percent at cruise power, a power density increase of 30 percent at takeoff power, and multifuel capability for advanced intermittent combustion engine cycles. Research emphasis for stratified-charge rotary engines, which have now demonstrated multifuel capability, includes improved understanding of the combustion process that will enable improvements in engine performance and operating boundaries. As an initial step, an improved computer model of rotary engine flow fields has been developed through the use of detailed rig flow measurements. At a U.S. industry contractor, a single-rotor engine demonstrated improvements of 21 percent in specific fuel consumption and 12 percent in power density. In 1988, higher rate fuel-injection schemes will be tested for faster burn rates as a means to improve the fuel consumption.

For rotorcraft, the objective is to develop small gas turbine technology that enables up to a 40 percent reduction in fuel consumption. Scaling studies of small turbine engine components have been completed, and results used to identify the payoff areas for future research. A new small compressor test facility is now complete and enables the use of laser measurements to define critical flow-field physics. The large, low-speed centrifugal compressor facility is also now operational, and research testing will begin in FY 1988 to investigate boundary layers and secondary flows, and verify advanced three-dimensional viscous flow codes which will guide the improvements of high-pressure ratio per stage, high-efficiency turbomachinery.

For high-performance applications, the goal is to develop propulsion systems technology for powered lift and in-flight thrust vectoring that will lead to improved aircraft short takeoff and vertical landing, and also supermaneuvering capability. The full-scale powered-lift test rig is now operational at Lewis Research Center and was used in 1987 to evaluate the U.S./Canadian ejector concept to obtain total system performance and loss data. Additional testing of this ejector system and initial full-scale testing of one U.S. contractor's ejector system are both scheduled for FY 1988 to determine overall performance viability. Fabrication of a hot gas ingestion model was also completed and testing begun in the low-speed 9x15-foot wind tunnel at Lewis Research Center to determine the extent and effect of hot gas ingestion into the inlet during powered-lift operations. These latter results and additional configuration testing will verify hot gas injection computer codes that are currently under development. Short diffuser inlet testing will also be conducted in FY 1988 to determine performance potential at high angle-of-attack operation desired for supermaneuvering capability.

In supersonic cruise research, the objective is to develop technology for lightweight, efficient propulsion concepts for Mach 2 to 4 operating conditions. Research has been primarily focused on the analysis and experimental verification of the supersonic throughflow fan concept. This component technology offers the potential of 20-percent fuel savings compared to an advanced variable-cycle engine for a long-range supersonic transport-type aircraft. The design of a proof-of-concept fan stage and test rig has been completed using advanced three-dimensional Euler and Navier-Stokes codes. In FY 1988, the rig fabrication will be completed and initial testing of the supersonic inlet and downstream diffuser will be performed without the fan. Complementary research on innovative high-speed propulsion concepts will also be initiated through contracts with industry and academia.

Hypersonic propulsion research has as its objective the maturing of supersonic combustion technology and the study and development of propulsion concepts for high-speed cruise in the Mach 4 and above range. Testing of a Mach 5 small-scale inlet, using flow visualization, verified detrimental boundary-layer migration which had been analytically predicted, thereby guiding necessary incorporation of a bleed system prior to large-scale testing in FY 1988. Additional experimental efforts in FY 1988 include the evaluation of a scramjet module that reduces stresses in the walls of the combustor by transitioning from a two-dimensional inlet to an axisymmetric combustor, an oblique detonation wave concept test that offers significant supersonic combustor length reductions, and combustion contaminant testing to quantify both adverse and potentially advantageous impacts on the combustion process.

Instrumentation and control research is aimed at developing advanced high-temperature sensors and optical nonintrusive measurement systems for research applications and advanced engine sensors and controls for future propulsion systems. An advanced anemometer with the capability to measure detailed flow characteristics very near fixed surfaces has been used to measure near-wall, boundary-layer flow in a turbine facility to verify advanced prediction codes. In the area of high-temperature electronics, progress continued on a silicon-carbide-based diode for 400°C applications, and the material antiphase boundaries were successfully eliminated to further improve silicon crystal quality and electronic characteristics. In FY 1988, a palladium-based 1000°C static strain gage for potential use in engine hot section research work will be demonstrated. A prototype fiber optic position sensor will also be tested in an aircraft turbine engine environment to demonstrate potential application in future fly-by-light systems. An initial advanced short takeoff and vertical landing (ASTOVL) linear control model will be completed and used to establish integrated control methodology concepts.

Internal computational fluid mechanics continues to be an increasingly important tool for understanding flow phenomena and as a basis for improved design capability in aeropropulsion systems. The objective is to develop advanced algorithms and methods for analysis of complex three-dimensional flows in high-speed inlets and nozzles, turbomachinery and chemically reacting flows, and to validate the analytical techniques with fundamental benchmark experiments. An explicit, unsteady quasi-three-dimensional viscous turbomachinery rotor and stator interaction code has been created and its predictive capabililties demonstrated. In FY 1988, a CFD code validation experimental data base, using the large, low-speed centrifugal compressor, will be created and used to compare the ability of the code to model important flow characteristics. Operational capability of a high-speed local area communications network linking additional special purpose internal fluid mechanics experimental and analytical computers to the Lewis Research Center computer system and the numerical aerodynamic simulation (NAS) system will also be completed.

CHANGES FROM FY 1988 REVISED BUDGET

The propulsion and power research and technology program was increased by $10.7 million. The major adjustments included a $5.2 million increase in hypersonic research, $1.5 million for wind tunnel efficiency improvement, and $0.8 million for short takeoff and vertical landing research. An additional $2.0 million has been included for rotary engine research as a result of Congressional action.

BASIS OF FY 1989 ESTIMATE

General aviation engine research activities will continue to focus on advancing rotary engine technology. The structural viability of a lightweight rotor for improved rotary engine power density will be demonstrated through 100 hours or more of testing at speeds to 10,000 revolutions per minute. Analysis of the combustion process through advanced computer modeling will guide improvements in combustion efficiency to enable the fuel consumption goal.

Rotorcraft engine research efforts will continue to concentrate on developing an experimental data base using the large low-speed centrifugal rig, which will be used to validate analytical codes currently in development. Detailed measurements using laser anemometers of boundary layers developed on the rotor, secondary flows, and separated flow regions in both the rotor and diffuser, and the effect of tip clearance on the overall flow structure in the compressor, will be made for future integration with the compressibility measurements in the complementary small compressor test facility. Work will also be initiated on technology development of a small, compact, high-pressure-ratio core concept using close-coupled radial turbomachinery. Benefits of 20 to 30 percent improvement in thermal efficiency are projected, and the concept as conceived also may be integrated with large transport gas turbines for comparable payoffs.

High-performance aircraft research will include an evaluation of a complete computer simulation of a supersonic ASTOVL aircraft and propulsion system to identify the interactions of individual system response rate dynamics. Engine studies that define cycle performance parameters for a FY 1995 technology readiness date (2005 initial operating capability) will be completed, and the most promising of the ASTOVL propulsion schemes will be selected. The capability of a supersonic inlet to operate satisfactorily at extremely high angle of attack will also be demonstrated in a model test for verification of code predictions. To calibrate exhaust gas ingestion codes under development, the experimental data base will continue to be expanded for promising configurations and new concepts. Technology development on variable

geometry components, such as inlets, nozzles, and internal flow control valves, which are critical to powered lift and supermaneuvering capability, will be significantly expanded. Projected performance benefits offered by these components include 25 percent subsonic and 15 percent supersonic fuel consumption reductions, and 15 percent increase in propulsion system thrust-to-weight ratio.

Supersonic cruise research will continue to focus on the supersonic throughflow fan concept. Tests will be completed on the full fan stage (with rotor) during FY 1989 and the results used to verify three-dimensional viscous analysis codes and help guide design refinements and the development of advanced off-design analysis codes. Systems studies will continue to define the critical technologies required for a propulsion system that incorporates a supersonic throughflow fan for high-speed applications. The ongoing work will be accelerated and expanded into the critical areas of airframe integrated inlets and nozzles, supersonic diffusers, compact high-work drive turbines, and lightweight high-temperature heat recovery systems necessary to bring an advanced high-speed propulsion system to fruition.

Hypersonic propulsion activities will continue with development of the analytical capabilities and supporting experimental data base for supersonic combustion and high-speed cruise systems. Code development will focus on the complex flow fields in scramjet combustors, variable geometry inlets and nozzles, and high-speed propulsion/airframe integration which must be understood to achieve system viability. Algorithms for high-speed flows (up to Mach 20) that reduce required computer time will be extended to three dimensions and will also include chemical heat release in order to accurately describe the total propulsion flow-field process. Advanced components to be used in development of a technology data base for improved airbreathing engine concepts will also be defined for future validation testing.

Advanced instrumentation and controls research will continue to be focused on both nonintrusive measurement of flow and high-temperature structural phenomena for code verification, as well as optical sensors and control methodology for propulsion system application. An analytical mechanistic model that predicts the epitaxial crystal growth of silicon carbide for high-temperature electronics will be created and verified to further enhance the repeatability and yield of the process. A four-spot laser anemometer for near-wall measurements will also be used to measure boundary-layer flow to verify advanced codes now being developed. In the controls area, an initial analytical model of a reconfigurable control expert system will be completed and exercised to guide the development of intelligent fault-tolerant logic. Development of the ASTOVL linear control model and integrated control methodology concepts will also be continued to improve system logic based on predicted response rate interactions from the combined aircraft and propulsion system simulation.

Research emphasis in internal computational fluid mechanics will continue on advanced prediction capabilities for high-speed propulsion. For both existing codes and new codes under development, predictions of the aerodynamic flow field will be expanded to include both chemical reaction and heat transfer to yield the capability of describing the total process taking place within a propulsion system. A three-dimensional Navier-Stokes analytical code with predictive capability for high-speed aerodynamics and heat transfer in inlets, ducts, and nozzles will also be demonstrated. Work will be initiated for the demonstration of instrumentation and data acquisition systems necessary for making nonintrusive, three-component, unsteady velocity measurements in complex flow fields, including separated regions. Work will also begin on turbulent reacting shear-layer flow-field validation experiments, with results used to determine the predictive accuracy of a three-dimensional Navier-Stokes code. Design of multistage axial research airfoils will also be completed for future testing in the large, low-speed test facility to complement the centrifugal compressor test data base now being developed.

	1987 Actual	1988 Revised Budeet	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Materials and structures research and technology.....	35,536	39,400	37,200	40,100

OBJECTIVES AND STATUS

The objectives of the materials and structures research and technology program are to: (1) develop and characterize advanced metallic, ceramic, polymer, and composite materials; (2) develop novel structural concepts and design methods to exploit the use of advanced materials in aircraft; (3) advance analytical and experimental methods for determining the behavior of aircraft structures in flight and ground environments; and (4) generate a research data base to promote improvements in performance, safety, durability, weight reduction of up to 40 percent, and reductions in aircraft life cycle cost. Areas of emphasis include high-temperature engine and airframe materials and structural concepts, composite materials application, life prediction, thermal and dynamic response including aeroelasticity, helicopter structural dynamics and airloads, and more accurate and efficient integrated design optimization methods for airframes and engines.

Research in turbine engine materials continues to create a strong technology base for ceramic materials applications up to 3000 degrees Fahrenheit with increased reliability and reproducibility. Toughened silicon-nitride ceramic composite materials with improved strength at high temperatures have been fabricated by a new slurry pressing processing method. The objective of the FY 1988 program is to identify critical processing variables controlling reliability, creep strength at elevated temperature, and toughening mechanisms for silicon-carbide and silicon-nitride ceramics. A major new emphasis on ceramic composite materials was initiated in FY 1988 as part of an advanced high-temperature engine materials program. The development of ceramic composites is expected to provide a materials system that is of sufficient strength and durability to have a wide range of design applications in advanced turbine engines, including high temperature blades and vanes.

In aircraft materials research, studies are being conducted in advanced composite materials to develop new, lightweight composites for high-temperature airframe and engine applications. A new thermoplastic polyimide, identified as LaRC-TPI, has been developed by Langley Research Center for use up to 450 degrees Fahrenheit with improved processability and high-temperature properties. This material is currently being evaluated by the airframe industry for potential future applications in advanced aircraft. Significant advances have been made in developing materials and processing methods for superplastic forming of aluminum alloys to achieve a 35 percent cost savings and 25 percent weight savings compared to conventional aluminum airframe construction. High-temperature intermetallic structures for airframe and propulsion systems have been fabricated using a new bonding process to demonstrate feasibility of lightweight structures for use up to 1800 degrees Fahrenheit. New processing methods for hot-forming, pultrusion and filament winding of composite airframe structures have been developed to demonstrate the potential for major reductions in fabrication cost of composite structures.

Computational structural mechanics (CSM), a major thrust in FY 1988, continues to focus on the development of advanced structural analysis and computational methods that exploit advances in computer hardware and software, such as multiple processors and parallel processing capability. CSM computational test models have proven to be an effective means to accelerate development of new computational methods and the exploitation of advanced computer technology. Advanced CSM methods are essential to permit efficient design and analysis of complex structural configurations and loading environments, such as composite strucutres, high-temperature structures, fluid-structure interaction and prediction of nonlinear structural response including post-buckling of airframe structures. CSM technology will be directed toward developing analysis methods for very large, complex structures requiring the latest and most powerful computer technology.

Research in aircraft structures emphasizes the development of design and analysis technology €or efficient damage-tolerant advanced composite structural components and innovative structural concepts to achieve reductions in structural weight of 50 percent and cost reductions of at least 25 percent through low-cost fabrication methods. Thermomechanical structural analysis using probabilistic modeling concepts to predict reliability of engine structural components has been developed for high-temperature complex engine structures. Interdisciplinary design methods, including design optimization, will be developed and compared in a joint NASA/industry program to assess optimization methods for aeroelastic designs of advanced wing configurations. Analytical and experimental methods will be developed to predict structural loads due to intense acoustic radiation resulting from interaction of jet exhaust plumes. Significant

accomplishments include the development and evaluation of a filament-wound composite spar and a pultruded composite wing panel, evaluation of high-temperature properties of intermetallic structures for airframe and engine application, and performance and analysis of a crash dynamics test of composite fuselage structures.

In the aeroelasticity program, new and more efficient unsteady aerodynamic computational methods, with emphasis on transonic flow, have been developed and verified experimentally. A comprehensive transonic unsteady aerodynamics computer code for complete aircraft modeling has been released to the Department of Defense (DoD) and industry for evaluation. The FY 1988 objective is to complete the code verification for this flutter analysis capability for complete aircraft configurations. Actively controlled flexible-wing concepts will continue to be evaluated in the transonic dynamics tunnel to explore the potential for reducing the maneuver loads with at least 30 percent improved roll rates. Flexible-wing concepts can provide a major advance in future high-speed aircraft design through improved performance and reduced structural weight.

In rotorcraft research, analytical models of interactions between rotor vortex and rotating blades are being developed to predict airloads and acoustic levels generated in forward flight. Tests of blade-vortex interaction (BVI) are planned for an S-76 rotor in the NASA 40x80-foot wind tunnel. BVI noise reduction concepts will be explored by conducting definitive experiments in low-noise rotor systems in the transonic dynamics tunnel. Tilt rotor acoustic prediction methods will be validated by wind tunnel and flight test data to be acquired in FY 1988. Low-noise tail rotor designs and analytical models of main rotor/tail rotor noise interaction will be developed to provide a basis for advanced rotorcraft with reduced rotor noise.

Hypersonic research continues to explore innovative new materials and structures concepts for airframe and propulsion systems for advanced aerospace vehicles. Current research is directed toward development of new lightweight materials systems and structural concepts that will withstand the extreme high temperature and loads encountered in the hypersonic flight regime. Scramjet strut test specimens will begin wind tunnel tests in FY 1988 to validate various structural concepts and materials systems for actively cooled structures. Hypersonic materials research on carbon-carbon fiber-reinforced material will be directed toward developing improved coating systems to reduce oxidation and on processing methods for improved thin gage high-temperature material properties. Carbon-carbon structural concepts for hypersonic control surfaces are being explored to determine the feasibility of using these composite systems for long-term applications. Analytical thermal/structural models will be developed to determine thermal effects on structural joints and stiffness, and an assessment of high-temperature effects on vehicle aeroelastic response will be made.

CHANGES FROM FY 1988 REVISED BUDGET

The materials and structures research and technology program reflects a decrease of $2.2 million, including $1.8 million for hypersonic research, which was realigned to the propulsion research and technology program, and a general reduction of $0.4 million to cover other high priority program requirements within the research and technology base.

BASIS OF FY 1989 ESTIMATE

Research on materials will concentrate on advancing the understanding of material behavior, properties, microstructures, and processing parameters for advanced metallic, ceramic, polymer, and composite materials with primary emphasis on high-temperature application. New and tougher resin/fiber composites, high-temperature polyimides (700 degrees Fahrenheit), carbon-carbon composites, intermetallic aluminides, and aluminide matrix-silicon carbide composites will be developed. Work on powder metallurgy and weldable superplastic forming techniques for aluminum will continue with greater emphasis. Fundamental material behavior and processing techniques for ceramic materials will be pursued. Generalized, multiaxial constitutive models for composites will be developed for prediction of environmental effects, high-temperature cyclic damage, and loading rate dependence.

Composite materials and structures research will continue to focus on development of advanced cryogenic composite materials systems for airframe and engine applications as well as analysis methods for structural life prediction. Analytical and experimental studies will concentrate on understanding failure mechanisms and developing improved methods for analysis of complex composite structures. New structural concepts such as pultruded wing panels will be examined through structural tests to verify performance of low-cost composite structures and identify failure modes of complex skin-stiffened panels. A major program initiative in advanced composite materials is planned for FY 1989 to focus on development of new composite materials, innovative structural concepts and advanced fabrication methods that fully exploit the benefits of advanced composite materials. The composites base research and technology program will provide the fundamental foundation for understanding failure mechanisms and fiber/matrix interactions that will then establish a basis for the innovative structural concept design program.

The dynamics and aeroelasticity program will emphasize the development of improved analytical tools for predicting 3-D unsteady aerodynamic loads for transonic flow for total vehicle configurations. This 3-D analysis capability is needed to enable accurate prediction of flutter boundaries for complex aircraft configurations including effects of external stores. Propulsion aeroelasticity programs will focus on

supersonic flow-through and counter-rotating turbomachinery research. New airfoil concepts, such as the flexible actively controlled wing that includes large-scale component development test and analysis verification, will be explored through wind tunnel testing to measure the expected reductions of up to 30 percent in maneuver loads and improved roll rates (30 percent) provided by this concept for high-performance aircraft applications.

Integrated analysis and design optimization efforts will concentrate on development of efficient methods in CSM for the analysis of complex aerospace vehicles and propulsion systems. The emphasis on innovative design concepts including minimum gage composite material systems for lightweight structurally efficient systems and the complex loads environment future aircraft vehicles experience requires a significant improvement in current structural analysis capability. Current analysis requirements are generally limited to linear elastic behavior but future missions and performance needs will require more detailed nonlinear structural prediction capability. Emphasis will be placed on nonlinear analysis of high-temperature engine structures, transient dynamics analysis of local/global airframe analysis and probabilistic analysis of complex engine components. Nonlinear analysis methods will be developed for large displacement of postbuckled composite panels required for new innovative fuselage and wing structures. CSM analysis methods development will continue on concurrent computing methods using multiple and parallel processing to enable implementation of solution methods for complex 3-D structures that cannot be achieved on conventional serial processing computers. CSM research will focus on developing solution methods for large, complex, structural analysis problems requiring the newest most powerful computer technology. Design optimization research will concentrate on development and comparison of optimized aeroelastic wing configurations and analysis methods for high-performance aircraft. The overall objective is to develop the next generation of new analysis methods required to effectively design future airframe and propulsion systems subjected to the complex thermal, mechanical and acoustic loads environment future aircraft vehicles will experience.

Subsonic transport, commuter airplane, and general aviation aircraft research will be focused on developing analytical models and conducting experimental studies to improve aircraft ground operations and crashworthiness. Composite fuselage structures will be evaluated for crashworthiness in the NASA crash facility to examine energy-absorbing composite structural concepts. The NASA/U.S. tire industry modeling program will continue to develop models for tire wear including contact models for various tire configurations. Advanced tire testing on radial-ply tires for military and commercial aircraft and wear models will be developed to predict performance of aircraft tires and improve safe operations.

Rotorcraft research will continue to concentrate on developing experimental and analytical methods for airloads and structural dynamics analysis of rotor systems and airframes. In FY 1988, transonic dynamic wind tunnel tests will be completed on tapered rotor blades with advanced airfoil sections to develop improved performance rotors for advanced rotorcraft. Vibration, aeroelastic stability, and performance investigations of tailored bearingless rotors with advanced airfoil sections will be continued to develop advanced rotor structures with improved life and reduced structural noise. A comprehensive analysis code for prediction of full system helicopter noise (ROTONET) will be completed and transferred to industry.

Hypersonic materials and structures research will continue to be a major emphasis in FY 1989. Innovative concepts to enable future high-speed, high-temperature aerospace vehicles will continue to be developed. Integrated flow/thermal/structural analysis methods will be used for accurate mission loads prediction to aid the development of lightweight, efficient, and durable design of airframe and propulsion systems. New materials concepts for scramjet struts will be evaluated to determine the high-temperature performance of actively cooled hot structures. Additional focus will be on intermetallic composites and carbon-carbon reinforced materials; constitutive behavior and characterization of high-temperature, lightweight composites; fabrication of intermetallic composites with low-density matrices; and oxidation-resistant and thermal barrier coatings. This will then provide the technology basis for development of design concepts for wing/fuselage structural configurations that are radically different than conventional skin/stringer/frame design concepts used today.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Information sciences research and technology.....	23,800	20,500	19,000	23,000

OBJECTIVES AND STATUS

The objectives of the information sciences research and technology program are to provide the fundamental capabilities to: (1) exploit advanced computer architectures to meet NASA's unique computing requirements, (2) increase the agency's ability to develop high-quality aerospace systems software, and (3) provide the advanced theory, concepts and capability to effectively use and manage aerospace information. Effective exploitation of computational modeling of physical processes, such as computational fluid dynamics (CFD), will be enabled through the development of a fundamental understanding of the relationship between physical algorithms and advanced parallel processing architectures. Research on the theoretical foundations for managing complex software systems and on the development and validation of reliable software is directed toward improving the quality and cost of complex mission-critical hardware and software.

Parallel processors offer the potential for enabling numerical simulation at affordable costs. Evaluating performance of parallel processors is an important problem to both computer system architects and application developers. A performance prediction method has been developed which is based on a graphical representation of the computational processes. This new method allows quantitative assessment of network queues, task residence times, and utilization of resources in a proposed concurrent processing system. These tools are expected to be useful in evaluating different concurrent architectures, and in the detection of bottlenecks in hardware and software, as well as in the comparison of task allocation and partitioning schemes.

A new concept in distributed operating systems has been developed this year. This distributed operating system is based on the concept of "objects," computer code or data, which users manipulate via "processes" and "transactions." The distributed operating system is operational on a cluster of VAX 750 computers. It provides the user with the capability to perform distributed computing tasks with no concern for machine boundaries.

The software automation generation and administration (SAGA) tool has been developed at the University of Illinois to improve the reliability and cost of mission-critical software. The SAGA software engineering environment supports the concepts of development by incremental refinement, executable specifications, and formal verification. The most promising software development methodologies are being incorporated in the NASA software acquisition life cycle and documentation standards which govern all NASA software projects.

The visual comparison of experimental and computational results is an important problem to the field of computational fluid dynamics (CFD). A new technique has been developed to digitize and store experimental holographic interferogram data and to extract, scale, color code, and overlay computational density contours from a CFD program. Methods to effectively compare experimental and computational results will provide a better understanding of the physics being investigated and contribute to the validation of CFD codes.

The high-speed mainframe computer networking subsystem continues to provide NASA aeronautical researchers remote access to the agency's mainframe computers. The system supports transmission rates up to 1.5 million bits per second from NASA's geographically distributed research centers.

CHANGES FROM FY 1988 REVISED BUDGET

The $1.5 million reduction in the information sciences research and technology program is part of a realignment of research and technology base funds to support priority work primarily in the areas of turbulence research and transonic wind tunnel testing being conducted in other disciplines.

BASIS OF FY 1989 ESTIMATE

Research on the use of novel parallel processors controlled by new algorithms for efficient numerical simulation will continue at the Research Institute for Advanced Computer Science (RIACS) located at Ames Research Center. A family of parallel processing computers will be utilized for this research, including a Sequent Balance, Intel Hypercube, Connection Machine 2, and Convex C1. Performance of special purpose CFD computers, including a systolic processor and the Navier-Stokes machine, will also be evaluated. These experimental parallel processors are comprised of a large number of very low-cost computers grouped to attack a computer problem, as opposed to the single very high-speed supercomputer approach typically employed. This research will address other aerospace applications of parallel processing including computional structural dynamics and vision research.

Research in sparse distributed memory, developed as a mathematical model of human long-term memory with the properties of associative recall, will continue. The ultimate capability of such a memory could include computer vision and natural language. A hardware simulator will be developed and evaluated in a number of aerospace application studies. One set of evaluations will include the study of how effectively the computer can be trained to recognize characters.

In the area of software engineering, studies will quantify the reliability gained from formal specification, software prototyping, computer-aided software engineering systems, software reuse, and formal verification. The approach of algorithm diversity appears promising and will be evaluated for a reasonably complex aeronautics control problem, The block grant for the Illinois Computing Laboratory for Aerospace Systems and Software will address characterization and evaluation of automated support tools for increased reliability in software specification and design.

NASA will continue to support the operation of the computer networking system to provide for the effective and productive use of NASA's distributed computing resources. NASA will continue to work through the Federal Coordinating Council on Science, Engineering and Technology to coordinate national access to high-performance computers.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Controls and guidance research and technology.....	22,789	25,400	21,200	35,700

OBJECTIVES AND STATUS

The controls and guidance research and technology program will provide a technology base supporting future aircraft designs which will be capable of safer and more efficient operation and will have greatly expanded flight envelopes. In order to provide this technology base, the specific ojectives of the controls and guidance program are: (1) exploit emerging controls, guidance, and artificial intelligence technologies for the development of advanced automation concepts; (2) development of highly reliable system architectures and validation methods leading to flight-crucial systems; (3) development of sensors for airborne wind shear detection and flight management avoidance techniques; (4) development of advanced control, guidance and display theories, concepts, and analysis methods; and (5) development of new methodologies for achieving multidisciplinary integration.

Knowledge-based control and guidance concepts have been shown to be feasible for both improving system performance and for improving crew-vehicle interface. Extensive simulation studies examining advanced time-based traffic management concepts were conducted and a preliminary series of flight tests was completed. The results of these tests indicate more accurate arrival times can be achieved, leading to airport capacity increases. A controller advisor and expert system schedule advisor have been evaluated in air traffic control simulations by Federal Aviation Administration (FAA) controllers in preparation for upcoming flight evaluations at Denver. The use of data link for the automated transmission of flight clearances has also been evaluated in simulation. These automation aids will improve controller workload in peak traffic situations. Concepts for automated, real-time mission planning have been identified and are being evaluated for application to rotorcraft all-weather, nap-of-the-earth flight.

A candidate system architecture for highly reliable, integrated airframe/propulsion control systems for high-performance aircraft has been established. Advanced analytical and experimental validation methodologies are being used to assess the reliability and performance of this architecture which will enable more efficient and higher performance in future aircraft. Lightning characterization studies

resulted in the definition of lightning wave forms which have been adapted as a Society of Automotive Engineers (SAE) standard for evaluating the effect of lightning on avionic systems. Initial planning for a research program to develop validation and verification methods for knowledge-based systems is underway. These methodologies will be required for the flight-critical application of future knowledge-based expert systems.

An analytical wind shear model has been developed, validated, and transferred to industry for use in simulation studies and in evaluating candidate detection and warning system characteristics. Design requirements for an experimental doppler radar wind shear sensor have been defined and the flight experiment plan developed. Sensor technology to be used with an aircraft hazard index for determining the severity of wind shear in front of the aircraft was developed, evaluated, and transferred to industry. Energy-based guidance techniques for wind shear recovery were developed and evaluated in simulation.

Innovative flight test techniques for the real-time evaluation of in-flight stability levels were developed and utilized in the X-29 flight test program, resulting in greatly reduced costs and flight test time. A study was completed which identified deficiencies in control power which exist for a class of generic hypersonic aircraft. Innovative approaches to overcome these deficiencies through the use of thrust modulation, pop-out surfaces, and other new types of force generators are being explored. A high-fidelity fighter simulation model, incorporating nonlinear, unsteady aerodynamics, structural dynamics, and thrust vectoring, has been developed for use in exploring advanced multidisciplinary concepts for supermaneuverable aircraft.

CHANGES FROM FY **1988** REVISED BUDGET

The *$4.2* million decrease in controls and guidance research and technology reflects reductions in flight crucial systems, electronics research, and other general reductions required for hypersonic research, wind tunnel testing support, advanced propulsion systems research and flight research activities being conducted within other research and technology base disciplines.

BASIS OF FY **1989** ESTIMATE

Beginning in FY 1989, approximately $10 million for operations and maintenance of simulation facilities at the Ames Research Center has been realigned to this program from human factors research and technology to more appropriately reflect the contributions of these facilities to this discipline.

Increased emphasis will be placed on development of automation concepts leading to enhanced safety and productivity in the national airspace system. Flight evaluations of the controller advisor and expert schedule advisor will be conducted jointly with the FAA at Denver's Stapleton Airport, allowing reductions in controller workload and more efficient handling of air traffic. Also in cooperation with the FAA, the feasibility of using advanced display concepts and operational procedures for close-spaced parallel and converging runways will be evaluated in flight at the Raleigh-Durham Airport. If successful, these tests could lead to an increased number of operations under instrument meteorological conditions at a number of major airports. Full mission simulations incorporating near- and far-field planning and advanced control and guidance concepts enabling rotorcraft nap-of-the-earth flight in all weather conditions will be conducted.

Experimental validation of methodologies for predicting effects of lightning on aircraft avionics will be conducted in Langley Research Center's avionics integration research laboratory (AIRLAB), utilizing a digital jet engine controller. An analytical program allowing the prediction of lightning interactions with aircraft systems will be made available to industry through the Computer Software Management Information Center (COSMIC). Increased emphasis will be placed on the development of validation methods for flight-crucial systems. These methods will be required prior to in-flight use of expert systems requiring high levels of reliability.

In FY 1989, development of the experimental radar scatterometer for flight evaluation of airborne wind shear sensing will be initiated. Adaptive guidance algorithms for the avoidance of, and recovery from, wind shear encounters will be evaluated in simulation studies.

Emphasis in guidance and display technology will be placed on improving the situational awareness of the flight crew. Materials and fabrication techniques enabling practical-sized, color, thin-film electroluminescent displays will be evaluated. Investigations of alternate formats and crew input-output techniques for a large-screen "whole-flight-deck" display concept will be conducted. Control algorithms leading to greatly enhanced maneuverability will be evaluated in a wind tunnel test of an advanced fighter design featuring a highly flexible, lightweight, wing design.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Human factors research and technology....	23,954	24,300	20,600	19,700

OBJECTIVES AND STATUS

The objective of the aeronautical human factors research and technology program is to provide the capability to design effective crew-cockpit systems using advanced cockpit automation technologies which will properly integrate the diverse systems, operators, and procedures within the mission requirements and environment. This is necessary for safety, productivity, efficiency, and increased effectiveness in advanced commercial and military aircraft, rotorcraft, and the national aero-space plane (NASP) program. Human capabilities and limitations of crew personnel and their interactions with systems, components, procedures, and flight requirements are determined and refined in order to delineate guidelines. These guidelines provide the roadmap to understand haw to integrate the crew with automation technologies in the cockpit. There are four areas of emphasis: (1) flight management, (2) human engineering methods, (3) rotorcraft, and (4) subsonic transports.

In the flight management research program, automation devices currently in use in cockpits were evaluated to determine the extent of situational awareness maintained by the flight crews. An expert system, called Faultfinder, was developed and evaluated to provide early detection of engine failures and recommended alternatives for safe flight operations.

The effects of wind shear were quantified and piloting techniques for recovery and escape evaluated by simulation. This information resulted in the development and verification of a wind shear hazard index which provides a standard by which wind shear at different sites and under different conditions can be evaluated. A full-mission simulation of the FAA traffic alert and collision avoidance system (TCAS) was conducted using pilot evaluation. A comprehensive set of conflict scenarios was investigated in a safe, controlled, but realistic, research setting. The initial research results demonstrated significant potential for increased safety in flight, and also identified additional areas of study to eliminate other problems in operational conditions.

Human factors research to support advanced military and civilian rotorcraft has resulted in a mission-oriented aircrew/aircraft integration simulation capability. This system allows rapid cockpit reconfiguration by the analyst at his/her desk to assess different combinations of personnel (anthropometric values), advanced displays and controls, and mission requirements. Night vision requirements for rotorcraft crews were translated into specific flight procedures to overcome existing problems in night operations. Both in-flight tests and simulator tests were conducted to support these procedures.

CHANGES FROM FY 1988 REVISED BUDGET

The $3.7 million decrease in human factors research and technology reflects a research and technology base realignment to support higher priority hypersonic and propulsion efforts within other research and technology base disciplines.

BASIS OF FY 1989 ESTIMATE

Beginning in FY 1989, approximately $10 million for operations and maintenance of simulation facilities at the Ames Research Center has been realigned from this program to controls and guidance research and technology to more appropriately reflect disciplinary support of this activity.

A new program initiative in human factors will begin as part of a special effort in aeronautical safety. Two purposes are to provide: (1) increased emphasis on optimal integration of humans and automated systems to reduce threats to aviation safety and (2) decision aids and flight crew/air traffic control (ATC) system support systems, especially for contingency operation. Research in the human factors program will continue to serve NASA's needs for identification of the effects of automation technologies in the cockpit. Development of design principles for the human-automation interfaces in intelligent, error-tolerant flight systems is a major focus. Pilot simulations to evaluate the onboard engine fault monitoring and diagnosis expert system, Faultfinder, will be conducted to qualify the benefits and to examine crew interface. The evaluation of new, improved strategies and procedures will be continued in order to verify automated flight decks and their usefulness and safety aspects in maintenance of full situational awareness.

Application of human performance measurement methods to high-risk rotorcraft flight environments and missions will continue, and results will be applied to police and medical evacuation rotorcraft operations. The computer-based rotorcraft aircrew/aircraft integration analytical tool will be expanded to support the predictive design and human engineering of Army rotorcraft cockpit systems.

Evaluation of human factors issues in operational use of TCAS will continue with particular attention to TCAS involved and excessive altitude deviations which could prove problemmatic. Aviation safety reporting system research activities will continue to examine incidents involving operational errors in the ATC system, pilot deviations and near mid-air collisions, and air carrier operations impacted by minimum equipment list issues. In-flight data collection and pilot simulation studies will be conducted to establish certification criteria for long-haul transport operations.

	1987 Actual	1988 Revised Budeet	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Flight systems research and technology...	23,134	24,200	24,800	28,800

OBJECTIVES AND STATUS

The objective of the flight systems research and technology program is to provide the necessary research and technology development for an improved and validated base of advanced technology for application by industry to future generations of the entire spectrum of aircraft. In many cases, joint funding is provided by NASA, the Department of Defense (DoD), and the Federal Aviation Administration (FAA). The program is organized into the following categories: (1) aviation safety; (2) flight instrumentation and test techniques; (3) fighter/attack aircraft; and (4) flight support. The activities within this program encompass advanced engineering techniques and the establishment of the feasibility of concepts to ensure rapid application of promising new technology essential to meeting one or more of the following goals: (1) reducing aircraft accidents resulting from weather effects (heavy rain and icing); (2) improving flight efficiency, enhancing data accuracy, and enabling the acquisition of needed information; and (3) establishing a technology base for the design of future fighter aircraft with unprecedented maneuverability at high angle-of-attack (up to 90 degrees) flight conditions and vertical landing capability.

The objectives of the activities in aviation safety are to provide a better understanding of aeronautical safety hazards and their consequences and to provide criteria for design of aircraft systems and operating techniques. The present effort involves the development of analytical models to predict ice accretion and its effects on aircraft handling qualities and airfoil performance for both rotary- and fixed-wing aircraft and development of ice protection concepts.

During FY 1988, the test of the composite wing section with an intercalated graphite thermal deicing system is being conducted in Lewis Research Center's icing research tunnel. In addition, a flight test program investigating the effects of artificial ice shapes on aircraft stability and control is being conducted. A design report on the electromagnetic impulse deicer system will also be published. In the

area of heavy rains, a full-scale wing section is being tested using the aircraft landing dynamics facility with a spray rig assembly straddling the track. The test data will be used to assess the aerodynamic performance penalties due to heavy rain effects.

The objectives of the flight instrumentation and test techniques activity are to improve flight test efficiency and information accuracy by using innovative techniques and devices to obtain needed data.

The objectives of the fighter/attack aircraft activities are: (1) to refine and validate aerodynamic predictive tools at high angle-of-attack flight conditions and demonstrate the performance benefits and utility of propulsive flight control and (2) to develop efficient concepts for advanced short takeoff and vertical landing aircraft. A technology development program for advanced short takeoff and vertical landing (ASTOVL) aircraft is being conducted under a memorandum of understanding with the United Kingdom, DoD, and NASA. A series of propulsive-lift concepts has been studied and assessed to determine which of the most promising concepts should be pursued into detailed technology development/validation phases. The objective of this collaborative program is to bring the most critical ASTOVL technologies to a state of readiness by the mid-1990's.

The objectives of the flight support program are to provide a variety of support services to flight research projects using standard aircraft for chase, airspeed calibration, remotely piloted research vehicle air drops, and flight crew readiness training. Replacement of the aging F-104 high-performance support aircraft at the Dryden Flight Research Facility with Navy-loaned full-scale development F-18 aircraft is continuing.

CHANGES FROM FY 1988 REVISED BUDGET

The flight systems research and technology program reflects an increase of $0.6 million in support of in-house research costs required to support critical flight research activity.

BASIS OF FY 1989 ESTIMATE

In FY 1989, the aviation safety program will emphasize coordinated wind tunnel and analytical investigations of the effects of ice accretion on rotary-wing aircraft performance and handling qualities. Data from the full-scale wing section tested in the aircraft landing dynamics facility will be available. This wing section will have been propelled along a track through an overhead water spray system simulating heavy rain. This data base will yield an understanding of the effects of heavy rain on aerodynamic performance.

Wind tunnel and analytical research will be conducted to investigate the potential benefits and the aerodynamic, propulsion system, and structural interactions resulting from multiaxis thrust vectoring at high angle of attack. Simulator and design studies will be completed to establish a data base for potential integration of aerodynamic and propulsive flight controls on the NASA F-18 high angle-of-attack research vehicle. In the U.S./United Kingdom ASTOVL program, activities will be initiated on the most promising aircraft concepts identified by the design studies completed in FY 1988.

During FY 1989, in the flight instrumentation and test techniques area, a flight test of the basic computer module for an advanced airborne information management system will be conducted. Also, an advanced flight test instrumentation package for measurement of pressures, temperatures, and aircraft motions will be assembled using newly developed sensors and systems.

Flight test support of flight research projects will continue using a variety of both fixed- and rotary-wing aircraft. These high-performance support vehicles will be flown as chase aircraft in support of research aircraft described under high-performance aircraft systems technology (X-29A, F-15, F-18, YAV-8B) and rotorcraft systems technology (X-wing, XV-15 tilt rotor). Also included during this period will be specialized training for critical personnel, as well as maintenance of flight data facilities, aircraft instrumentation, and flight data processing.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Systems analysis.....	5,507	6,300	5,600	6,000

OBJECTIVES **AND** STATUS

The objectives of the systems analysis effort are to identify and quantify the impact of emerging technologies in aerodynamics, materials, structures, propulsion, and systems that can lead to new plateaus or major improvements in civil or military aircraft of the future, create new markets, reduce noise and environmental impact, and provide potential new economic benefits. Conceptual designs are performed incorporating new technologies, and sensitivity analysis and tradeoff studies are conducted to quantify the benefits of the emerging technologies.

Systems analysis studies of transport aircraft concentrated on the impact of ultra high-bypass propulsion systems for improving the efficiency of large (500-passenger) long-range transport aircraft. These propulsion systems offer the potential of reducing fuel usage by 20 to 25 percent compared to conventional turbofan engines. Also, the benefits are being assessed for the application of superconductivity to general aviation, commuter, and subsonic transport propulsion and control systems. If electric motors and generators can be made to be very lightweight and powerful through the use of superconductivity, the conventional propulsion and control system could be revolutionized.

In FY 1988, systems analysis for rotorcraft is concentrating on advanced configurations and propulsion systems for high-speed tilt rotors and helicopters. High-speed rotorcraft has the potential application in the civil market to efficiently transport passengers between the downtown city and remote airports and, in the military market, to transport both troops and equipment to remote battle locations and to perform air combat missions. Computer conceptual design codes are being improved so that the benefits of new technologies to alternative high-speed rotorcraft configurations can be quantified. These codes have been and will continue to be used both by NASA and the Army as part of the V-22 joint technology assessment study.

A major study effort is in progress to identify the most promising vehicle and propulsion system concepts for high-speed civil transportation (from Mach 2.0 up to Mach 25). The studies show that commercial supersonic passenger transportation can be economically viable for a 300-passenger, 6500-nautical-mile high-speed civil transport. Also, the studies show that these advanced vehicle concepts could only be enabled by the development of advanced technologies. The studies, performed by two major aircraft manufacturers with propulsion systems manufacturers as subcontractors, address advanced vehicle concepts enabled by emerging technologies, including those from the national aero-space plane (NASP) program. Sensitivity studies are in progress to assess the benefits and technical risk of configuration options in terms of civil airline operations. To augment the contractual studies, in-house studies are being performed in the following key opportunity and problem areas: sonic boom, community noise, environmental impact, airframe propulsion integration, and fuels. In FY 1988, the concept feasibility is being developed and potential benefits assessed for an advanced supersonic throughflow fan engine capable of powering a supersonic civil transport. The concept has the potential of a 12-percent efficiency improvement over a conventional turbofan engine for this application.

Systems analysis for high-performance aircraft in FY 1988 focuses on advanced short takeoff and vertical landing (ASTOVL) aircraft. As part of a cooperative U.S./United Kingdom program, five conceptual configurations developed by contractual studies have been normalized for evaluation, and the down-selection is in progress. The focus for the technology development will be on the selected configuration. Preliminary investigations are in progress for the potential aeropropulsion application of superconductivity to highly maneuverable fighter aircraft. These concepts offer the potential of having remote electric propulsion systems for active aircraft control and enhanced maneuverability.

CHANGES FROM FY 1988 REVISED BUDGET

The $0.7 million decrease in systems analysis primarily reflects a realignment of hypersonic research previously in this program to the propulsion and power discipline within the research and technology base.

BASIS OF FY 1989 ESTIMATE

In FY 1989, studies to identify specific high-payoff technologies and associated benefits for ultra-high-bypass engines suitable for large long-range transport application will continue. By incorporating advanced technologies in the core of these propulsion systems, their fuel efficiency can be further improved by at least 25 percent.

Systems studies for rotorcraft will continue to focus on the high-speed regime. Two major contractual studies are planned. These studies will provide direction and research focus toward high-payoff technology areas for rotorcraft capable of high subsonic cruise speeds, quiet and efficient hover, and economic viability. Helicopter, tilt rotor, X-wing, stowed rotor and other unique concepts will be assessed. Efficient, high-speed and low-noise rotorcraft have many applications to civil transportation for solving such problems as air and ground congestion and to the military for enabling new combat strategies and missions. The studies will identify new and emerging technologies to enable low-noise configurations, advanced propulsion systems, automated single-pilot operation, and advanced composites and structures concepts. Computer codes used in the conceptual design process will continue to be updated with new technologies data for the credible prediction of the performance, weight, cost, and other characteristics of advanced rotorcraft concepts.

The high-speed civil transportation studies with the two major airframe manufacturers will continue through FY 1989. The studies are focused to assess the impact of advanced technologies on the most promising, economically viable concepts. The in-house systems analysis efforts are concentrating on assessing the benefits that advanced technologies have on reducing the airport noise which high-speed transports create, and the sonic boom levels for overland supersonic flight, as well as assessing the impact a fleet of high-speed civil transports would have on the earth's atmosphere. Atmospheric models will be utilized to determine the impact of aircraft emissions on the earth's stratospheric ozone layer. Also, studies will be performed addressing cycle and noise suppression concepts for reducing community noise. A variable-sweep wing configuration will be evaluated for reducing the engine power required for landings, thus reducing community noise, and for increasing fuel efficiency at subsonic cruise speed. By wind tunnel testing of advanced high-speed transport configurations, sensitivity studies will be performed to assess the effect aircraft configuration has on sonic boom over pressure levels and signature characteristics. A high-speed transport with supersonic overland operational capability would be much more economically attractive to the airlines. Studies are being initiated to determine the public acceptability of sonic boom over pressures and the sensitivity of this acceptability to the signature. In-house conceptual designs will be performed for two concept vehicles, one that has a cruise speed of Mach 3 and the other that has a cruise speed of Mach 4. These designs will focus on key opportunity and problem areas, such as propulsion/airframe integration including inlets and nozzles, supersonic laminar flow, advanced materials and structural concepts, thermal management, and advanced wing planforms.

In FY 1989, high-performance aircraft systems analysis will focus on new capabilities enabled by key technology developments in high-thrust propulsion systems for supermaneuverable ASTOVL and conventional takeoff and landing fighter aircraft. Performance evaluation criteria will be established for assessing advanced configurations. Improved high-thrust engine models will be developed for assessing the impact of advanced technologies. Studies will continue to assess the advantages of advanced thrust vectoring technology and superconductivity technology to supermaneuverability.

BASIS OF FY 1989 FUNDING REQUIREMENTS

SYSTEMS TECHNOLOGY PROGRAMS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
		(Thousands of Dollars)			
Materials and structures systems technology	(7,200)	(8,800)	8,800	29,200	RD 13-47
Rotorcraft systems technology	18,700	4,600	4,600	4,800	RD 13-51
High-performance aircraft systems technology	25,985	12,800	12,800	11,000	RD 13-53
Advanced propulsion systems technology	28,220	26,800	18,000	14,000	RD 13-56
Numerical aerodynamic simulation	29,984	39,000	39,000	41,000	RD 13-59
Total	102,889	83,200	83,200	100,000	

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Materials and structures systems technology				
Advanced high-temperature engine materials technology.....	(7,200)	(8,800)	8,800	9,200
Advanced composite materials technology.....	---	---	---	20,000
Total.....	---	---	8,800	29,200

OBJECTIVES AND STATUS

The objective of the materials and structures systems technology program is to develop advanced materials and structural concepts for future advanced aircraft propulsion systems and primary structures

In FY 1988, the turbine engine hot section technology element and the ceramics for turbine engines element were combined and augmented to form the advanced high-temperature engine materials technology program. The programs were combined to focus their efforts on developing fundamental technology for revolutionary advances in high-temperature materials for advanced propulsion systems. The objective of the advanced high-temperature materials research is to develop very high thrust-to-weight (20 to 1) gas turbine engines with durable, long-life, hot-section components which can endure sustained operation without cooling air and thus enable significantly higher fuel efficiency. Key to these applications are materials capable of operating at much higher temperature and strength levels than now possible. These advanced materials will provide for a significant decrease in weight, while allowing an increase in maximum operating temperature and an extension of life. Existing materials currently in use, such as titanium alloys and nickel-base superalloys, offer only minor potential gains in performance. The candidate advanced materials include ceramics and ceramic matrix composites, metal matrix composites, intermetallic matrix composites, polymer composites and carbon-carbon composites,. Advanced materials such as these are vital to attaining higher turbine inlet temperatures for sustained supersonic cruise, higher

thrust-to-weight engines for advanced high-performance concepts, and engine hot-section components without cooling air for greater fuel efficiency. In addition, analytical codes to conduct design, predict life and establish failure mechanisms will be developed to enable effective utilization of these new classes of materials by engine manufacturers.

In FY 1988, techniques and methodologies to fabricate and test revolutionary new materials, such as metal matrix and ceramic matrix composites, were developed. Also, work in several supporting technologies, including high-temperature sensor development, nondestructive evaluation, and loads definition, was pursued. Techniques to optimize the fabrication of silicon-carbide/intermetallic alloy composites were developed and introduced into laboratory practice. An initial data base compilation on the high-temperature oxidation characteristics of candidate alloys for metal matrix composites was completed. Initial efforts were conducted to produce, by chemical vapor deposition, ceramic matrix composites containing silicon-carbide fibers to enhance resistance to sudden brittle failure. Progress was made in developing resins capable of oxidative stability at 700 degrees Fahrenheit and above. Novel test methods were developed for measuring elevated-temperature tensile, fatigue and fracture characteristics of metal matrix and ceramic matrix composites.

The objective of the advanced composite materials systems technology program is to develop advanced materials and innovative structural concepts to fully exploit the benefits of advanced composite materials for cost-effective primary structures for future aircraft applications. The program objectives will be accomplished through materials development, design and fabrication of innovative structural concepts, structural analysis and improved life prediction methods, and demonstration of improved structural performance through subscale and full-scale tests of critical components representative of advanced composite airframe structures.

Composite replacements for conventional metallic structures have demonstrated that organic-matrix composites can reduce airframe structural weight for primary structures on fighter aircraft and helicopters, as well as medium primary and secondary structures on transport aircraft. These first-generation applications have demonstrated the potential for composite materials, but the full benefits of advanced materials and new design and fabrication concepts have not yet been realized. It was determined that the full potential of 40- to 50-percent weight reduction and 25-percent cost reduction can be obtained by incorporating new materials in optimally designed composite structures that are both structurally efficient and more cost effective than current metallic or state-of-the-art composite structures. To achieve these objectives, a major advanced composite materials research program, building on current NASA and DOD research, is planned for FY 1989. This program will focus on developing advanced toughened thermoset and thermoplastic composite materials; new structural concepts using cost-effective

fabrication techniques such as advanced thermoforming, multidirectional weaving, pultrusion, filament winding, and advanced fiber placement techniques; analysis, design and test methodologies to validate structural concepts; and analysis of failure mechanisms and methods for extending subscale laboratory tests to prediction of full-scale composite structural performance.

CHANGES FROM FY 1988 REVISED BUDGET

The advanced high-temperature engine materials technology program has been transferred from the advanced propulsion systems technology program to more appropriately group and manage systems technology efforts in this area.

BASIS OF FY 1989 ESTIMATE

For FY 1989, advanced high-temperature engine materials research will emphasize fiber development, composite mechanics, and interfaces. Strong, stiff, lightweight reinforcement fibers, which are capable of maintaining chemical stability and mechanical properties at elevated temperatures, are a central issue to this entire program. To date, much emphasis has been placed on silicon-carbide fibers. Research will be pursued to develop small-diameter silicon-carbide fibers, as well as additional candidate fibers. This will include the development of processes for fiber fabrication and a comprehensive determination of fiber properties. The mechanical behavior and failure mechanisms of composite materials under the combined influences of stress (both static and cyclic) and elevated-temperature environment are highly complex and incompletely understood. Work in this area will be pursued at both the micro- and macro-mechanical levels. Time-dependent, visco-elastic effects, such as creep and creep-fatigue interactions, will be included. New concepts in damage mechanics will be pursued, including both analytical and experimental approaches. The characteristics and behavior of fiber/matrix interfaces can dominate the overall performance of composite materials at elevated temperature. The mechanical strength and environmental resistance of interfaces can exert disproportionate effects on composite strength and durahility. Fundamental understanding of elevated-temperature interface behavior under severe oxidizing conditions in metal, intermetallic and ceramic composites will be pursued. In addition, other areas of emphasis will include the development of mechanical testing and environmental durability experimental capabilities for temperatures of 3000 degrees Fahrenheit and above, and development of metal-ceramic and ceramic-ceramic joining methods.

During 1988, advanced composite materials and structures research in the Research and Technology Base will focus on developing fundamental technology for application of composites to primary airframe structures. This research will be directed toward exploiting new organic-composite materials for use up to 600 degrees Fahrenheit and advanced processing and fabrication concepts for low-cost composite structures. These advanced materials incorporated in innovative structures, such as geodesic fuselage panels and pultruded wing planks, will provide structural weight savings of 40 to 50 percent. Advanced analysis methods including probabilistic modeling of composites for improved life prediction and analysis of composite failure mechanisms will provide essential components of the technology required for the full use of composite materials in advanced aircraft. The composite materials and structures technology developed in the research and technology base in FY 1988 will form the basis for the expanded program effort planned in the FY 1989 systems technology program. This research will focus on developing and demonstrating in the laboratory advanced structural concepts for wing and fuselage primary structures using new composite materials and will include in-house structural test validation to provide the confidence essential for use of composite materials in future aircraft systems.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Rotorcraft systems technology				
Advanced rotorcraft technology.....	2,000	4,600	4,600	4,800
Technology for next generation rotorcraft.....	16,700	---	---	---
Total.....	18,700	4,600	4,600	4,800

OBJECTIVES AND STATUS

The rotorcraft systems technology program consists of interrelated research on three fronts: (1) completion of noise prediction and reduction in cooperation with industry, (2) increased focus on technology for high-speed rotorcraft, and (3) completion of the flight research on the X-wing concept under a joint program with the Defense Advanced Research Projects Agency (DARPA).

In the noise research focus, the NASA/American Helicopter Society (AHS) cooperative program with industry concludes with the final release to industry of the NASA-developed comprehensive noise prediction code called ROTONET. Validation of the code with industry will determine if the prediction accuracy goal of ±1.5 decibels for flyover noise was met. Final tasks under this program are the design of a low-noise rotor using conventional techniques and two innovative approaches: a radical planform concept (in small-scale testing) and a low-noise airfoil (in full-scale testing). Several noise sources that dominate in approach and takeoff have proved difficult to model and will be addressed in the research and technology base activities.

In high-speed rotorcraft research, there is an increased activity for tilt rotor technology and a new look at other, higher speed designs. The advanced composite blades for the XV-15 tilt rotor research aircraft are in flight testing to evaluate their promise for increased maneuverability, lower noise, and more efficient performance. Download reduction and a large-scale wind tunnel test of the rotor and wing of the Navy V-22 Osprey tilt rotor are being completed in cooperation with the Navy.

In the joint DARPA/NASA rotor systems research aircraft (RSRA)/X-wing rotor investigation, the goal is to investigate a stoppable circulation-control rotor concept which could increase the operational capability for future rotorcraft into the high subsonic flight regime. The prime objectives of this test program are to provide baseline technology, to generate engineering development design criteria, to acquire flight test data on the x-wing rotor system with stopped rotor and no blowing and with stopped rotor and manually controlled blowing, and to continue wind tunnel testing of the powered scale model through stopped-rotor blowing. Special areas to be investigated are performance, aeroelastic stability, and rotor control characteristics of the X-wing rotor and control system. The aircraft, cleared to begin flight testing, has successfully completed high-speed taxi tests. A series of flight tests will be conducted in FY 1988 to include tests with the rotor blades in a stopped/fixed configuration.

BASIS OF FY 1989 ESTIMATE

In FY 1989, the program will increase the effort on high-speed rotorcraft. In noise technology, with the completion of the NASA/AHS noise program, the emphasis will shift to in-house acoustics research for military application and specific issues for high-speed rotorcraft designs. Far-field propagation and detection prediction are two military acoustics activities to be investigated. In addition, prediction of tilt rotor noise will be validated in all flight modes in order to understand the source phenomena and potential areas for reduction.

In other tilt rotor activities, the potential for active control, drag reduction, and improved performance will be investigated in the wind tunnel and in flight. A pressure-instrumented blade for the XV-15 will be manufactured to obtain the needed data base for the validation of methodologies that are applicable to tilt rotor unique regimes. Cooperative efforts will also take place with the FAA for civil certification issues and with the Navy for V-22 tilt rotor technology assistance. The immense payoff of this technology for the nation through civil application is recognized in the government and by the industry and regional transportation authorities. The NASA technology program will help ensure the successful introduction of the tilt rotor to commercial service to meet urgent air traffic congestion reduction needs. In higher speed rotorcraft efforts, an X-wing model will be tested at transonic speeds to determine its maximum speed potential.

In FY 1989, the RSRA/X-wing research program will be concluded. The completion of the flight tests of a full-scale X-wing rotor will provide the data base for determining the next step in the development of this technology which offers significant potential for high-speed rotorcraft applications.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
High-performance aircraft systems technology				
High-performance flight research.....	14,430	12,800	12,800	11,000
Turbine engine hot section technology	5,000	---	---	---
Ceramics for turbine engines.....	2,200	---	---	---
Oblique wing technology.....	4,355	---	---	---
Total.....	25.985	12.800	12.800	11.000

OBJECTIVES AND STATUS

The objective of the high-performance aircraft systems technology program is to generate validated engineering methods and design data applicable to the development of advanced high-performance, high-speed aircraft applications. The program objectives are accomplished by analysis, ground-based simulations, wind tunnel experimental research, and flight research tests of advanced aircraft concepts and systems.

The F-18 high angle-of-attack research vehicle has been modified to a research configuration with the goal of obtaining a flight-validated data base for the design of highly maneuverable aircraft. Initial flight tests are focusing on the measurement of high angle-of-attack aerodynamics for correlation with wind tunnel and analytical predictions. For the NASA/Air Force advanced fighter technology integration (AFTI) F-111 mission adaptive wing (MAW) program, aircraft performance flights with the manual control modes of the mission adaptive wing system operational have been completed, and an industry workshop has been held to report the results. An 8 to 20 percent improvement has been obtained in the lift-to-drag ratio of the variable camber MAW wing compared to the basic F-111 wing configuration. This translates into significant performance benefits with both range and maneuverability improvement payoffs. Flight testing of the automatic camber control modes has been initiated. For the F-15 highly integrated digital

electronics control (HIDEC) project, which builds on the capability developed during the digital electronic engines control (DEEC) and F-100 engine model derivative programs, flight tests of the adaptive engine control system (ADECS) were completed showing 15 to 25 percent improvement in overall aircraft performance. Work has been initiated on the performance-seeking-control (PSC) system development which will greatly improve the practicality of implementing the ADECS technology on various engine configurations without the necessity of obtaining a specific model of engine performance characteristics for early application. Final development of the **F-106** vortex flap assembly has been completed, and the system has been installed and readied for test flight. The first flight will take place in FY 1988 to validate the predicted improvements in aircraft takeoff, landing, and manuevering flight performance. Flight research utilizing a YAV-8B Harrier testbed is continuing to obtain validation of wind tunnel, analytical, and simulator predictions of vertical/short takeoff and landing aircraft aerodynamic, propulsion, and control characteristics. The NASA/DARPA X-29A forward swept wing flight demonstration program successfully completed envelope expansion flights which included evaluation of an enhanced flight control system and loads evaluations at elevated "g" levels. Results from the flight tests were presented to industry and DOD at several on-site workshops, with over 800 people in attendance. Results were well received as being applicable and timely to ongoing activities within the aerospace community.

The objective of the joint NASA/Navy oblique wing research aircraft program was to establish a flight-validated data base for application of the technology to future civil and military aircraft. This effort is being terminated in FY 1988 due to withdrawal of Navy funding.

In FY 1988, the turbine engine hot section technology element and the ceramics for turbine engines element were combined and augmented to form the advanced high temperature engine materials technology program in the advanced propulsion systems technology program. In FY 1989, the advanced high temperature engine materials program has been transferred to the reestablished materials and structure systems technology program to more appropriately group and manage systems technology efforts in that area.

CHANGES **FROM** FY 1988 **REVISED** BUDGET

The oblique wing technology program has been terminated, and the funding has been realigned to high-performance flight research in support of high angle-of-attack research requirements in both FY 1987 and FY 1988.

BASIS OF FY 1989 ESTIMATE

The flight research activity in FY 1989 will involve several high-performance aircraft tests designed to investigate advanced concepts. Several projects will continue their flight phases during this period. Flight research on X-29 aircraft number one, including evaluation of buffet characteristics, performance evaluation and characterization of structural dynamics, will be completed in late FY 1988 and reported to industry through workshops and symposia in FY 1989. High angle-of-attack testing on X-29 aircraft number two will be carried out primarily in support of DoD requirments in this area. Design of a performance-seeking-control system, including hardware and software, that will enhance performance improvements already demonstrated by the F-15 HIDEC, will be completed, and initial ground tests conducted prior to flight test evaluation on the F-15 HIDEC research vehicle. Flight tests of a self-repairing flight control system design, developed jointly with the Air Force to improve system failure detection and reliability, will also be tested on the F-15 aircraft during this period. Modification of the F-18 high angle-of-attack research aircraft will be initiated for installation of turning vanes and flight controls to permit thrust vectoring at high angles of attack. Results of the AFTI/F-111 MAW flight test program, having been completed in FY 1988, will be presented to the industry and DoD agencies in FY 1989 through workshops and symposia.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Advanced propulsion systems technology...				
Advanced turboprop systems.....	25,820	15,500	15,500	11,300
General aviation/commuter engine technology.....	2,400	2,500	2,500	2,700
Advanced high-temperature engine materials technology.....	---	8.800	...	---
Total.....	28,220	26.800	18.000	14.000

OBJECTIVES AND STATUS

The objective of the advanced propulsion systems technology program is to explore and exploit advanced technology concepts for future aircraft propulsion systems in high-payoff areas through the focusing of fundamental research and technology efforts and integration of advanced propulsion components.

Activities in the advanced turboprop systems program are devoted to establishing concept feasibility and providing the broad research and technology analytical and experimental data base necessary for achieving the concept's full potential. Information on aerodynamic performance, aeroelastic stability, and acoustic environment obtained from small-scale wind tunnels will be used for verification of analysis codes and also to support the gathering and analysis of experimental data under actual flight conditions using aircraft testbeds. During last year, the nine-foot-diameter large-scale advanced propeller and propulsion system was installed on the propfan test assessment (PTA) aircraft and structural, aeroelastic, and acoustic performance verified for propellers at large scale during flight tests. Good quality data have been acquired and indicate structural and acoustic levels better than, or at least equal to, predicted values. A high-aspect-ratio, contoured, nacelle-powered, semispan model was tested in a wind tunnel to gather detailed aerodynamic data behind the propeller to aid in the analysis of the large-scale results. The development and application of advanced analytical codes, such as Euler and Navier-Stokes, to the analysis and design of an integrated turboprop system were continued. Experimental installation aerodynamics wind tunnel research was also continued on a variety of turboprop and airframe configurations, including single- and counter-rotation propellers using wing- and aft-airframe mounts.

In the general aviation/commuter engine systems technology program, the objectives are to raise the performance level of small turbine engines to approximately that of large transport turbine engines, and to enable a 10-percent reduction in direct operating cost. The work continues to be focused on providing a detailed understanding of the design parameters that affect performance at the component level. Small engine component technology studies have been completed and provide a prioritized technology development plan. From these studies, it was determined that high-temperature materials, such as ceramics for the hot section, improved aerodynamics of components, and advanced cycles, including waste heat recovery, have the potential of reducing fuel use by 20 to 50 percent, with a corresponding reduction in direct operating costs of 12 to 20 percent for applications using small engines. The experimental evaluation of an advanced ceramic matrix combustor liner was completed, and full analysis of the data will be accomplished in FY 1988. Ceramics offer the potential of eliminating cooling requirements for combustor liners, thus increasing engine cycle efficiency. During FY 1988, the new small turbine facility, which is now operational, will be used to evaluate turbine performance penalties associated with inlet boundary-layer size and blade surface finish.

CHANGES FROM FY 1988 REVISED BUDGET

The advanced high-temperature engine materials technology program has been transferred to the materials and structures systems technology program which has been re-established to more appropriately group and manage systems technology efforts in this area.

BASIS OF FY 1989 ESTIMATE

In FY 1989, advanced turboprop systems research will continue to emphasize source noise, cabin environment, turboprop and airframe installation aerodynamics, and the development of advanced aerodynamic and structural analysis techniques for both single- and counter-rotation propellers. The results of the flight test of the large-scale advanced propeller will be fully analyzed and compared to small-scale results to confirm scaling techniques for structures, aerodynamics, aeroelastics, propeller source noise, and untreated cabin environment. The combination of aerodynamics and aeroacoustic analysis will continue in order to accurately predict the source noise of the complex shapes and multitude of configurations available for counter-rotation propellers. Experimental installation aerodynamics wind tunnel research will continue on a variety of turboprop and airframe configurations, including single- and counter-rotation and wing and aft mounts. These experimental results will be used to verify Euler and

Navier-Stokes analysis codes for predicting aircraft flow fields. Advanced propeller research will include code development and verification using three-dimensional steady and unsteady transonic methods that consider counter-rotation interaction and evaluation of advanced concepts such as swirl recovery vanes and ultra-high-bypass-ratio ducted propellers, offering weight, noise, performance, and aircraft installation tradeoffs.

The general aviation/commuter engine technology effort will continue to demonstrate component improvements through the practical application of validated analysis codes that will enable high-performance small engine systems. Advanced turbine technology will continue to be emphasized in FY 1989 with the experimental evaluation of a cooled, high-work radial turbine and a mixed-flow turbine. Radial turbines offer very high work capability per stage, and successful cooling of small radial rotors has the potential to yield a very high-power compact turbine that can be used in high-pressure-ratio engines to provide system efficiency improvements of 15 to 25 percent. In another approach, the need for cooling can be potentially eliminated by using high-temperature materials, such as ceramics, although ceramics have not as yet proven strong enough to be used in a radial turbine. A compromise would be a mixed-flow turbine with almost as high work per stage, while significantly reducing stress levels. A mixed-flow metal turbine rotor will be used to evaluate the maximum stress levels during rig tests in preparation for fabrication and test of a ceramic rotor at a future date. Modifications to the combustion research test rig will also be completed in preparation of testing the ceramic matrix liner to higher temperature levels for further thermal efficiency increases.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Numerical aerodynamic simulation				
Numerical aerodynamic simulation.....	29,984	26,000	26,000	27,500
NAS operations.....	---	13.000	13.000	13.500
Total.....	29.984	39,000	39.000	41.000

OBJECTIVES AND STATUS

The numerical aerodynamic simulation (NAS) program objective is to significantly augment the nation's capabilities in computational fluid dynamics (CFD) and other areas of computational physics by developing a preeminent capability for numerical simulation of aerodynamic flows. Ongoing research and technology base efforts in computational aerodynamics are benefiting significantly from the advanced computational capabilities to be provided by the NAS program. This program provides the computational capabilities required to obtain solutions to problems which are currently intractable. The combination of the NAS and CFD programs will provide pathfinding aeronautical research for the future, allowing solutions of the full Navier-Stokes equations and enabling the prediction of performance of complex aircraft geometries. To meet this goal, the NAS program is pursuing the following objectives: (1) acquire pathfinding, state-of-the-art high-speed processors; (2) provide a uniform, user-friendly system with equivalent capabilities for local and remote users; (3) provide an auxiliary processing center for secure processing; (4) investigate and incorporate parallel architecture machines into future generations of NAS; (5) provide a hardware and software development environment for prototyping and testing of computers, networks, storage devices, workstations, and graphic output devices; and (6) continue to research and develop an increasingly sophisticated system of hardware/software tools and environment to assist the user in performing CFD tasks and to improve productivity.

Since NAS is both a development and operational system, two high-speed processors are necessary. The first high-speed processor (HSP-1), a Cray 2 supercomputer, has been integrated into the system in the NAS facility. In FY 1988, a memory upgrade was acquired for the Cray 2 which provided a 20-percent performance increase. The second high-speed processor (HSP-2) will be acquired and delivered in FY 1989. One processor will be devoted exclusively to production computing. The second, newer and more powerful

processor, will be integrated into the system, while software for production use is being developed. When a new supercomputer becomes available with over four times the performance of HSP-2, that machine will be acquired as HSP-3. To make room for more advanced processors, HSP-1 will be replaced by HSP-3, when HSP-3 is fully integrated into the **NAS** system.

The **NAS** system provides the **UNIX** operating system on all levels of the processing system from the supercomputer to the workstation. With support from the **NAS** program, **UNIX** has become the defacto standard operating system for supercomputer centers. With high-speed communication links to remote users, remote users are provided an environment which is equal to local on-site users. The **NAS** system is currently supporting over 700 users on 203 projects at over 70 sites.

An applied research and advanced development program has been initiated to support the pathfinding goal for **NAS. As** part of this program, an advanced development laboratory, an advanced architecture study, and a CFD workbench project have been formed. This program will provide the capability to evaluate commercial products, to provide industry with requirements for future products, and to design new systems and software to support new architecture machines.

BASIS OF FY 1989 ESTIMATE

FY 1989 will be an important year in the development of the **NAS** system. The second high-speed processor will be integrated into the **NAS** system. This event had slipped due to unavailability of a supercomputer meeting the HSP-2 requirements. With HSP-2 integrated into the system, secure processing will be available while users have access to the other high-speed processor.

With the second processor, the number of users and projects supported by **NAS** will increase accordingly. Support processing will be upgraded to satisfy the additional requirements of the system. Mass storage continues to be a primary concern for computer systems. The **NAS** program will double the mass storage capacity in late FY 1989 and efforts with industry on developing more capable systems are being pursued.

TRANSATMOSPHERIC
RESEARCH
AND TECHNOLOGY

RESEARCH AND DEVELOPMENT

FISCAL YEAR 1989 ESTIMATES

BUDGET SUMMARY

OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY — TRANSATMOSPHERIC RESEARCH AND TECHNOLOGY

SUMMARY OF RESOURCES REQUIREMENTS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
		(Thousands of Dollars)			
Transatmospheric research and technology	45.000	65.500	52,500	84.400	RD 14-2
Total	45,000	65,500	52.500	84.400	
Distribution of Program Amount by Installation					
Ames Research Center	2,312	800	3,600	4,000	
Langley Research Center	7,210	1,700	13,000	13,200	
Lewis Research Center	2,065	2,000	8,200	3,600	
Headquarters	33,413	61,000	27.700	63,600	
Total	45.000	65.500	52,500	84.400	

OFFICE OF AERONATUICS AND SPACE TECHNOLOGY **TRANSATMOSPHERIC RESEARCH AND TECHNOLOGY**

PROGRAM OBJECTIVES AND JUSTIFICATION

The National Aero-Space Plane (NASP) program is a joint effort between **NASA** and the Department of Defense to accelerate the development of critical enabling technologies for a revolutionary class of hypersonic/transatmospheric vehicles. Such vehicles could be capable of taking off from and landing on conventional runways, using airbreathing propulsion up to, or near, orbital speed, and providing rapid and lower cost access to space. The program will accelerate the development and validation of key technologies through application of analytical prediction methods coupled with testing in ground-based facilities. The critical technologies being pursued in the current phase of the program include efficient airbreathing propulsion systems, with emphasis on scramjet performance that provides the necessary thrust from takeoff to near orbital speeds; reusable thermal structures that can withstand repeated combinations of extreme peak heating and significant long-duration heat loads; and complete integration of the propulsion system with the airframe for a minimum weight system with good performance throughout a broad range of accelerating, cruising, and maneuvering flight conditions. A necessary precursor to the development and flight validation of an experimental vehicle (X-30), these technologies will form the critical data base required for design and integration of complex propulsion and structural systems into a vehicle configuration capable of transatmospheric flight.

This program is an outgrowth of the ongoing aeronautics and space research and technology programs. It is a multicenter effort (Ames, Langley, and Lewis) directed at generating the technologies required to provide the variety of options afforded by airbreathing transatmospheric vehicles. The opportunities for exploiting this regime for advancement of national interests are broadly recognized -- including launch vehicles, hypersonic transports, and military applications.

CHANGES FROM REVISED FY 1988 BUDGET ESTIMATE

The transatmospheric research and technology program has been reduced by $13.0 million as a result of Congressional action on the FY 1988 budget request. The allocation by installation reflects the joint NASA/DOD NASP program management office plans and approval of individual tasks to be performed by the respective organizations during the current year.

BASIS OF FY 1989 ESTIMATE

The FY 1989 NASP activities will emphasize extensive detailed design, component fabrication, and tests by the engine and airframe contractors, as well as continued refinement of the supporting technology maturation effort in preparation for the decision on whether to proceed with development of the X-30 research vehicle.

The engine contractors will continue to refine their concepts to achieve the performance required to accomplish the X-30 mission goals. Emphasis will be on integration with the vehicle configurations being developed by the airframe contractors, since the desired performance depends critically on the integrated propulsion-airframe system. A major effort will be extensive ground testing of the contractors' near full-scale modules to a simulated flight speed of Mach 8. The tests are essential for building confidence in engine operation under as realistic a set of conditions as possible. These tests will include evaluation of component performance under severe environmental conditions. Hydrogen-cooled engine components, for example, will be evaluated under Mach 25 heating conditions to validate predicted operation and lifetime. Successful demonstration of engine performance in the ground facilities to Mach 8 and computational fluid dynamics (CFD) analyses of engine performance at higher Mach numbers are critical to the X-30 decision.

The airframe contractors will further develop their preferred configurations, using data from the engine contractors. Emphasis will be on increasing the performance of the integrated propulsion-airframe system, reducing drag through detailed CFD analyses, and reducing weight through careful evaluation of advanced structural designs. Significant activities will include development, fabrication, and test of large-scale sections of the hydrogen tank and thermal protection system to validate analytical predictions of systems performance; large-scale advanced materials panels with the necessary joints, fasteners, and gap seals to develop realistic weights for vehicle designs; full-scale nose, engine strut, and wing leading-edge models to evaluate survivability in simulated flight thermal conditions between 4000 and 6000 degrees Fahrenheit; and full-scale fuselage sections and wing/fuselage attachments to evaluate vehicle structural integrity. Control system designs will be developed and evaluated for control of complex, integrated vehicle systems under simulated flight conditions. Subsequent predictions of overall vehicle performance based on these data are critical inputs to the decision to build the X-30 research vehicle,

The technology maturation effort will continue to focus on critical disciplines as an underpinning of the engine and airframe efforts. The technology maturation activities concentrate on four key objectives: (a) an airbreathing propulsion system with high specific impulse; (b) vehicle structural weight improvement with reusability and durability over a wide temperature range; (c) integrated systems and subsystems in aeropropulsion, thermal management controls, etc.; and (d) sound design and analysis tools based on advanced computational methods fully verified by test. Significant activities will include integration of finite-rate air and hydrogen reactions into three-dimensional Navier-Stokes computer codes

for complex geometries to allow for accurate prediction of flow fields; investigation and prediction of laminar-to-turbulent flow transition using advanced computational techniques and a low-turbulence wind tunnel modified to conduct hypersonics flow experiments to permit accurate prediction of thermal heating loads in flight; detailed real-gas validation of CFD codes by advanced test facilities to predict external flows, inlet flows, and combustor/nozzle flows for more realistic prediction of engine performance; and continued development and evaluation of advanced metal matrix composite materials to provide the lightweight structures needed to meet X-30 performance goals. The major effort to scale up and characterize advanced lightweight, high-temperature materials in a cooperative effort with contractors begun in FY 1988 will be significantly expanded in FY 1989.

SPACE RESEARCH
AND TECHNOLOGY

RESEARCH AND DEVELOPMENT

FISCAL YEAR 1989 ESTIMATES

BUDGET SUMMARY

OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY — SPACE RESEARCH AND TECHNOLOGY

SUMMARY OF RESOURCES REQUIREMENTS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
		(Thousands of Dollars)			
Research and technology base	130,646	107,900	108,400	134,100	RD 15-8
Systems technology programs	75,354	---	---	---	RD 15-49
Civil space technology initiative (CSTI) program	---	130,700	115,200	156,800	RD 15-50
Pathfinder program	---	---	---	100.000	RD 15-70
Total	206,000	238,600	223,600	390.900	

Distribution of Program Amount by Installation

Johnson Space Center	10,169	11,600	9,600	24,000
Kennedy Space Center	180	500	400	4,300
Marshall Space Flight Center	53,653	49,100	36,600	71,400
Goddard Space Flight Center	6,025	8,700	8,500	11,600
Jet Propulsion Laboratory	18,896	27,000	29,400	48,000
Ames Research Center	18,931	27,500	23,600	37,100
Langley Research Center	52,830	59,600	56,800	65,600
Lewis Research Center	38,662	48,600	49,200	74,500
Headquarters	6.654	6,000	9.500	54.400
Total	206,000	238,600	223,600	390.900

OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY **SPACE RESEARCH AND TECHNOLOGY**

PROGRAM OBJECTIVES AND JUSTIFICATION

The overall goal of the space research and technology program is to provide advanced technologies that ensure continued U.S. leadership in space to meet national needs. Achieving this goal requires a commitment to provide a broad base of advanced technology for vehicle and subsystem concepts, components, devices, and software; to develop technical strengths in the engineering disciplines within the agency, industry, and academia; and to perform critical technology demonstrations that facilitate the transfer of new technology to future space missions with a high level of confidence.

The research and technology base program provides the wellspring of innovative and fundamental research for future NASA and other civil space missions. Within this program, high-leverage technological advances and concepts are, if successful, brought to the level of demonstrating proof of principle. This program is in effect a seedbed for generating the more highly mission-focused technology programs. The Civil Space Technology Initiative (CSTI) program is a mission-focused program that consists of major technology thrusts to enhance Earth-to-orbit transportation, improve operational capabilities at low Earth orbit for enhancing the effectiveness of Shuttle/Space Station, and provide increased capabilities to conduct Earth-orbital science programs. The Pathfinder program provides those emerging and innovative technologies required to enable a broad set of future space exploration missions. Depending on future decisions, such missions could include a return to the Moon to build an outpost, and both autonomous and piloted missions to Mars and other destinations in the solar system. Proof-of-concept testing for mission-critical engineering designs will be an important product of the CSTI and Pathfinder programs and will directly support the continuing evolution and maturation of mission plans. In support of the objective of encouraging the development of engineering and research capabilities in the academic sector, the university activities have been combined into a separate focused budget line item which includes the space engineering research center program, the university system design program, and university innovative research.

CHANGES FROM REVISED FY 1988 BUDGET ESTIMATE

The space research and technology program was reduced by $15.0 million as a result of Congressional action on the FY 1988 budget request. This reduction is reflected in the CSTI propulsion program.

BASIS OF FY 1989 ESTIMATE

In FY 1989, the space research and technology program will be significantly augmented to provide a greater emphasis on focused technology (CSTI and Pathfinder) and university space research programs. The research and technology base program will shift emphasis to explore newly emerging areas that offer longer range, high-leverage program benefits. The university space research program includes augmentation and expansion of the university engineering research centers and the university advanced design effort. Development of the concepts and plans for an expanded in-space research and demonstration program will be pursued. The following describes in greater depth the planned FY 1989 activities.

The aerothermodvnamics program provides the basis for fundamental understanding and prediction of the combined effects of heat transfer and aerodynamics on vehicles during ascent and entry. This activity is enabling to the successful development and design of advanced aerospace vehicles. Current program emphasis is on development and validation of computational fluid dynamics codes that incorporate real-gas and nonequilibrium effects to more accurately predict performance of aeroassisted orbital transfer vehicles.

The space energy conversion program provides the fundamental understanding and technology basis for the development of future space power systems ranging from relatively low power levels required for spacecraft to high-capacity, nonnuclear power for large space systems. Photovoltaic power technology will focus on improving the efficiency and reducing the degradation rate of photovoltaic cells through improved designs and materials. Technologies for lightweight deployment systems, reduced weight substrates, and ultrathin cover glass are being developed. Higher energy chemistry and improved battery designs are being developed to provide improvements in the energy density and life of storage systems. The goal is to improve the total system (photovoltaic and storage) performance to permit a 50 percent increase in payload weight. Research continues on fuel cells for application at higher power levels (greater than 25 kilowatts) where they offer significant potential weight advantages. New conversion catalyst materials and designs are being developed to achieve reduced system weight and increase life. Technologies for high-efficiency

thermal-to-electric conversion, high-temperature thermal storage, and lightweight high-concentration-ratio solar collectors are being developed for solar dynamic systems. The goal of these technologies is to provide a 25 percent reduction in collector area and a substantial reduction in weight over current high-capacity systems,

The propulsion technology program focuses on key lifetime and performance issues associated with space propulsion systems. Variable-flow turbomachinery, enhanced heat transfer combustors, and high-expansion-ratio nozzle technology for space-baseable orbit transfer vehicles will be investigated. The ultimate benefit will be to reduce substantially the cost of space operations by reducing the amount of mass required to be transported to Earth orbit. In addition, the potential of very high-energy-density propellant combinations, such as liquid oxygen with metalized fuels, will be assessed for Earth-to-orbit propulsion systems. For ascent vehicle operations, candidate propulsion systems that can operate efficiently with propellants produced in-situ on Mars or on the Moon will be identified and their performance and operational capabilities explored to greatly reduce Earth launch requirements. Research on auxiliary propulsion will develop concepts for control of an evolutionary space station and space vehicles which operate with mixtures of gaseous oxygen and hydrogen derived from electrolytic systems. Electric propulsion technology will address fundamental issues governing thruster life, performance, and weight through improved inert gas ionization processes and cathode materials and designs.

The materials and structures program will focus on extended space durability, structures for lightweight vehicles, and concepts to enable the development of large space structures. The dimensional stability and durability of metal-matrix, carbon-carbon and graphite-epoxy composites will be evaluated for long-term service life in both low-Earth-orbit and geosynchronous-Earth-orbit environments. The approach will include both the development of computational chemistry methods to describe atomic oxygen interactions and accelerated testing methods. Structural concepts will be developed incorporating mechanisms to adjust stiffness, damping, and shape in order to enable construction of large high-precision space structures. Hot structures for integral cryogenic tankage will be pursued, and toughened ceramic thermal protection systems will be developed.

Space data and communications research will be directed toward increasing traveling wave tube efficiencies, developing and packaging monolithic microwave integrated circuit components, refining 20/30 gigahertz antenna technology, and advancing electro-optic research aimed at laser communications.

Areas addressed by the information sciences program include computer sciences, sensors, and photonics. In the computer science area, emphasis will continue to be placed on concurrent processing for improved physical simulations and visualization of scientific data. Sensor research will concentrate on the use of artifical intelligence techniques in autonomous onboard data analysis. Investigation of new materials, devices, and analytical models leading to the development of improved sensor systems will continue. In the area of photonics, research will focus on improved photonic materials and devices for use in real-time computer vision systems and very low-cost, wide-bandwidth signal analysis.

Controls and guidance research will support the implementation of future advanced Earth-to-orbit transportation systems, aeromaneuvering vehicles, and interplanetary space travel. Particular emphasis is being placed on real-time, fault-tolerant distributed control architectures and system autonomy in the real-time environment of a maneuvering vehicle. The development of analytical tools and techniques for the precision pointing and control of large flexible spacecraft and the control of extremely large flexible transportation vehicles is a principal research focus.

Space human factors research includes development of advanced concepts and hardware for extravehicular activity, such as hard space suits, and development of highly integrated displays and controls to support telepresence and astronaut and crew performance.

Space flight research includes the continued development of orbiter experiments to use the shuttle as a research testbed vehicle. The in-space technology experiments program was expanded to define and develop seven flight experiments selected from 58 NASA in-house generated proposals. The program was also expanded further by the selection of 41 externally sponsored flight technology experiments from 231 university and industry proposals.

The systems analysis area will focus on the identification of high-leverage technologies for future space missions.

The objective of the university space research program is to enhance and broaden the capabilities of the nation's engineering community to participate more effectively in the U.S. civil space program. It is an integral part of the strategy to rebuild the space research and technology base. The program responds to remedy the decline in the availability of qualified space engineers by making a long-term commitment to universities aspiring to play a strong engineering role in the civil space program. The program elements

include the university space engineering research program that supports interdisciplinary research centers, the university innovative research program which provides grants to individuals with outstanding credentials, and the university advanced space design program which funds advanced systems study courses at the senior and graduate levels.

The objective of the Civil Space Technology Initiative (CSTI) program, begun in FY 1988, is focused on research in technologies to enable reliable and lower cost access to space and to support space operations and science missions. The CSTI program is a positive first step to restore the agency's technical strength and provide options for high-priority civil space goals of the future. The research is targeted at opportunities with clearly defined end objectives to validate technology advances. Three broad categories -- transportation, operations, and science technology -- are supported.

Automation and robotics is directed at developing and demonstrating the technology to enable intelligent autonomous systems and telerobotics applications to space and autonomous ground systems. Propulsion includes Earth-to-orbit propulsion that will provide the experimental data base and test environment to verify the models needed for the design and development of advanced, reusable, and high-performance propulsion systems and also booster technology that will develop alternate propulsion concepts for the Shuttle booster with higher performance and a safe-abort option. Vehicle-oriented technology is focused on an aeroassist flight experiment that will provide critical design and environmental technologies for an aerobrake orbital transfer vehicle. Information technolony is directed at developing the high rate/high capacity data technology for onboard real-time data processors and storage systems with up to ten times increase in data rates and 1000 times increase in storage capacity and at providing new sensor technologies for Earth observation and space science. Large structures and control includes a series of in-space experiments to provide fundamental data on structural dynamics and control of a very large, flexible structure to enable development of lower weight, more stable, space structures while technology will be developed for a precision segmented reflector to enable the design of large, high-precision, orbiting astronomical instruments for making deep space observations in the submillimeter portion of the spectrum. Power technology is focused on advanced technology development efforts to increase nuclear system conversion efficiency fivefold to meet the long-duration, high-capacity power requirements for future space initiatives.

Project Pathfinder is an important new program, through which NASA will develop a broad set of technologies to enable future space missions. Project Pathfinder is the critical next step, augmenting CSTI, in strengthening the technology foundation that supports the civil space program and the nation's technology leadership. Moreover, Pathfinder is an essential prerequisite to any later decision by the nation's leadership to go forward with ambitious civil space missions, such as an outpost on the Moon.

Until key technologies are developed, these ambitious civil space missions will always remain 10-20 years in the future. Pathfinder will provide the technology required for the future robotic exploration of the solar system, an outpost on the Moon, a piloted mission to Mars, and advanced Earth orbserving missions and Earth orbit operations. Project Pathfinder addresses technologies in the areas of: space transportation and operations, in our ability to live and work productively in space, and for exploration. Through these program thrusts, and a strong partnership between NASA, industry, and universities, Pathfinder will push American space technology forward in the coming decade, as the Apollo program did during the 1960's.

The technologies included in the exploration element are related to the gathering of scientific knowledge and technical understanding at mission sites on the Moon and Mars. Specific objectives will provide the capabilities needed to precede piloted flights to Mars and for the construction of a lunar outpost. The space operations element deals primarily with the lunar outpost, with piloted missions to Mars, and with operations in Earth orbit. For lunar and Mars missions, this program will address critical technologies for preparing to depart Earth orbit, for performing mission tasks on arrival at surface sites, and for safe return from the Moon or Mars. For Earth orbit operations, this program will greatly extend our capability to maintain an infrastructure and to support major new science missions. Specific objectives include extensive capabilities for in-situ materials processing, fabrication and assembly, and repair of massive and complex systems in Earth orbit and at lunar and Martian orbits and surfaces. The humans-in-space program will address the technology for making it feasible and productive to send astronauts on lengthy missions. Specific objectives include improving astronaut productivity, maintenance of health, and minimal or no dependence on resupply of expendables. The transfer vehicle element will support transportation to and from geostationary Earth orbit, the Moon, Mars, and other planets. Specific objectives include significant reduction in the mass that missions require to be launched into low Earth orbit and in transit, as well as reductions in the time required for transit. The mission studies element will (starting with the exploration scenarios identified in the report entitled "Leadership and America's Future in Space") identify, define, and analyze future space missions. These studies will lead to continuing refinement of the Pathfinder program to ensure that critical, long-lead technologies are receiving proper attention.

BASIS OF FY 1989 FUNDING REQUIREMENTS

RESEARCH AND TECHNOLOGY BASE

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
		(Thousands of Dollars)			
Aerothermodynamics research and technology	11,678	10,300	10,300	11,500	RD 15-9
Space energy conversion research and technology	20,922	13,100	12,500	13,800	RD 15-13
Propulsion research and technology	18,844	13,900	13,300	19,700	RD 15-17
Materials and structures research and technology	20,877	15,900	15,900	17,500	RD 15-22
Space data and communications research and technology	13,252	8,300	7,900	9,300	RD 15-28
Information sciences research and technology	8,827	7,600	7,700	9,000	RD 15-31
Controls and guidance research and technology	7,300	5,800	5,500	6,700	RD 15-34
Human factors research and technology	2,274	4,400	4,200	5,300	RD 15-37
Space flight research and technology	20,096	22,600	21,400	18,100	RD 15-40
Systems analysis	6,576	6,000	5,700	6,900	RD 15-43
University space research	---	---	4,000	16,300	RD 15-46
Total	130,646	107,900	108,400	134,100	

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Aerothermodynamics research and technology.....	11,678	10,300	10,300	11,500

OBJECTIVES AND STATUS

Future aerospace vehicles, such as aeroassist orbit transfer vehicles (AOTV), the aerospace plane, and hypersonic cruise and maneuver vehicles, must be capable of sustained hypervelocity flight in both rarefied and continuum flow flight regimes. The design of these vehicles presents formidable performance prediction challenges. To meet these challenges, the aerothermodynamics program is pursuing the following objectives: (1) development and application of advanced computational methods and numerical techniques covering the entire spectrum of continuum, transitional, and rarefied flows; (2) development of accurate and detailed real-gas chemistry and high-speed turbulent flow models and the efficient integration of these models with standard computational flow codes; (3) establishment of a high-quality ground and flight experimental data base for code validation and verification; (4) direct correlation and comparison of computations with available ground and flight data; (5) establishment of a detailed aerothermal loads data base and development of fully integrated analysis techniques; and (6) enhancement of engineering design codes and advanced configuration analysis capability to support rapid evaluation of future vehicle/mission concepts.

Progress continues to be made on the direct simulation Monte Carlo techniques to better understand and predict the complex flow problems associated with aerospace vehicles operating in the rarefied or noncontinuum flow regime. During FY 1988, stagnation point and axisymmetric body solutions, including global radiative heating, temperature, and electron number density, were obtained for the aeroassist flight experiment (AFE) reentry trajectory.

The ability to efficiently and accurately simulate chemically reacting flows is critical to the successful design and optimization of proposed hypersonic vehicles. Toward this end, a two-dimensional equilibrium real-gas code has been developed, and this first-order inviscid code has successfully computed a number of flow fields. This code allows accurate, simplified analyses of a wide range of internal and

external flows about advanced space transportation vehicles. Numerical results for Mach 20 real-gas flow over a hemisphere compared well with results obtained from other methods. The code has also been used to compute equilibrium flow through a hypersonic inlet and supersonic flow about a missile with exhaust plume.

The computational analysis capability for the AFE has been expanded to include predictions of flight aerodynamic coefficients, forebody pressure distributions, and Mach 10 heating distributions using the high angle-of-attack inviscid solver code coupled to a three-dimensional boundary-layer code. These calculations are critical to finalizing the design for the AFE. At the other end of the lift/drag spectrum, a preliminary analysis of a hypersonic slender body configuration has been completed using a three-dimensional viscous shock-layer code. This calculation was able to isolate and quantify the effects that variations in nose bluntness and angle of attack have on laminar and turbulent heating.

Complementary to the development of computational fluid dynamics codes and numerical simulation capability is the requirement to establish a high-quality aerothermodynamics experimental data base applicable to a wide range of vehicles and flow conditions. In FY 1988, wind tunnel tests conducted in the hypersonic facilities complex at the Langley Research Center provided detailed aerodynamic performance data on both U.S. and foreign space transportation systems. This included critical information on pitch and yaw stability and control limits. Complete force, moment, and pressure distributions for the baseline AFE configuration were also obtained. These are being compared with the latest computational calculations to verify present performance predictions.

During the past year, a Shuttle ascent abort study was undertaken to evaluate the feasibility of safe aerodynamic separation of the orbiter from the lower stack (external tank and solid rocket boosters) from liftoff through solid rocket booster staging. A vital part of this study involved single- and two-body wind tunnel tests which provided the detailed interference aerodynamics data. While these tests were able to establish the preliminary feasibility of various separation options, they also confirmed the highly complex and nonlinear nature of the localized air flow which cannot be accurately predicted or simulated by current computational techniques.

An ongoing activity to improve and verify the aeroheating predictions of current engineering design codes has been successfully completed. Flight test data, benchmark computational codes, and wind tunnel tests were compared with engineering code predictions relative to nose bluntness and angle-of-attack effects, gas chemistry (real versus perfect gas), and turbulence heating methods. These codes have been verified and were successfully used in the down-select process of the National Aero-Space Plane program.

In the area of aerothermal loads, the first operation of a fully integrated flow thermal-structural analysis technique was accomplished. Excellent agreement between theory and experiment was found for a blunt leading-edge case. As a companion activity, an experimental study of shock wave interference heating (compression wave impinging on a bow shock) on a cylindrical leading edge was completed in the Calspan Corporation's 48-inch and 96-inch shock tunnels. Analysis of these results indicates a tenfold increase in heating rate for the shock-shock condition versus the undisturbed, no-shock impingement case.

BASIS OF FY 1989 ESTIMATE

The FY 1989 program in computational methods will emphasize techniques for efficient coupling of real-gas chemistry to Navier-Stokes flow codes. This will involve the development of more sophisticated chemistry models and more robust and computationally efficient solution algorithms. A second area of emphasis will be continued development of user-friendly two-dimensional and three-dimensional adaptive grid generation techniques, which can be applied to a variety of flow fields and configurations, i.e., plumes/nozzles, cowl lip, inlets, forebody, and base flows. These improved capabilities will permit more accurate simulation of continuum flow about advanced space transportation vehicles under ascent and entry conditions.

In the area of direct simulation techniques, focus will be given to developing a highly efficient particle kinetic simulation method. Unlike the Monte Carlo approach, this method restricts or limits the allowable energy and momentum states that can result from a collision of two ideal diatomic molecules. Therefore, it is not as computationally intensive as the Monte Carlo method and will be better suited to predicting transitional and near-continuum flows. This capability will allow for the inclusion of more complete physics resulting in more accurate simulations, as well as enabling rapid parametric studies of maneuvering vehicle trajectories in the upper atmosphere.

Continuing the efforts to expand the current aerothermodynamic ground test data base, emphasis will be given to code calibration and validation experiments and, in particular, to simulating nonequilibrium flows through the initiation of a series of high-velocity tests on slender conical bodies. To this end, plans to establish a high-enthalpy/high-velocity ballistic range facility and to further develop nonintrusive diagnostic techniques for hypersonic flows will be actively pursued to enable realistic hypersonic experimentation.

Aerothermal loads research efforts will concentrate on completing shock-on-lip tests to provide a better understanding of leading-edge sweep and multiple shock effects on hypersonic inlet heat transfer in order to facilitate structural analysis and design. In FY 1989, a more complete validation of the integrated flow-thermal-structural analysis technique will be accomplished utilizing the complete experimental data set obtained in past Langley Research Center and Calspan Corporation wind tunnel and shock tube tests. The calibration of the flow-thermal-structural integrated analysis code will produce the first ever integrated analysis for high-speed aerodynamics/aerothermodynamics/structure interactions.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Space energy conversion research and technology.....	20,922	13,100	12,500	13,800

OBJECTIVES AND STATUS

The objective of this program is to develop technology alternatives that improve performance, reliability, and cost effectiveness of space power for manned space operations, as well as autonomous Earth-orbiting and planetary exploration spacecraft. To meet the challenge, greater than 50 percent improvements and increased life potential are being sought in alternative solar power generation components, energy storage systems, electrical power management and distribution, as well as the thermal management systems. For spacecraft photovoltaic technologies, the goal is to improve the total system performance enough to permit a 50 percent increase in payload mass while not increasing the spacecraft overall mass.

Recently, two significant advances in photovoltaic cell technology were achieved. Over 18 percent efficiency was demonstrated in an indium phosphide solar cell. This measurement, when combined with data indicating that indium phosphide should be more resistant to space radiation than any other material, shows real promise, for the first time, of using photovoltaics in high radiation environments such as extended missions in the Earth's radiation belts. Using prismatic solar cell covers, which direct incident sunlight away from electrodes to active areas of the cell, gallium arsenide (GaAs) concentrator cells set an efficiency record of over 22 percent. This result demonstrates the promise of substantial reductions in array areas. Electrochemistry research has identified a relationship between electrolyte concentration and cycle life of nickel-hydrogen batteries which provides sufficient cell life to meet the Space Station cycle life goal. Other improved nickel-hydrogen technology components that will further extend life and improve cell reliability were verified and provided to battery cell manufacturers for consideration in their space station cell designs. Feasibility investigations have identified promising cathode, electrolyte materials and processes suitable for long-life (10 years), higher energy density (100

watt-hours/kilograms), secondary lithium cells for application to mass-critical planetary spacecraft. An advanced hydrogen-oxygen regenerative fuel cell system investigation to establish life-performance interrelationships and system weight tradeoffs was initiated to identify the technology payoff benefit areas and to guide the critical technology efforts.

In the power management and distribution area, installation and initial full-power operational testing of a 20-kilohertz, 1000-kilowatt component test facility was completed. A major technology achievement during this period has been the development, maturation, and acceptance of the 20-kilohertz power management and distribution system as the Space Station baseline. The benefits include very low electromagnetic interference, 50 percent reduction in weight, 7 percent increase in end-to-end efficiency, increased crew safety, and compatibility with any energy source.

The feasibility of a high-efficiency, thin-film alkaline metal thermal electric conversion (AMTEC) system electrode has been demonstrated at representative cycle temperatures. A power flux of 0.6 watts/centimeter squared was achieved with a thin-film molybdenum electrode. AMTEC is an alternate static conversion concept that potentially could achieve system efficiency on the order of 20 percent, as compared to efficiencies of approximately 6 percent for other static conversion systems. It is suitable for application with chemical, solar, and nuclear heat sources.

CHANGES FROM FY 1988 REVISED BUDGET

The space energy conversion research and technology program has been reduced by $0.6 million, which reflects the consolidation of the ongoing university space research activities into a separate research and technology base budget category.

BASIS OF FY 1989 ESTIMATE

In FY 1989, the space energy conversion research and technology program will continue to extend the fundamental understanding of energy conversion systems and to develop technology options for future space missions with power levels ranging from hundreds of watts for small planetary spacecraft to many kilowatts for large space platforms and manned spacecraft and bases. Energy conversion research includes solar and nuclear power generation systems, energy storage systems, power management, and thermal transport and heat rejection.

For spacecraft photovoltaic technologies, fabrication of a prototype advanced array will be completed and engineering tests initiated to demonstrate 300 watts/kilogram array components. This is a fivefold improvement over today's state of the art. Efforts will be made to combine future thin-film cells, such as amorphous silicon, with optimized blankets and deployment mechanisms to attain even higher specific power. Work begun in FY 1986 continues on mitigating the effect of low-intensity, low-temperature degradation of silicon solar cells to lead to a cell capable of efficient operation in Jupiter orbit. Research and technology efforts with thin-film indium phosphide cells are expected to culminate in a manufacturing design. Space environmental effects experimental work to understand and reduce the damaging effects of space radiation is continuing.

Component level testing of solar dynamic concentrator concepts will be completed, and performance testing of several concentrator designs under various conditions of sunlight and pointing will be initiated. Thermal energy storage materials will be formulated and evaluated to establish heat of fusion, thermal conductivity, and coefficients of thermal expansion. Materials with high thermal conductivity and high heat of fusion are needed to develop efficient and lightweight thermal energy storage systems and receivers. A low coefficient of thermal expansion is needed to reduce failures due to cyclic fatigue. In FY 1989, selection of concentrator, receiver, and thermal storage concepts for integration into a high-temperature, high-concentration ratio and long-life solar dynamic system is to be accomplished. AMTEC electrode life of 1000 hours will be demonstrated.

Laboratory experiments to develop a fundamental understanding of the chemical mechanisms governing the cycle life of lithium secondary (rechargeable) cells will be conducted. Assessments of the performance and life potential of high-temperature sodium sulphur cells will be initiated. Both lithium and sodium batteries are of interest because of their high-energy densities (100 watt-hours/kilogram). However, both suffer from problems of insufficient cycle life and reliability. In some applications the sodium-sulphur may not be able to meet environmental (vibration, shock, etc.) constraints. Technology efforts will address these issues. University efforts will continue to develop improved catalytic materials and electrode designs for regenerative fuel cells.

Experimental and analytical efforts to study droplet formation, heat transfer mechanisms and zero-gravity phase change, and fluid flow phenomena will be conducted to evaluate materials and designs and develop the required technology base for advanced radiator concepts that will allow the large amounts

of heat generated by high-power level systems to be dissipated. High-frequency power system designs and components will be developed to reduce the weight, increase the life, and meet the space radiation and temperature constraints. Experimental power systems, biased to simulate space charging effects, will be tested in vacuum chambers to determine the possible detrimental effects of high-voltage arcing and to develop designs which will be suitable for use in civil missions.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Propulsion research and technology.....	18,844	13,900	13,300	19,700

OBJECTIVES **AND STATUS**

The objectives of the propulsion research and technology program are to develop a fundamental understanding of the chemical and physical processes that occur in space propulsion systems, to develop and validate accurate analytical simulations of those processes, to identify and evaluate advanced higher thermal and mechanical load-resistant materials, and to evaluate the potential benefits and feasibility of advanced concepts that will improve our propulsion capabilities well beyond those that are achievable with today's operational systems. Depending upon the application, the thrust range of these chemical and electric propulsion systems varies from millions of pounds to millipounds. Included are propulsion systems for Earth-to-orbit (ETO) vehicles, orbit-to-orbit transfer vehicles (near Earth and planetary transfer), planetary orbit insertion, lander, ascent, and Earth return vehicles. Also included is Earth-orbiting satellite auxiliary propulsion needed for such functions as attitude control and station keeping. Finally, a part of the program is dedicated to the identification and evaluation of very high-energy advanced propulsion concepts that, if proven feasible and ultimately practical, would provide a quantum leap in propulsion capabilities that could be applied to a number of the above applications. The propulsion technology advances being pursued in support of future vehicle and spacecraft design concepts will greatly enhance our ability to perform these missions with increased capability and at greatly reduced cost.

ETO propulsion technology is directed toward advanced concepts that offer significantly increased propulsion system density impulse characteristics, i.e., increased propellant density while a high level of engine specific impulse is maintained. This combination results in the smallest vehicle size and dry weight (thus, reduced cost) for any given payload delivery capability. Recent studies conducted to evaluate a number of candidate high-density impulse propulsion approaches identified metallized gelled fuels, such as hydrocarbon and aluminum, as the most promising approach. Suspending small particles of metal in the fuel greatly increases its mass with a minimum increase in volume. Current efforts are being directed toward developing techniques for creating stable metallized fuel gels, and the successful gelling of hydrocarbon/aluminum has been demonstrated. Another effort in the ETO area is focused on developing a

fundamental understanding of combustion instabilities, including combustion response characteristics, combustor acoustic characteristics, triggering mechanisms, resonance-avoidance techniques, stability aid devices, etc. The work is aimed at the oxygen/hydrocarbon propellants generally used in booster stages, but the analytical techniques developed will be generic to other propellant combinations and beneficial to all future propulsion systems. To date, experimental testing with liquid oxygen/methane has demonstrated that a fuel temperature ramping technique developed with hydrogen is also valid for methane. Efforts to understand and model the basic physics of combustion instabilities and to define experimental verification techniques have been initiated.

One other area of interest in ETO technology involves the evaluation of very high-temperature materials (up to 4000 degrees Fahrenheit), such as rhenium/iridium, for use as combustor inner liners. The ability of an inner liner to operate at these temperatures would greatly reduce heat transfer through the combustor, which will ease the regenerative cooling problem and allow higher combustion pressure operation, resulting in much higher engine performance. Design configurations utilizing these high-temperature materials in conjunction with transpiration cooling have been generated, and plans for the fabrication and test of these designs are being developed.

Efforts are also being directed toward demonstrating the performance characteristics of propulsion systems designed to operate with propellants derived from lunar and planetary resources. Studies have been conducted to identify resources available at Mars and on the Moon that could be used for rocket propellants. It has been determined that both oxygen and aluminum can be extracted from the lunar soil, and that both oxygen and carbon monoxide can be obtained from the carbon dioxide in the Martian atmosphere. Combustion devices which could generate chemical energy through the reaction of these resources are currently in design. In both cases, using in-situ derived propellants for ascent from either the lunar or Martian surface will have a pronounced effect on mission costs, since these propellants would otherwise have to be carried all the way from Earth to the lunar or Martian surface for use in the ascent propulsion systems.

The orbit transfer propulsion technology program will provide the design and analysis tools needed for the future design and development of reusable, space-based, high-performance, throttleable, oxygen/hydrogen expander cycle engines. These next-generation high-capability space engines will be used for highly efficient orbital transfer from low Earth orbit to geosynchronous Earth orbit and to lunar and planetary transfer trajectories. They will also be used for lunar and planetary landers, where high performance over a wide throttling range is of paramount importance for efficient propellant utilization during hovering and landing operations. Advanced expander cycle engine concepts that will provide the needed capabilities have been developed and key technologies identified, including those that will allow

the expander cycle engine to be maintained and operated in low Earth orbit. Key technologies include enhanced heat transfer combustor designs that will provide greater turbine drive energy, hence higher combustion pressure operation, and the development of small high-speed turbopumps that can provide high-efficiency operation over a wide flow range (for throttling). In addition, integrated health monitoring and control systems need to be developed to permit automated in-space servicing, as well as fault-tolerant flight operations. Laboratory-scale and bench-type experiments have successfully demonstrated enhanced heat transfer combustor and critical turbomachinery subcomponent designs. In addition, overall health monitoring/control systems have been configured and needed control components and diagnostic sensors identified. Design and analysis tools, as well as materials and fabrication techniques for component level hardware designs, have been developed. Efforts in the chemical transfer element funded in the Pathfinder program will be directed toward the design, fabrication, and verification testing of full-scale components and leading ultimately to an integrated component test capability needed to verify component performance, operation, and predicted interactions at the engine system level.

Auxiliary or low-thrust propulsion technology is directed toward improved capabilities in resistojets, arcjets, ion thrusters, magnetoplasmadynamic (MPD) thrusters, and long-life, efficient gaseous and storable liquid chemical propellant rockets. Two of the recent technology products of this program have been selected for the Space Station baseline design. One is a 25-pound-thrust gaseous hydrogen/oxygen thruster that has operated for over 20 hours without degradation. This thruster will be combined with an electrolysis unit to turn surplus Station water into propellants to provide orbit control and station maneuvers. The other is a multipropellant resistojet that will operate with the anticipated waste gases from the Space Station to both aid in drag makeup and dispose of the gases, so that they do not have to be returned to Earth. An engineering model of the resistojet has completed over 2000 hours of operation without a problem. Another technology transfer item is the selection for planned future solar system exploration projects of the iridium-coated rhenium chamber which adds 10 percent to performance from storable bipropellants by operating uncooled at up to 4300 degrees Fahrenheit. Since the future spacecraft would be more than 70 percent propellant by weight, this 10 percent improvement means hundreds of pounds of added payload. During 1987, a 5-pound rhenium thruster attained an operating time of 12 hours, and a 100-pound unit was made and tested indicating a need for a better injector spray pattern and an improved internal coating procedure. An arcjet thruster, operating at 1 kilowatt (kw) level with hydrazine byproducts, has operated successfully for over 750 hours in two-hour-long pulses followed by cooling, simulating the operational mode of a thruster on a geosynchronous Earth orbit (GEO) communications satellite during 15 years of operation. This test proved that a startup problem which badly eroded the central electrode has been solved. The impulse level of the arcjet is 450 seconds, 50 percent higher than the best system now operating with hydrazine. The potential saving in control propellant is enough to add 2 or 3 years to the life of a GEO satellite. A joint program has been

initiated with a satellite manufacturing company to include a pair of arcjets on a future GEO satellite to verify performance and to investigate interference with communications during arcjet operation. Thirty-centimeter (cm)-diameter ion engines have been operating for hour-long periods in vacuum chambers at ever-increasing power levels. Redesign has allowed more than 20 kw to be processed by this engine, originally designed for 3 kw. More power per engine means fewer engines for future megawatt flights and better reliability. A pair of 30-cm ion engines has been operated as a system to investigate control problems and possible simplifications, such as common power supplies and beam neutralizers. A 50-cm-diameter ion engine has been designed and is in construction. This size could be operated at 100 kw with over 70 percent efficiency. MPD thruster work has been scaling up in anticipation of Pathfinder applications. Megawatt-level pulse work continues at Princeton University. Meanwhile, sustained operation tests at levels of 40 kw for 20 minutes and 70 kw for several minutes have been attained with acceptable electrode erosion. An increase to 100 kw at the Jet Propulsion Laboratory is planned to better understand the critical electrode erosion problem that still limits life.

Advanced propulsion concepts studies continue to investigate promising capabilities not yet within our reach. Efforts include determining the critical research needs for antimatter propulsion and the selection of critical experiments, evaluating the status of fusion propulsion and selecting possible applications to NASA missions, and appraising the ram cannon and railguns. A magnetically confined microwave-induced plasma experiment has been initiated at the Massachusetts Institute of Technology as the first experimental effort under the advanced concepts program.

CHANGES FROM FY 1988 REVISED BUDGET

The $0.6 million decrease in propulsion research and technology reflects the consolidation of the ongoing university space research activities into a separate research and technology base budget category.

BASIS OF FY 1989 ESTIMATE

In the ETO propulsion program, efforts will continue toward developing techniques for creating stable gelled metallized fuels. Experimental efforts aimed at understanding and modeling combustion and heat transfer characteristics of oxygen/metallized fuel reactions will be initiated. Efforts aimed at developing an experimental data base for validating combustion instability analyses will be initiated. The evaluation of very high-temperature materials (4000 degrees Fahrenheit) as potential combustor inner liners will move toward the fabrication and test of alternate design approaches. Propulsion concepts designed to operate with propellants derived in-situ on the Martian and lunar surfaces will be generated, test hardware fabricated, and experimental efforts initiated.

In FY 1989, the orbit transfer propulsion program will focus on developing design concepts, improving analytical techniques, and evaluating advanced technologies for high-pressure combustors, turbomachinery, and health monitor/control systems that will provide the basis for the design and development of advanced components for breadboard testing and evaluation.

The high-temperature iridium-coated rhenium engine technology program will be completed, resulting in design criteria and fabrication procedures that will allow initiation of 100-pound thruster development. Characterization of arcjet designs and systems will be completed with long-life tests (900 hours), vibration testing, and operation at conditions above and below nominal and with plume and electrical interference measurements. The test units for flight on a communications satellite will be fabricated and installed. The 50-cm-diameter ion engine will be operated to develop more design data points for the operations model and to determine the power limits and operating efficiency. A new large vacuum chamber will be completed, allowing continuous operation of 100-kw electric thrusters, both ion and MPD. Experiments will be performed to add an externally induced magnetic field to the field which is self-induced in an MPD thruster to determine whether efficiency can be increased above the current estimate of 35-50 percent. A low-thrust chemical propulsion test stand with very accurate measurement equipment will become available, allowing verification of small, low Reynolds number flow models and a better understanding of the basic physics and combustion in small thrusters.

Advanced propulsion concept studies will continue toward the objective of identifying the most fruitful areas for agency interest and the critical experiments necessary to prove their potential. The magnetically confined, microwave-induced plasma experiment at the Massachusetts Institute of Technology will be in the final stage of fabrication and preparing for test initiation.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Materials and structures research and technology.....	20,877	15,900	15,900	17,500

OBJECTIVES AND STATUS

The objective of the materials and structures program is to provide technology that will enable the development of future spacecraft, large-area space structures, and advanced space transportation systems with significant improvements in performance, efficiency, durability, and economy. Major technical areas of emphasis in materials include fundamental understanding of the properties and behavior of advanced space materials; characterization of the long-duration space environmental effects on space materials; development of computational chemistry to predict fundamental physical properties of materials and their interaction with the space environment; development of advanced space-durable materials for structures, propulsion and power systems; and development of ceramic, metallic, and advanced carbon-carbon thermal protection systems. Structures technology focuses on the development of erectable and deployable structural concepts; methods for in-space construction, monitoring, and repair of large complex structures; dynamics of flexible structures and concepts for active configuration control and vibration suppression; new structural concepts for active cooling of hot structures and cryogenic tanks for advanced Earth-to-orbit rocket propulsion systems, hypersonic vehicles, and orbital transfer vehicles; and efficient analysis and design methodology for advanced space structures, including multidisciplinary analysis and optimization.

Activities in the materials program are focused on understanding the fundamental effects of the space and reentry environment on materials and developing advanced materials with significantly improved durability. The primary environmental effects of concern are atomic oxygen, radiation, thermal cycling, and debris impact. Atomic oxygen is the dominant factor in low Earth orbit and can reduce the useful lifetime of polymer coatings, lubricants, and lightweight polymer composites to a few years. In geosynchronous orbit, radiation and thermal cycling are the major concerns. In both cases, temperature variations affect the short-term and long-term dimensional stability of most materials. Impact from small debris particles (one millimeter to one centimeter) is becoming a more serious problem in low Earth orbit, requiring the development of new lightweight shielding materials and concepts. High temperature from

frictional heating is the main concern during reentry, though catalytic reactions between rarefied gases and the hot surfaces of the thermal protection system can significantly increase the heating rate. Recent accomplishments have identified thermal protection materials and coatings that can minimize this effect. Advances in computational chemistry have demonstrated the potential to predict the catalytic heating effect and have recently demonstrated the ability to predict certain complex, high-temperature, molecular atmospheric interactions. These same methods are being used successfully to predict the interaction of hydrogen with metals and to predict the structure of clusters of metal atoms. These predictions are being validated by data from tests conducted especially to confirm computational methods. Similarly, a special test series is being conducted to evaluate the ability of ground-based test methods to predict the effects of atomic oxygen on space materials. This program began in FY 1987. During FY 1988, the atomic oxygen beam facility at the Jet Propulsion Laboratory will be fully characterized and calibrated. Also, real-time reaction products and the velocity distribution of the fast oxygen atom interactions with space materials were determined, which will provide the basis for improved test methods. New polymers for films and composites, based on fluorocarbon chemistry, are showing significantly improved atomic oxygen durability relative to hydrocarbons. Recent experimental work in this general area has determined the combined effects of thermal cycling and atmosphere on composite tubes. The capability to combine a thin 2-mil outer aluminum foil to graphite epoxy composite tubes was demonstrated and provides a validated approach for development of the Space Station core truss members. The outer aluminum foil provides a barrier for atomic oxygen protection, and, by using an anodizing process, the spectral characteristics of the surface can be tailored for thermal control requirements. Also, methods to predict the damage (crater size) from debris impact have been developed along with concepts for improved impact resistance using composite materials. During FY 1988, a model will be developed to predict hypervelocity impact damage to graphite-epoxy composites.

The program in advanced space structures is directed toward methods to build large structures in space and to predict and control their behavior. This includes concepts for lightweight tight-locking joints and methods to maintain dimensionally precise configurations. It is closely coordinated with the large space structures and control element of CSTI but is directed toward basic methodology rather than applied technology. Erectable and deployable concepts are being developed to build large two-dimensional and three-dimensional structures in space. The 5-meter erectable truss concept for the baseline Space Station configuration came largely from this fundamental research program. The development of the baseline Space Station erectable joint concept was completed and includes a dual locking feature to prevent accidental unlatching of the core truss members. Also, a greater emphasis has been placed on automated in-space

construction methods. This has led to the development of a concept for a mobile remote manipulator system to enable rapid construction and easy expansion of the space station. Prototype versions built and tested in the neutral buoyancy facilities at Johnson Space Center and Marshall Space Flight Center will be completed during FY 1988.

In the area of dynamics of flexible structures, accurate methods have been developed and validated to experimentally determine the fundamental stiffness and damping characteristics of complex structures with closely spaced or clustered natural frequencies using relatively sparse test data. In particular, these methods require much less data than currently established methods and quantify damping properties more accurately. They are very applicable to truss-like structures which display frequency clustering and can be very difficult to analyze accurately. A concept also has been developed to control the dynamic motion of flexible structures by placing actuators at the base of the structure with distributed sensors along the structure. Computationally, an advanced capability has been developed to predict the nonlinear dynamics of multibody structures, and multidisciplinary analysis and optimization methods were used to develop a new concept for the Shuttle solid rocket motor field joint and to redesign the external tank attachment ring. During FY 1988, a large amplitude, transient dynamics code for flexible three-dimensional structures will be completed and validated. This will provide the capability to analyze large motions and deployment dynamics of large spacecraft systems.

The area of aerothermal structures is currently focused on developing lightweight, multiwall cryogenic tanks for reusable space transportation systems and advanced thermal protection systems (TPS). A new tankage concept has been developed weighing about three pounds per square foot, and a new lightweight ceramic TPS has been developed with greatly increased structural durability. The brittle nature of advanced ceramic TPS is its primary drawback, and a new surface coating approach has increased fracture toughness of current Shuttle TPS by a factor of ten. Also, analytical methods were developed and validated to predict the interaction of a shock wave impinging on a blunt leading edge at high Mach numbers. This phenomenon, which can increase local heat generation by a factor of ten, is a potential problem in very high-speed vehicles. During this past year, the accuracy of this analytical capability was validated over a range of applications by test data.

The space materials and structures program in hypersonics includes development of high-temperature metallics, intermetallics, and metal matrix composites; coatings for surface protection and thermal control; advanced joining and bonding methods for hot structures, including integral structure/cryogenic

tank concepts; and minimum-gage, oxidation-protected, carbon-carbon materials. A new carbon-carbon research facility has been established at Langley Research Center to develop oxidation-resistant materials. During FY 1988, layered titanium TPS for use up to 900 degrees Fahrenheit will be fabricated and tested for cryogenic tank applications.

BASIS OF FY **1989 ESTIMATE**

In FY 1989, the materials program will continue to focus on the effects of the space environment and on developing more durable materials. A strong emphasis will be placed on using accelerated testing methods to validate new materials. In particular, materials development will concentrate on developing polymers for protective films and composite matrices with 20- to 30-year life on orbit. Work will continue to develop improved protective metallic coatings, which can offer protection from atomic oxygen and micrometeorites, and significantly enhance dimensional stability. Low thermal expansion resins, ceramic fiber composites, and tailored surface treatment to optimize radiative properties also will be studied as ways to maintain dimens'ional stability. This factor will become more important as larger structures are built in space with stringent requirements to act as a stable platform for scientific experiments and astronomical observations. Computational chemistry will place more emphasis on describing combustion kinetics and atomic oxygen interactions with polymers and on predicting properties of large atomic clusters (approximating pure bulk properties). Areas which will start receiving greater emphasis are high-temperature materials for space power and propulsion and materials and shielding concepts for protection from space debris. Strong candidate materials for all three areas are metal-matrix, ceramic-matrix, and carbon-carbon composites.

The program in advanced space structures will continue to develop erectable/deployable concepts for large two-dimensional and three-dimensional structures with a strong emphasis on automated construction methods. However, new design concepts including understanding of joint effects will be developed for precision structures with requirements for high dimensional tolerance and precise pointing, slewing, and tracking capacity. This emphasis is consistent with the space materials program and the large structures and control element of CSTI. A supporting effort will be the development of efficient and accurate methods for multidisciplinary analysis and optimization for this class of structures. The area of dynamics of flexible structures will continue to develop analytical and experimental dynamic characterization methods and will focus on the concept of "smart" structures as a means for control. This involves the development of structural elements which sense vibration and distortion, either by internal or external sensor devices, and respond with the aid of embedded integral actuators in a manner which opposes the disturbance. Piezoelectrically activated structures will be developed to explore concepts of this type. Components will be designed, fabricated, and tested to demonstrate "smart" structures capabilities for

vibration suppression or load alleviation. A goal of at least 25 percent improvement in structural damping using "smart" structural components will enable efficient performance gains not achievable with current technology. The focused control/structure interaction technology program, conducted under the large structures and control element of CSTI, will benefit from and be closely coordinated with this research and technology base activity.

The aerothermal materials and structures activity will continue development and testing of lightweight cryogenic tank concepts and advanced ceramic TPS with higher temperature capability (approximately 3000 degrees Fahrenheit) and high structural strength. Design and analysis emphasis will be placed on validating design concepts for curved tank structures. Curvature causes more severe realistic thermal stresses such that concepts for flat panels may not be suitable for complex shapes. Integral and separate cryogenic tank subscale components will be fabricated and tested to validate design concepts for advanced thermal protection systems and structural integrity. Ceramic composite TPS design concepts including advanced fabrication methods using improved multiaxis weaving will be continued in FY 1989. The goal of improving transverse mechanical properties by at least 50 percent will be emphasized which will then enable effective use of ceramic composites as both structural components and TPS. Here, as well, curved TPS ceramic-ceramic concepts will be fabricated and validated using arc jet tests required to achieve the high-heating rate environments for hot structures. These activities will be supported by a strong program in analytical and experimental methods to predict aerothermal loads. An increasing part of this activity will be extensive testing of hot structures, including cryogenic tankage concepts.

The effort in space-related hypersonics will emphasize generic concepts for lightweight structures with complex shapes, including novel concepts for areas of extreme heating, such as leading edges and nose caps. One concept currently under study, in small scale, is a spinning leading edge. Advanced joining and shaping methods will be studied for thin-gauge sheet and multiwall concepts, again emphasizing curved complex surfaces. Work also will continue on carbon-carbon materials including methods to improve transverse properties. Various coating concepts will be explored to improve oxidation resistance of advanced carbon-carbon composites. Small-scale components will be fabricated and tested under simulated service environments up to 3000 degrees Fahrenheit to assess the potential for carbon-carbon high-temperature structures for hypersonic vehicles.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Space data and communications research and technology.....	13,252	8,300	7,900	9,300

OBJECTIVES AND STATUS

The space data and communications research and technology program is directed toward developing advanced ability to control, process, store, manipulate, and communicate space-derived mission data and enabling new communications concepts.

In the area of advanced data systems, an erasable programmable read-only memory based on the Hopfield model of neural networks was demonstrated. Materials for a variable-strength reversible synaptic connection have been evaluated. These neural memory systems have the potential to replicate the capability of the human mind for pattern recognition and deductive reasoning and will serve as hardware-based natural intelligence machines and smart knowledge bases for space applications such as robotics. The implementation of an integrated software development environment was demonstrated, and the system design was expanded to include software experience from successful programs. An advanced software life-cycle simulation development was applied to a model of the Space Station software development environment. These tools are intended to provide software managers with critical tools for evaluation of software development cost and schedule.

The communications effort is directed toward maintaining the research and technology base to enable reliable, ultra-high-rate communication links for future NASA missions. An engineering model of a 5.5-watt X-band solid-state power amplifier using gallium arsenide materials technology has been developed with greater than 30 percent efficiency. Two such models, successfully tested in a vacuum environment, have been integrated to produce more than 10 watts of radio-frequency power. A program combining existing structural and thermal computer codes and geometrical optics/aperture integration codes has been developed to enable the prediction of the far-field performance of complex dual-reflector antenna systems. A procedure has been developed for determining the amplitude and phase excitation coefficients for an array transmit or receive feed which will allow on-orbit compensation for degradation in performance due to antenna distortions. This technology may alleviate the need for more complex and costly antenna shape

control. In the area of optical communications, a high-power diffraction-limited aluminum gallium arsenide semiconductor diode laser with a channel substrate planar structure has yielded less than 1/30th wave phase-front error and has demonstrated over 15,000 hours lifetime at 50 milliwatts output power. Finally, two highly efficient 200-milliwatt semiconductor diode laser arrays were employed to pump a niodynium-doped yttrium-aluminum garnet laser yielding 120 milliwatts of continuous output power. This represents significant increases in both power and reliability and comes much closer to meeting projected requirements for space applications than previous lasers. Long-life space qualifiable lasers are critical to practical space optical communications.

CHANGES FROM FY 1988 REVISED BUDGET

The space data and communications research and technology program has been reduced by $0.4 million, reflecting the consolidation of university space research activities into a separate research and technology base budget category.

BASIS OF FY 1989 ESTIMATE

To enable an erasable neural network memory, the design of reversible synapses will be optimized; test structures and devices will be fabricated; and a study of advanced neural network applications will be initiated. A generic software life-cycle model will be validated by application to a number of NASA-managed software projects. The initial version of the software management environment will be applied to management and acquisition of software systems, and the knowledge base and tools will be validated and expanded toward meeting the objective of providing a complete and integrated set of tools and measures for management and acquisition of major software systems. Funding will be provided to continue support for the software engineering research center at the University of Houston at Clear Lake for continued research in Ada software development, integration, and validation for embedded and distributed systems.

In FY 1989, work will focus on the technology to develop more efficient, lighter, and smaller deep space communications. The Ka-band (32 gigahertz) promises significant improvements in these areas. Research will continue on the development of an efficient Ka-band spacecraft solid-state power amplifier. At the same time, this will enable efficient power combining and electronic beam steering with the use of monolithic microwave integrated circuits in the transmit and receive modules. Phased-array feed codes

will be applied to the 15-meter hoop column antenna to evaluate their potential for compensibility for reflector distortion. The techniques will be essential for large radiometric antennas for Earth remote-sensing applications. In the area of optical communications, research will continue on the development of laser arrays using the distributed-feedback structure with the advantage of single-frequency operation under conditions of high speed modulation. Coherent laser arrays allow the combining of low-power, solid-state, laser diodes into a high-power, high-data-rate optical communication transmitter. For deep space communications applications, high peak power laser output pulses are required. Since holmium-doped yttrium-lithium fluoride has a fluorescence lifetime 60 times longer than niodynium-doped yttrium-aluminum garnet, these materials offer the potential of greatly increased peak powers. Research will continue on semiconductor diode array pumping of this longer life laser material.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Information sciences research and technology.....	a,a27	7,600	7,700	9,000

OBJECTIVES AND STATUS

The objective of the information sciences research and technology program is to provide new concepts, techniques, system algorithms and architectures, hardware devices and components, and software in order to enable viable and productive space information systems.

In the information sciences area, the distributed access view integrated data base (DAVID) system software has been built and tested to provide scientific users a transparent access to space data stored in dissimilar data bases. In addition, design and detailed software specifications for a library layer on top of the DAVID system have been successfully completed. Refinements to the initial prototype version of the hyperspectral image analysis expert system have been completed. This tool supports the heavy software analysis requirement presented by the data generated by imaging spectrometer instruments. In the concurrent processing research area, five algorithms were successfully run on the massively parallel processor. One algorithm used in the study of climatology executed 4,000 times faster than conventional virtual address computers.

In the sensing area, two focal plane deep diode X-ray imaging detectors have been fabricated and are undergoing tests. They provide high-resolution (250 electron volt) imaging capability in the 1- to 130-kilovolt x-ray energy range and have the potential of providing better spatial and energy resolution than a charged-coupled device and calorimeter instruments. High-purity mercury iodide crystals for application as an x-ray spectrometer detector have been shown to have an energy resolution of less than 400 electron volts. Electron property measurements of liquid phase epitaxy grown mercury/zinc/telluride (HgZnTe) material have yielded superior carrier mobilities and lifetimes of 2670 nanoseconds to make it superior to mercury/cadmium/telluride as a detector material. This new material offers the promise of low-cost, highly reliable far-infrared sensors with reduced transmitter output energy requirements and reduced telescope size.

In the area of photonics, a new theoretical mathematical technique for the construction of matched spatial filters has been developed which will enable the identification of multiple objects in a viewed scene irrespective of the objects' scale, orientation, and aspect angle. For the first time, these filters have been demonstrated in an optical correlator at video rates of 30 frames per second, a significant step toward real-time correlation vision systems. A prototype acousto-optical spectrum analysis system has accomplished coarse grain spectral resolution producing a thousand frequency bins. This system allows rapid, low-cost analysis of radio frequency signals.

CHANGES FROM FY 1988 REVISED BUDGET

Information sciences research and technology reflects an increase of $0.1 million, which results from a realignment of $0.5 million from high rate/capacity data in the CSTI information technology program for photonics research, offset by a reduction of *$0.4* million which was included in the consolidated university space research program.

BASIS OF FY 1989 ESTIMATE

A high priority item for infrared astronomy research is to develop an ideal detector which can detect the arrival of a single signal photon in a "nearly noiseless'' fashion. Research will continue on the following detectors that have the potential to fulfill this goal. The deep diode X-ray detector array will undergo further testing to delineate the mechanism for variations in pixel response and resolution. A large-area high-resolution mercury iodide detector will be constructed, and the design of improved detector/preamplifier electronics will be completed. Experiments will continue on mercury/zinc/telluride, in particular on the possibility that it has a longer wavelength cutoff than mercury/cadmium/telluride. Recent experiments on a solid-state photomultiplier for infrared astronomy applications indicate that this device may have quantum efficiencies of over 30 percent, fast response, and low dark current. The avalanche mechanism of carrier gain multiplication will be investigated; models of device noise will be developed; and experiments will be done on the output pulse shape. Besides detectors, solid-state lasers must also be researched for improved power performance and new lasing wavelengths for in-situ sensing of planetary atmosphere and surfaces. To rapidly study possible candidate laser materials, fibers of these materials will be grown and fabricated. An analytic model describing absorption due to laser-induced emission, affected by the length of the fiber from excitation to emission, has been developed in order to study the spectroscopy of these materials. These models allow the early analysis of a complete laser system to guide the development and transfer of new laser materials.

In the area of photonics, one of the objectives is to provide real-time computer vision which requires research to increase the speed of the optical devices. The matched spatial filter component research will be dedicated to improving device size, contrast, and speed. New solid-state materials with large electro-optical coefficients will be investigated for use as spatial light modulators. A second objective is to provide very low-cost signal analysis for applications such as the microwave observing project which needs to scan a large number of frequencies with ultra-high resolution in order to detect signals from other planets. The acousto-optical spectrum analyzer research will be directed toward increasing frequency resolution by employing two-dimensional charge-coupled imaging arrays whose output can be digitized in real time and further processed by digital electronics.

	1987 Actual	1988 Revised Budeet	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Controls and guidance research and technology.....	7,300	*5,800*	*5,500*	6,700

OBJECTIVES AND STATUS

The goals of the controls and guidance research and technology program are to develop and validate advanced control synthesis techniques for large, flexible, loosely coupled structures; to establish analytical and design tools attendant to such developments; to provide the basis for onboard guidance, navigation, and control techniques for future space transportation systems; and to define and develop methodologies for the design and validation of highly reliable advanced flight-crucial controllers. The emphasis is placed on establishing analytical tools for the control of both large space structures and space transportation systems and testing these tools in high-fidelity computer simulations and, where applicable, in ground and flight tests.

One focus of the work for the past year has been the development of mathematical techniques for analyzing and controlling large, lightweight, flexible structures, such as space station and large space antennas. This multidisciplinary research, done in collaboration with the materials and structures research and technology program, emphasizes control techniques. Large flexible structures that will be used in space are not easily characterized by the linear models frequently used for structural analysis and control design. Accurate mathematical descriptions are required for control design because of the lack of structural stiffness of these structures. Slewing control laws have been developed using nonlinear models which are more difficult to analyze than the linear models, but which provide much higher fidelity mathematical description of real space hardware. The vertical beam/antenna configuration at the Marshall Space Flight Center has been used to validate three new control concepts based on multiple sensors and actuators which show promise for use in large antennas and the Space Station. The use of fiber-optic sensors and piezoelectric actuators that are continuously distributed throughout the structure has been demonstrated on a generic large space structure test article. These extremely lightweight elements will greatly reduce the complexity of sensor and actuator systems. A breadboard has been designed and fabricated for a three-dimensional spatial high-accuracy position encoding sensor. This technology is essential for the real-time shape identification of large space structures that must

maintain precise surface accuracy. The fiber-optic gyro shows promise of significantly reducing the cost, complexity, and power demand while increasing the usable lifetime of rotation sensors for spacecraft. Significant progress is being made in replacing the electrical components in these devices with lightweight, low-power optical components and in reducing these optical components to the microchip level. A 3-component optical chip for a fiber-optic rotation sensor has been evaluated, and the preliminary demonstration of an 8-component optical chip version has been completed.

In the space transportation technology area, control laws have been developed for aerodynamically assisted orbit transfers using trajectories that skip through the upper atmosphere, and these have been tested in computer simulations. This type of trajectory will be required for vehicles returning from lunar or Mars missions. Computer simulations for testing onboard, real-time guidance logic for aeroassisted space vehicles have been developed and interfaced with more complete mission simulations using a program that optimizes space trajectories. These simulations are required for comparing various approaches for guidance, navigation and control in a realistic mission environment.

CHANGES FROM FY 1988 REVISED BUDGET

The controls and guidance research and technology program was reduced by $0.3 million, which reflects the consolidation of university space research activities into a separate research and technology base budget category.

BASIS OF FY 1989 ESTIMATE

Research in the space controls and guidance area will continue to emphasize development of theoretical tools for identification and control of large flexible space structures and for guidance and control of space transportation systems. Advanced laws for the identification and control of large space structures will be tested using ground-based facilities at the various NASA centers to determine which approaches can be effectively applied to the real structures, such as space station and large deployable reflectors. Research and testing will continue into the application of distributed fiber-optic sensors and actuators to more complex space structures in order to reduce the complexity and weight of systems required for structural control. The sensor will be evaluated for real-time position sensing in three dimensions and for simultaneous tracking of a number of different targets to simulate the task of tracking the precise position of a large space antenna. The fiber-optic rotation sensor will be tested using an 8-component version of the optical chip in order to further reduce the weight and complexity of the final optical gyro.

In the area of space transportation technology, the emphasis will remain on the development of algorithms for onboard real-time guidance and control for the purpose of reducing the operational costs associated with space missions. This emphasis is also imperative for the vehicles, such as aeroassist orbital transfer vehicles and the National Aero-Space Plane, which have special requirements for autonomous guidance, control, and mission planning, Guidance algorithms for ascent and abort will be developed in order to reduce operational costs and increase system reliability for new vehicles such as the advanced launch system (ALS). Technologies for validation of flight software and hardware using state-of-the-art fault-tolerant computers will be developed using a systematic approach that takes advantage of advanced information processing architectures.

	'1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Human factors research and technology.....	2,274	4,400	4,200	5,300

OBJECTIVES AND STATUS

The objectives of the space human factors research and technology program are to provide a technology base for intelligent operator interfaces, especially with autonomous subsystems, and to develop a new generation of high-performance space suits, gloves, and tools/end effectors to meet the requirements of advanced space missions. Development of guidelines for man-machine interfaces in space, computer-generated models of human performance in weightless conditions, and unique means for collection of human performance data in weightless conditions are included in these objectives. This research is focused on the space station and other manned missions now being planned which will involve more autonomous operation to reduce the cost of ground support. The technology base is intended to provide increased productivity, efficiency, and safety in complex manned operations within automated onboard systems and extravehicular activity (EVA) environments. Two key areas of human factors research are crew-station design and extravehicular activity.

Crew-station research focuses on: (1) development of integrated operator-interface technology for the supervision of space subsystems, (2) development of human-computer interface technology, including guidelines for effective three-dimensional interactive visual and aural displays, (3) providing a data base and standards of human capabilities and limitations in the space environment, and (4) development of a technology for autonomous vision and other perceptual systems to be used in space operations and maintenance.

Extravehicular activity research builds on progress made in the design, testing, and operational evaluation for an advanced hard space suit (AX-5). The utility of advanced gloves, tools, and end effectors for EVA activities is being determined through tests in special buoyant facilities for space assembly and construction tasks.

Research in crew-station operations has included: (1) applied studies of crew operations for docking maneuvers with Shuttle models, (2) analysis of astronaut operational procedures in the space workstation, and (3) identification of window requirements. An anthropometric, computer-based model was developed, providing the capability to simulate human performance in the weightless environment. A number of vision studies were performed to determine and verify algorithms of retinal sampling and color coding to allow the analytical evaluation of alternate crew-station approaches. Characteristics of visual displays and computer-generated graphics that automatically capture the operator's attention were analyzed and documented to identify the better methods to use in the design of operator displays. An ongoing project to develop a workstation in which the operator, through use of a helmet with controlled audio and video input, is made to think he is in a computer-generated environment has been demonstrated. This virtual workstation capability can allow the crew to have a natural interaction with complex operational tasks which may be performed miles away from the crew's location in either a training or actual situation.

Operational experience of NASA personnel who have been involved in designing and piloting spacecraft provides an important base of information and insights relative to lessons learned. This information is being collected and organized as a data base and will be used to avoid repetition of errors and to increase the quality of the human interface. The National Research Council, National Academy of Sciences, completed an analysis of human factors needs for advanced space missions, especially those associated with the Space Station. The report was published in August 1987 and provided specific research recommendations for man-in-space operations, habitation, and productivity in unique and inhospitable environments. This study will serve as a guide to selecting our future research activities.

Research to achieve safe and productive EVA operations continues. A helmet mounted display was developed to assist the astronaut during EVA operations by making it easy for him/her to view data needed in the EVA task and to increase productivity. Test and evaluation of the AX-5 hard suit in the Ames Research Center's neutral buoyancy test facility provided a strong astronaut endorsement of the high-pressure (eight pounds per square inch) hard-suit concept. New tasks included development of a three-point body restraint system for use in EVA operations.

CHANGES FROM FY 1988 REVISED BUDGET

The $0.2 million reduction in human factors research and technology reflects the consolidation of university space research activities into a separate research and technology base budget category.

BASIS OF FY 1989 ESTIMATE

Evaluation of realistic, but simulated, Space Station proximity operations will be continued. Among the important topics for research are the effects of intense sunlight or darkness on visual displays and on workspace layout, including windows, other displays, and simulated operational capabilities in place. This will allow realistic workload levels to be imposed on the operators in order to evaluate operational methods and procedures. Advances in the virtual workstation will allow realistic test and information management capabilities and control of robotic operations. This effort will include assessment of three-dimensional virtual visual and auditory displays. Tests of previously developed vision and image coding methods and methods for attracting human attention to one item in preference to others will provide a baseline for advanced test and evaluation of new interfaces used in Space Station operations.

The interaction of the astronaut and his/her EVA suit will be evaluated by a series of tests on the ground, in simulated weightlessness, and under weightless conditions. Important tasks to be evaluated include astronaut strength capabilities and requirements during EVA and under weightless conditions, the relation between EVA suit design features and EVA operational maintenance requirements, and astronaut training.

Research recommended in the National Academy of Sciences report on space human factors will be reviewed with the goal of putting increased emphasis in three important research problem areas: (1) human supervision and control of autonomous space systems, (2) teamwork and interaction between automated systems/robotic systems and humans, and (3) the appropriate use of expert systems for aiding space operations and maintenance. These areas provide both the biggest challenge for humans in space operations and the largest payoff in increased productivity, safety, and effectiveness.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Space flight research and technology.....	20,096	22,600	21,400	18,100

OBJECTIVES AND STATUS

The objective of this program is to provide research-quality flight data supportive of ground-based research and technology efforts for the development of future space systems and operations. Data obtained from this effort support the development and verification of analytical theories and verification of ground facility performance, test methods, and techniques. This program encompasses the design, development and flight test of experiments, and the development of special purpose, reusable, flight research facilities for use in space.

Cryogenic fluid management flight experiment concepts which will provide a basic understanding of the storage, acquisition, and transfer of cryogenic fluids in the near-zero gravity environment have been formulated for flight. In FY 1988, three parallel feasibility study contracts were awarded to examine both of these concepts in greater detail. Additionally, in the supporting ground-based program, a contract will be awarded for a liquid hydrogen flowmeter and for the design and qualification of a fail-safe valve to control the flow of hydrogen between the tanks of the flight experiment. Individual computer codes, such as that for the heat exchanger, will be incorporated into a master program which will have a preprocessor menu for easy access to its use.

In the orbiter experiments program, the Shuttle upper atmosphere mass spectrometer (SUMS), Shuttle entry air data system (SEADS), Shuttle infared leeside temperature sensor (SILTS), and the high-resolution accelerometer package (HiRAP), which characterize the aerodynamic/aerothermodynamic environment, will be recertified and reinstalled on OV-102. The design and fabrication of the advanced ceramic thermal protection system (ACTPS) materials experiment, which provides actual flight data on durable high-performance material concepts, will be completed. Fabrication will be completed on the orbital acceleration research experiment (OARE), which will provide data to evaluate aerodynamics induced decelerations in the free molecular flow flight regimes at orbital altitude and during entry.

The space technology experiments platform (STEP) is being developed as a cost-effective, reusable payload/experiment support system for interfacing with the Space Shuttle systems. In FY 1987, fabrication of the payload integration hardware was completed. The development of the platform avionics interface systems will continue through FY 1988.

The industry/university in-space technology experiments program (outreach) was initiated in FY 1986 to stimulate the aerospace community through the utilization of Space Shuttle and Space Station for advancing the total U.S. technology inventory. The initial selection of 41 potential flight experiments was completed in FY 1987, and contracts for definition and development will be awarded in FY 1988. Critical space technology requirements for future U.S. missions will be identified at a workshop in FY 1988.

The NASA in-space technology experiments program (inreach) was initiated in FY 1986 to stimulate flight validation of advanced space technologies being developed in the NASA research and technology ground-based facilities. Seven potential flight experiments were selected in FY 1987 for development and are planned to culminate in space flight tests during the early 1990's.

The light detection and ranging (LIDAR) in-space technology experiment (LITE), being developed to evaluate the capability of making measurements of aerosols and other atmospheric parameters from a spaceborne platform, has completed the fabrication and testing of a prototype laser transmitter module. These tests have verified the laser architecture and the power and beam quality that allows flight design to proceed. In addition, the protoflight development of the boresight assembly, telescope support structure, and the aft optics system has been completed. Systems design of the experiment will be completed and parts fabrication initiated.

The long-duration exposure facility (LDEF) awaits retrieval by the Shuttle and subsequent data analysis. Also, the ion auxiliary propulsion system remains in flight-ready status for flight on an Air Force satellite. Fabrication and flight certification have been completed on the heat-pipe radiator experiment which is awaiting an early Shuttle flight.

CHANGES FROM FY 1988 REVISED BUDGET

The space flight research and technology program reflects a realignment of $1.2 million into the consolidated university space research program.

BASIS OF FY 1989 ESTIMATE

For the cryogenic fluid management program, development of the liquid hydrogen and gaseous flow meters and the cryogenic relief valves will be completed.

Under the orbiter experiments program, flight testing for SUMS, SEADS, SILTS, and HiRAP will begin in early FY 1989. Two flights for each of these experiments are scheduled. Additionally, installation of the remaining experiments, orbital acceleration research experiment (OARE), aerothermal instrumentation package (AIP), tile gap heating experiment (TGHE), catalytic surface effects (CSE), and the advanced ceramic thermal protection system (ACTPS), will be accomplished on OV-102 for flight beginning in mid-1989. Analysis of the data from these experiments will occur throughout the year.

STEP will continue with the development and ground testing of the platform and avionics systems.

The second solicitation in the in-space technology experiments program (outreach and inreach) will be initiated for critical space technology flight experiments. These experiments utilizing Space Shuttle and Space Station are an integral element in regaining U.S. leadership in space technology development.

Experiment assembly and certification testing for LIDAR LITE will be conducted during FY 1989.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Systems analysis.....	6,576	6,000	5,700	6,900

OBJECTIVES AND STATUS

The objectives of the systems analysis program are to identify technology requirements for prescribed mission concepts and opportunities for enabling new and improved concepts; to integrate these into a comprehensive technology set of planning options; and to generate candidate plans to develop these technologies in a timely manner. Close coordination with the Offices of Space Flight, Space Science and Applications, Space Operations, Space Station, and Exploration and other users is maintained to ensure proper understanding of missions and to gain assistance in prioritization of enabling and high-leverage technologies. This analysis program is directed at the systems-focused areas of space transportation, spacecraft, and large space systems and at emerging, new, mission concepts and mission-enabling technologies.

Spacecraft systems analysis is concentrated in five science and applications areas: astrophysics, space physics, Earth science, communications, and solar system exploration. In FY 1988, efforts to understand the critical technologies associated with geosynchronous Earth science observations and tethered upper atmospheric satellites will be continued. A comprehensive series of studies on the technologies required for a Mars surface sample return mission is being completed. A second Mars rover workshop was held to establish future directions of the automation and robotics program. Detailed analyses of technology tradeoffs for the Mars rover sample return (MRSR) orbital spacecraft have been initiated. Working through the spacecraft 2000 government/industry steering group, a joint strategic plan was developed for future spacecraft technology development, and definition of a spacecraft experiments testbed was continued.

The space transportation systems analyses are focused on advanced Earth to orbit (ETO) vehicles, aeroassist orbit transfer vehicles (AOTV), and advanced space transportation systems conceptual design and analysis methods. Studies and analyses focus on the generic architecture from the ongoing space

transportation architecture studies (STAS). The ETO studies include the technology to support a second-generation fully reusable piloted vehicle, an advanced heavy-lift launch vehicle, and very advanced (post-2010) future space transportation systems. The ETO studies also include the definition of nonintrusive flight instrumentation and measurements applicable across the speed range during ascent and entry of an ETO vehicle.

Three specific study areas constitute the large space systems analysis program: (1) systems analysis methods, to develop and maintain advanced analytic simulation/emulation computer-based capabilities for determining the operational characteristics of large space systems, predicting nominal and worst-case failure modes, and identifying critical system/subsystem interfaces; (2) future space systems, to address mission and system requirements and to identify their associated technology needs and trends; and (3) in-space research and technology experiments planning, using the Shuttle and Space Station as a laboratory facility. Analysis activities continue to examine the technology implications for designing a lunar base with emphasis on power systems and habitat facilities. Also, the definition of support hardware necessary to use the Space Station for in-space research and technology experiments is being completed. Specific efforts continue to develop generic space system models to permit the conduct of sensitivity trade studies incorporating advanced technology concepts and options. Additional tasks are investigating advanced power system technology for evolutionary space stations and a lunar base, low-gravity structures for the Moon, propellant and oxygen production from lunar oxides and Martian permafrost and atmosphere, and food production and enhanced human capability for extended space missions. FY 1988 activity includes the preliminary definition of experiment support equipment for an aggressive in-space experiments program in the technical areas of fluids, power, environmental effects, and structures and control.

CHANGES FROM FY 1988 REVISED BUDGET

The $0.3 million reduction in the systems analysis program reflects the consolidation of university space research activities into a separate research and technology base budget category.

BASIS OF FY 1989 ESTIMATE

In N 1989, many of the long-range efforts currently underway will be continued. These efforts will have substantial impact on the development of future CSTI and Pathfinder technology program elements, as well as on identifying thrusts for the research and technology base and the evolving flight experiments program.

For spacecraft systems, the Mars rover studies will be completed, and emphasis will be directed toward the study of other human expansion precursor missions and an outer planet science station study. A focused study effort will examine the technology planning options for more extensive exploration of planet Earth. Within the astrophysics focus, activities will center on the technology requirements for interferometric observatories across a range of wavelengths. The definition study of a space flight testbed for validating government and industry technology development will be completed. Work will be initiated to synthesize the analytical techniques developed for past studies into a general purpose spacecraft systems analysis capability.

The transportation systems analysis effort will continue the definition of key areas for technology growth in orbit transfer vehicles and advanced systems for delivery of payloads to low Earth orbit. The analyses will focus on concepts and technology requirements for a lunar orbit transfer vehicle, a heavy-lift launch vehicle, and the shuttle replacement. The continued development of design and analysis tools and the technology base for advanced transportation vehicles will enable the development of economical space systems in the future.

In large space systems, the transition of the systems analysis focus from the initial space station to an expanded mission perspective, including evolutionary space stations, lunar bases, and long-duration manned space trips, will be continued. The primary thrust of the extended perspective is to ensure that the research and technology base program is structured to enable and support the needs of these missions in the turn-of-the-century time frame. Additionally, the FY 1989 program will continue to include planning for the use of the Space Station as a facility to support research and technology.

In FY 1989, an added program element will address studies and analysis of opportunity-oriented technologies and their impact on enabling new mission/system capabilities. These studies will explore the potential applications of emerging, high-leverage technologies such as superconductivity, antimatter, and high-level machine learning to the formulation of new or improved system concepts. Detection of extrasolar planetary systems is a mission concept that could be enabled by technological innovation and/or breakthrough.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
University space research.....	---	---	*4,000*	**16,300**

OBJECTIVES AND STATUS

The objective of the university space research program is to enhance and broaden the capabilities of the nation's engineering community to participate more effectively in the U.S. civil space program, and this program is an integral part of the strategy to rebuild the space research and technology base. The program responds to the need to remedy the decline in the availability of qualified space engineers by making a long-term commitment to universities aspiring to play a strong engineering role in the civil space program. The program utilizes technical advisors at NASA centers to foster collaborative arrangements, exchange of personnel, and the sharing of facilities between NASA and the universities. The program elements include the university space engineering research program that supports interdisciplinary research centers; the university innovative research program, providing grants to individuals with outstanding credentials; and the university advanced space design program, which funds advanced systems study courses at the senior and graduate levels.

The university space engineering research program is designed to advance the traditional engineering disciplines applicable to space and bring together the knowledge, methodologies, and engineering tools needed to advance future space systems. The research centers promote the kind of multidisciplinary teamwork that systems technological problems demand and bring individuals from a wide range of engineering and scientific fields into a single research structure. These partnerships provide the universities with a broader charter for independent research and enable new mission concepts and ideas that might alter NASA's own visions of the civil space program. In the summer of 1987, the Office of Aeronautics and Space Technology issued a notice calling for proposals by November 1987. A total of 115 proposals were submitted, and 310 evaluators were selected from NASA, industry, universities, and other government agencies to conduct the evaluation process.

The objective of the university innovative research program is to sponsor individual research on highly innovative space technology concepts directed toward far-term mission use. The grants will be awarded to persons who have a demonstrated record of performance in generating and validating innovative concepts.

Selection of grantees will be made through a competitive evaluation conducted by a peer review selection panel. The grants to innovative researchers are for a three-year duration, with one-year awards and two annual renewal options. Each grant requires a center-designated person to serve as technical advisor for the research activity. Eventually 20 or more small ($100 thousand/year order of magnitude) individual research grants will be awarded.

The objectives of the university advanced design program are to foster engineering design education in the universities and to supplement **NASA's** in-house efforts in advanced planning for space systems design. Expanding from the original 9 to a total of 25 universities cooperating with 8 **NASA** installations in 1988, the advanced design program continues to mature and strengthen. The study topics include potential missions which could be undertaken during a 20-30 year period, beginning with the space station initial operating configuration scheduled for the mid-1990's. During FY 1988, design studies for both manned and unmanned endeavors included a lunar storage and transfer system, variable artificial gravity facility for the Space Station, ram accelerator direct launch system for space cargo, long-term space habitat, construction equipment for lunar base, and a Mars oxygen processor demonstration unit. The university advanced design program has been an effective mechanism for integrating the educational objectives of the university community with the advanced engineering design interest of **NASA.**

CHANGES FROM FY 1988 REVISED BUDGET

A total of *$4.0* million has been realigned from other programs within the research and technology base to consolidate the university space research activities into a separate research and technology base budget category.

BASIS OF FY 1989 ESTIMATE

The FY 1989 university space research program will be augmented to enable an increased number of universities and academic researchers to participate effectively in the program.

In FY 1988, the program funding will permit establishment of eight research centers. The FY 1989 program funding is required to continue the support of the incumbent centers, as well as to expand the number of centers. The enthusiastic response from universities, both in number and in the quality of the proposals, demonstrates the timeliness and perceived value of the program. Many excellent proposals will not be funded in FY 1988. The augmented program will allow **NASA** to expand university participation, achieving a better technical balance and a broader geographic involvement, and to more fully satisfy program goals.

It is intended to continue funding, as planned, those eminent researchers selected in FY 1988 to participate in the university space innovative research program and to continue to add on a quarterly basis additional three-year grantees. The total number of grants is planned to reach a level of approximately 20 during FY 1989. Grant additions will continue in future years, with some rollover of grantees occurring at the lapse of their three-year grant periods. The university space design program will continue during FY 1989 and will seek to become more effectively coupled to the NASA future missions activities, particularly with the space exploration program studies efforts. There will also be an attempt to increase the interactions and cooperative efforts between universities so that related studies can be coupled for a more effective program. Semiannual conferences will be continued to promote these interactions.

BASIS OF 1989 FUNDING REQUIREMENTS

SYSTEMS TECHNOLOGY PROGRAMS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Chemical propulsion systems technology	46,100	---	---	---
Space flight systems technology	11,254	---	---	---
Automation and robotics	18,000	---	---	---
Total	75,354	---	---	---

These programs were incorporated into the CSTI program in FY 1988.

BASIS OF 1989 FUNDING REQUIREMENTS

CIVIL SPACE TECHNOLOGY INITIATIVE (CSTI) PROGRAM

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
		(Thousands of Dollars)			
Automation and robotics	---	25,100	25,100	25,900	RD 15–51
Propulsion	---	38,800	23,800	46,700	RD 15–55
Vehicle	---	15,000	15,000	28,000	RD 15–58
Information technology	---	17,000	16,500	17,100	RD 15–60
Large structures and control	---	22,000	22,000	25,100	RD 15–64
High-capacity power	---	12.800	12,800	14,000	RD 15–67
Total	...	130,700	115,200	156.800	

The Civil Space Technology Initiative (CSTI) is developing the technologies to enable reliable and lower cost access to space and to support enhanced space operations and science missions. Support for future space transportation systems includes: autonomous systems research for prelaunch and postlaunch operations; reusable, high-performance engines for next-generation launch vehicles; and a flight demonstration of aerobraking for orbit transfer vehicles. Future Earth-orbiting operations and science missions will be enhanced through an expanded effort in automation and robotics; technology to significantly increase data processing and storage capabilities; ground and in-space experiments to expand the design data base for very large, flexible structures; and technology for high-capacity nuclear power conversion systems. New sensor technologies and capabilities to deploy large, extremely precise surfaces will further enhance Earth and deep space observation.

BASIS OF FY 1989 FUNDING REQUIREMENTS

CSTI - AUTOMATION AND ROBOTICS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Robotics	---	11,500	13,000	13,600
Autonomous systems	---	13,600	12,100	12.300
Total	---	25.100	25.100	25,900

OBJECTIVES AND STATUS

The objective of the automation and robotics program is to exploit the potential of artificial intelligence and telerobotics to increase the capability, flexibility, and safety of space and ground operations while decreasing associated costs. The goal of the robotics element is to evolve the capability for remote space operations from the current level of teleoperation (direct human control) of a single crane-like arm, through the telerobotic operation (human supervisory control) of dexterous multiarmed manipulators, to the robotic operation (human task-level control) of multiple intelligent manipulators. The goal of the autonomous systems element is the use of artificial intelligence technology to effect the reduction of manpower involved in ground control; automation of control of subsystems aboard the Space Station, spacecraft, and space transportation vehicles; and elimination of astronaut time spent performing housekeeping functions.

The robotics element consists of a sequence of evolutionary demonstrations, together with five core technology elements: sensing and perception, control execution, task planning and reasoning, operator interface, and systems architecture and integration. In FY 1988, the telerobot demonstration facility, which consists of a two-arm manipulator, a third arm with a vision system, and a suspended spacecraft (Solar Max) model, completed its first demonstration task. Using machine vision and integrated position/force control, a spacecraft rotating at two revolutions per minute (RPM) was captured without having a preprogrammed spatial trajectory. Several scientific achievements were accomplished in the core technology areas. In sensing and perception, a machine vision system demonstrated its capability to

identify and track a satellite spinning at 15 RPM with labeled vertices (i.e., lit with light-emitting diodes) and at 9 RPM with unlabeled vertices. This capability will be required for robotic capture of spinning satellites for retrieval and servicing. In the area of operation interface, it was demonstrated that the assembly concept for construction of erectable space structures (ACCESS) could be assembled using teleoperation in a one-gravity environment. Another space structure, the erectable assembly structures experiment (EASE), was actually assembled by the beam assembly teleoperator (BAT) in the zero-gravity simulation of the neutral buoyancy test facility at the Marshall Space Flight Center. These telerobotic assembly tasks establish the feasibility of telerobotic assembly in space. When the robots become operational on the Space Station, they will dramatically decrease the required amount of astronaut time spent doing time-intensive, expensive, and potentially dangerous extravehicular activity. In the area of control execution much more precise manipulation of a single workpiece, required for complex assembly and servicing applications, was achieved through coordinated hybrid position/force control of two arms.

The autonomous systems element is composed of a sequence of evolutionary demonstrations using Space Station, a set of operational demonstrations using Shuttle and spacecraft, and research elements in the following core technology areas: planning and reasoning, control execution, operator interface, and systems architecture and integration. This program is closely coordinated with that of the Defense Advanced Research Projects Agency (DARPA), assuring that relevant technologies in the DARPA strategic computing initiative are fully leveraged.

In the evolutionary demonstrations for Space Station, all preparations were completed for the initial test of the expert system for control of the thermal control subsystem. This system incorporates capabilities for fault diagnosis of a majority of failure modes, real-time control and reconfiguration, and incipient failure prevention through trend analysis of the Space Station's thermal control system. This capability, when operational, will increase the Space Station scientific throughput by allowing the astronauts to spend their extremely valuable workhours on scientific experiments rather than on mundane housekeeping functions. In the operations demonstrations, one expert system has been developed for monitoring and making recommendations on management of Space Shuttle communications, and another has been developed for autonomous control and diagnostics of the Space Shuttle's environmental control system during launch processing. In the core technology program, an expert automation classification (AUTOCLASS) system has been developed which through deduction automatically learns the most probable set of subclasses of a data base. Such a system will help scientists who are studying large data bases, such as the infrared astronomical satellite data base, by automatically breaking down the entire data base into smaller sets of highly similar data vectors. For example, (AUTOCLASS) has provided the indication that

there are more classes of heavenly bodies than astronomers previously recognized. In control execution, a mathematical theory is being developed to integrate artificial intelligence and conventional control system design methodologies. In systems architecture and integration, preliminary performance tests have been completed for an advanced very large-scale integration (VLSI) space-qualifiable symbolic processor developed under this program.

CHANGES FROM FY 1988 REVISED BUDGET

Within the automation and robotics program, $1.5 million has been realigned from autonomous systems to robotics in order to fund priority university research.

BASIS OF FY 1989 ESTIMATE

In robotics, development and advancing technologies are described by a sequence of evolutionary ground demonstrations scheduled through 1996. In FY 1989, the telerobot demonstration facility at the Ames Research Center will perform its first test in which all of its subsystems (artificial intelligence, run-time control, sensing and perception, operator control, and manipulation and control mechanization) are implemented. The task will be to remove and replace a module in the spacecraft mockup. This will be the first implementation of the concept of traded control in which the automatic control system and the human operator can pass control smoothly to each other during the task. Since all existing remote manipulators are either robotic or teleoperator in nature, this will be the first time the integration of the two has ever taken place. Further demonstrations will take place in 1993 and 1996. The 1993 demonstration will incorporate automated replanning for error conditions. The 1996 demonstration will extend repair tasks to include cutting and fabrication.

Research and development in each of the five robotics core technology areas will continue. In task planning, artificial intelligence techniques will be used to develop telerobot arm movement sequences and trajectories to provide more precise and more rapid positioning. In operator interface, development of virtual workstation concepts will continue to focus on the telepresence aspect of the operator control station. In sensing and perception, the machine vision system will be extended to include tracking with partial occlusion, which may occur in real applications, and a 160-module vision system will be developed. In control execution, algorithms will be developed for control of robot arms with redundant links, i.e., with more than six degrees of freedom, thus allowing the same end-effector position to be achieved using different configurations of the arm. In the area of systems integration and architecture, a new grant made to Carnegie Mellon University in FY 1988 will develop a working model of a planetary rover.

Integration of advancing technologies in the automation element is also described by a sequence of evolutionary ground demonstrations through 1996. The first demonstration (in FY 1988) will be of the expert system for control of the Space Station thermal system and will be tested on the thermal testbed at Johnson Space Center. It will be rule-based for control of a single subsystem in which reasoning is limited to standard procedures, and knowledge of the task world is complete and unambiguous. The second demonstration (in 1989) will be of a model-based expert system for coordinated control of multiple subsystems, and it will be capable of reasoning about nonstandard procedures.

The expert system for monitoring of Shuttle communications will be tested during the next Shuttle flight, where it will operate in parallel with the human controllers who will have actual control. The expert system for control of the environmental control system during launch processing actually will be used during the next Shuttle launch. This will be the world's first operational use of artificial intelligence in a space mission. In core technology, the following actions will occur: (1) In planning and reasoning, the classification system findings will be evaluated by astronomers, and development of a generic tool for very complex scheduling problems will be developed; (2) in control execution, the development of methods for integrating artificial intelligence and conventional tools for control system design will continue; and (3) in systems architecture, a brassboard system of the complete space-qualifiable symbolic processor, including system software, will be developed.

BASIS OF FY 1989 FUNDING REQUIREMENTS

CSTI - PROPULSION

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Earth to orbit	---	27,800	15,800	37,700
Booster technology	---	11.000	8,000	9,000
Total	---	38,800	23.800	46,700

OBJECTIVES AND STATUS

The objective of the CSTI propulsion program is to provide a validated design and analysis capability that can be applied to the design and development of advanced propulsion systems for future low-cost reusable Earth-to-orbit (ETO) vehicles and recoverable boosters.

The ETO propulsion technology program will validate advanced design concepts and analytical techniques that have been developed with laboratory-scale, subscale, and rig test hardware through the design, fabrication, and test of large-scale component technology hardware. The technology hardware will be highly instrumented and will be capable of varying operating conditions over a wide range, in order to provide a broad experimental data base with which to validate analytical codes and evaluate new design concepts. Typical components include large-scale combustors and gas generators and high-pressure turbopumps designed for efficient performance over long operating times. Being able to operate at a high combustion pressure provides the opportunity to optimize engine performance, weight, and size for specific vehicle designs. For this reason, most of the effort will be related to high-pressure systems. Accurate modeling of combustion performance, stability, and heat transfer, as well as turbopump hot gas flows, bearing thermal and mechanical characteristics and rotor dynamics, will provide the design and analysis tools needed to develop long-life reusable engine components with accurately defined design margins and performance capabilities.

Candidate propellant combinations include oxygen/hydrogen (at Space Shuttle main engine **(SSME)** and oxygen-rich mixture ratios) and oxygen/hydrocarbons. The program includes the **SSME** testbed engine which will be used to verify the performance of advanced technology components in a system-level environment, including advanced bearings, hollow and single-crystal turbine blades, and diagnostic instrumentation.

In the development of advanced design concepts and analytical techniques, significant progress has been made in a number of areas. A thermal model under development for cryogenic bearings was used to predict bearing temperatures as a function of speed, load, and coolant flow and was validated with data obtained in a bearing tester. Results indicate that two-phase flow may be occurring in the **SSME** pump bearings, and based on this analysis, the cooling flow is being increased. The use of powder metallurgy gives promise of longer life bearings based on the results of rolling contact fatigue testing. This processing technique will be used in the fabrication of new ball bearings for evaluation in the bearing tester. Using a new measurement technique, bearing materials auto-ignition temperatures have turned out to be lower than expected based on classical test procedures. This is due to internal endothermic and exothermic reactions that have been masked in previous testing. In the future, the bearing thermal model will be used to provide adequate temperature margins relative to the newly established auto-ignition temperatures. Advanced single-crystal hollow turbine blades have been evaluated in a burner test rig and show promise of extending blade life up to 30 times that expected with currently used directionally solidified materials. A method of detecting engine anomalies by viewing the exhaust plume with a spectrometer has been developed and has been used to detect degrading bearing materials in the plume. Eventually, with further development, the instrument will be reliable enough for active engine shutdown in real time. Both a fiber-optic deflectometer for measuring bearing wear and an optical pyrometer for detecting turbine blade temperature anomalies have been demonstrated in the laboratory, and design efforts have been initiated for installing these diagnostic sensors in the Space Shuttle main engine pumps for evaluation in the technology testbed.

In the liquid oxygen (LOX)/hydrocarbon combustion area, carbon deposition characteristics of RP-1, propane, and methane at mixture ratios commensurate with gas generator turbine drive operating conditions have shown that methane appears to have the cleanest combustion process at the combustion temperatures of interest, Efforts have been initiated to design and fabricate large-scale LOX/hydrocarbon combustor hardware that will be used to validate combustion performance, stability, and heat transfer analytical models developed in the subscale hardware test program over the past several years. In addition, the procurement of highly instrumented large-scale technology turbopumps for in-house testing to validate turbine stage performance codes, hot gas flow codes, rotor dynamic codes, and advanced design concepts, including new shaft bearing suspension systems, has been initiated.

The booster technology program will investigate alternate propulsion concepts for the Space Shuttle booster, both solid-liquid hybrid boosters and pressure-fed bipropellant liquid boosters. Performance models will be generated and verified with data from a number of static firings with increasing size. Thrust levels of up to a million pounds will be considered. A single system will be selected for large-scale demonstration of performance and safe abort capability. There has been limited experience with either booster system to date. Hybrid firings have not exceeded 75,000 pounds of thrust and pressure-fed systems have not exceeded 250,000 pounds. There has been no technology effort with either system for booster applications for several years.

CHANGES FROM FY 1988 REVISED BUDGET

The CSTI propulsion program has been reduced by $15.0 million as a result of Congressional action on the FY 1988 budget request -- $12.0 million in Earth-to-orbit and $3.0 million in booster technology.

BASIS OF FY 1989 ESTIMATE

In FY 1989, the CSTI Earth-to-orbit propulsion program will continue to conduct LOX/hydrocarbon specific technology tasks to verify high-pressure ignition, combustion performance and stability, heat transfer and cooling, and will begin the design and fabrication of appropriate large-scale technology turbopumps. Models and design concepts developed in the subscale research and technology base program will be used for the design of the large-scale hardware.

The Space Shuttle main engine testbed effort will include the final assembly of the testbed engine and the initial hot-fire operations utilizing the newly activated S1C test stand at the Marshall Space Flight Center. Research-quality diagnostic instrumentation, including selected advanced technology sensors, will be installed and calibrated. Advanced technology components (turbine blades, diagnostic sensors) will be prepared for installation for the second hot-fire test sequence.

For the hybrid booster system, FY 1989 efforts include evaluating candidate fuels, establishing burning characteristics, evaluating propellant configurations, selecting an oxidizer pump concept, evaluating spray concepts, and establishing the mechanisms for a safe abort option. For pressure-fed liquid booster systems, tasks include propellant selection, combustion stability characterization, pressurization systems, design, nozzle size and number optimization, and structural design and material evaluation. Both systems will enter the mid-size hardware fabrication and test phase in FY 1989.

BASIS OF FY 1989 FUNDING REQUIREMENTS

CSTI - VEHICLE

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Aeroassist flight experiment.....	---	15,000	15,000	28,000

OBJECTIVES AND STATUS

The aeroassist flight experiment (AFE) will investigate the critical vehicle design and environmental technologies applicable to the design of the aeroassist orbital transfer vehicle. Aerodynamic braking maneuvers, which occur in the upper regions of the Earth's atmosphere at or near geosynchronous return velocities, produce aerothermodynamic environments that cannot be simulated in ground facilities or modeled using existing analytical techniques. It is necessary, therefore, to obtain critical aerodynamic and aerothermodynamic data from flight experiments. The technologies that will benefit from the AFE are categorized into environmental and vehicle design technologies. The environmental technologies include nonequilibrium heating (radiative and convective), wall catalysis, and real-gas aerodynamics. Vehicle design technologies involve thermal protection materials, structural loads, avionics, and guidance and control. Design technologies are strongly influenced by the variations associated with the upper atmosphere.

The technology data base developed by the AFE will enable the use of aeroassist in conjunction with an orbital transfer vehicle to achieve minimum fuel expenditure in a return to low Earth orbit from a high energy orbit, such as geosynchronous. Application of the aeroassist or aerobrake concept to the orbit transfer vehicle on return to low Earth orbit has the potential for increasing the payload by a factor of two.

In FY 1988, wind tunnel and arcjet tests will be performed to support the establishment of the AFE aerodynamic and aerothermodynamic design requirements. Experiment feasibility studies will be completed, instruments will be selected, preliminary design will begin, and procurement for the propulsion system and the thermal protection system tiles will be initiated.

BASIS OF FY 1989 ESTIMATE

In FY 1989, the preliminary design of the AFE spacecraft and associated ground and airborne support hardware will be completed and final design initiated. Component structural testing on the aerobrake will begin. Software simulations will be conducted to evaluate guidance and navigation control schemes. Wind tunnel and arcjet testing will be continued to support the design data base for the AFE. Additionally, mission requirements will be defined and a preliminary mission operation timeline prepared.

BASIS OF FY 1989 FUNDING REQUIREMENTS

CSTI - INFORMATION TECHNOLOGY

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Science sensor technology.....	---	7,800	7,800	7,800
Data: high rate/capacity.....	---	9,200	8.700	9.300
Total.....	---	17,000	16.500	17,100

OBJECTIVES AND STATUS

The objective of the information technology program is to discover, invent, and develop new materials, devices, components, and systems that will enable active and passive detection and imaging of electromagnetic radiation and subsequent data storage systems for space missions in the next century. Of special importance are tunable laser sources and millimeter wave sensors for both active and passive remote sensing of the Earth's atmosphere and surface.

Passive remote sensing in the relatively unexplored submillimeter portion of the electromagnetic spectrum relies on space-qualifiable heterodyne detection systems employing a local oscillator and mixers. The programmatic goal is to develop oscillators with frequencies of up to 1.5 terahertz allowing detection of the lowest wavelengths of interest from stellar sources. The world's first fundamental solid-state oscillator for use in submillimeter heterodyne detectors will be demonstrating useful power levels at 200 gigahertz (GHz), and frequency multiplying by tripling 67 GHz to 201 GHz. Small-area superconducting-insulating-superconducting (SIS) junctions made of niobium nitride with magnesium-oxide insulating layers are demonstrating nonlinear characteristics necessary for a successful submillimeter detector mixer. Research is continuing on scaling this device to higher frequencies. At the same time, new mixers are being developed that can detect very low light levels and whose electronic noise levels are less than the theoretical limit. A mercury/cadmium/telluride photodiode mixer employing a novel interdigitated electrode concept will be successfully operated at a wavelength of 28 micrometers with 2 percent efficiencies

over a 500-megahertz (MHz) bandwidth. These devices will allow astrophysics observations in the far infrared spectrum. Because of limited life and reliability, the cooling of spacecraft detectors to low temperatures with current refrigerators has been a problem for system design engineers. In collaboration with the National Bureau of Standards, a single-stage pulse tube refrigerator has been built and will be successfully demonstrated by producing 12 watts of cooling at 80 degrees Kelvin, thus demonstrating the feasibility of this inherently reliable technology.

Current lasers lack the degree of reliability, tunability, efficiency, and frequency purity required for space operation. A solid-state titanium-doped sapphire laser has been used to demonstrate, in the laboratory, amplification by a factor of 2, injection locking tuning, and generation of picometer pulses. This will meet projected requirements for tunability, efficiency, and frequency purity. Additional work will be directed toward reliability and long lifetime requirements. LIDAR remote sensing of the earth's atmosphere requires lasers with wavelengths of 2-3 micrometers to detect methane. Research to develop a holmium-doped yttrium-aluminum garnet laser in the 2-3 micron wavelength range was initiated with a design where only the laser cavity needed cryogenic operation. Finally, an autotracking second harmonic generator has been integrated with a vibronic alexandrite laser leading to improved detection and quantification of numerous tropospheric trace species and pollutants.

In the area of onboard processors, a 4-element parallel processor is being successfully demonstrated, applying the evolving 1750A very high-speed circuit technology to the development of a new generation of high-speed general processors. The concept for an expandable flight optical disk recorder/controller was developed based on drive modules comprised of two 14-inch counter-rotating disks and a modular controller concept. A controller architecture is being initiated which allows expandability to a tera (10^{12}) bit capacity with error coding/correction, onboard data formatting, and in-flight reconfigurability.

A breadboard optical disk system demonstrated the write, read, and erase capability with the magneto-optical technology, including the necessary 14-inch media laser devices and electro-optical system. The erasable optical disk system and media were developed through a multiagency consortium of which NASA is a major partner. An 8-bit slice general processor, utilizing gallium arsenide technology, is being developed during FY 1988. This processor technology, integrated in a system with a controller enabling bitslice and pipeline computer operations, will achieve operational speeds required by imaging preprocessors (e.g., 5×10^9 operations per second). A study to evaluate the applications of onboard processing digital synthetic aperture radar (SAR) data was completed and resulted in a patent application and design architecture which provides for significant power and mass reduction for future SAR flight missions.

CHANGES FROM FY 1988 REVISED BUDGET

The information technology program reflects a decrease of $0.5 million in high rate/capacity data research in order to support photonics research in the information sciences research and technology base program.

BASIS OF FY 1989 ESTIMATE

The next major thrust in science instrumentation is submillimeter heterodyne detectors utilizing coherent detection principles and concepts with simultaneous spatial array imaging capabilities. This notion will greatly enhance the future scientific instrument throughput by at least two orders of magnitude in these wavelengths. Research efforts will proceed in three technically deficient areas: direct detectors and heterodyne frequency sources (local oscillators), frequency mixers, and quasi-optical components for the submillimeter portion of the electromagnetic spectrum. In the local oscillator area, research will continue to focus on the development and evaluation of novel backward wave oscillator tubes employing electronic microfabrication techniques, quantum well semiconductor oscillators and frequency multipliers, and submillimeter lasers sources. In the mixer area, work will continue on SIS as well as Schottky diode mixers. In the quasi-optical area, exciting concepts on coupling the SIS mixer arrays with planar antenna structures and possibly integrated lenses will be pursued. Finally, since a majority of these components will need to be cooled to low temperatures, a concomitant effort will be dedicated to cooler or refrigerator technology to enable and extend sensor system performance and life.

In the active remote sensing area, the research effort will be focused on the necessary technology to implement solid-state laser systems for future missions. Future science-sensing active instruments will require semiconductor laser array pumping, new solid-state laser crystal materials, and efficient frequency doubling and tripling materials, with system efficiencies of 5 percent and reliabilities of 3 years, respectively. To enable this, research will be focused on new electro-optic materials including the chromium-based compounds, alexandrite, emerald, sapphire, and possibly diamond. The emphasis will be on achieving adequate heat dissipation, frequency stability, and spectral purity.

The high rate/capacity data effort is directed at efficient and timely collection, extraction, manipulation, and utilization of space-derived data. A new generation of data and information systems will be developed to enable smart sensors to maximize information return from future space missions and increase scientific productivity. In addition, onboard processing and storage will enable the compression of data into more useful information at the source of the space data. Work will continue on the modification of the 4-processor very high-speed integrated circuit (VHSIC) breadboard. Test software written in Ada will be developed for measurement of multiprocessor efficiency and demonstration of system fault tolerance. The development of an optical disk controller and a brassboard optical disk buffer module will be initiated. The gallium arsenide processor and controller will be integrated to implement a space data compression algorithm designed to operate at a 200-MHz clock speed. A preliminary design of a single-azimuth processing channel for the onboard digital SAR processor will be implemented with discrete components in a developmental testbed environment. The preliminary design of a very large-scale integrated circuit chip for implementation of the azimuth correlator function will be accomplished.

BASIS OF FY 1989 FUNDING REOUIREMENTS

CSTI - LARGE STRUCTURES AND CONTROL

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Control of flexible structures.....	---	17,100	17,100	20,200
Precision segmented reflectors.....	---	4.900	4.900	4.900
Total.....	---	22.000	22.000	25.100

OBJECTIVES AND STATUS

The objective of the large structures and control element of CSTI is to develop integrated structures and control technology to enable the development of large flexible structures and high-precision structures to meet long-range requirements for complex multibody platforms, spacecraft, and large scientific instruments. Past and current systems, including the space station, have been designed so that on-orbit stability, control, structural integrity, and performance could be assured by analysis and ground-based testing. Future systems will be very large and flexible and possibly require extreme precision (e.g., a large lightweight telescope); therefore, current design and test methodology will be inadequate to assure on-orbit performance. In particular, gravity loading on earth can significantly affect structural natural frequencies and damping of large flexible structures, and the dynamics of an onboard control system can interact with the dynamics of the structure leading to uncontrollable, or even unstable. motion.

In 1985, the control of flexible structures (COFS) program was initiated, consisting of two key thrusts: (1) a fundamental research and technology program to develop integrated control structures interaction (CSI) technology as an approach to the multidisciplinary analysis, design, and testing of large flexible structures, and (2) a progressive series of Shuttle-based flight experiments to provide a data base for CSI technology development and to validate new methods and concepts. The series of flight experiments, designated COFS I and 11, would begin with a simple beam truss, scheduled for 1991, and end with a multibody experiment. In addition, a scale model of the Space Station, COFS 111, was planned to compare ground-based predictions with in-space measurements.

During FY 1987, a 20-meter ground test version of the 60-meter flight article was delivered to NASA for testing. Also, a guest investigator program was developed to enable universities and industry to participate in the flight test program. However, cost and schedule problems led to cancellation of the contract for the flight article. As a result, the FY 1988 program plan was revised in order to consider several options for comparable flight experiments that could still meet the FY 1991 schedule and provide valuable CSI data. A basis for these options is to use existing hardware rather than develop the more specialized hardware as had been the course under the original plan.

During FY 1988, an experiment will be selected to meet the 1991 schedule, consistent with the existing COFS budget, and development of the test article configuration will begin. Also, a comprehensive ground-based CSI program is being developed consisting of advanced analysis, design, and test methods and concepts for controlling structural response through a robust global control system and through "smart" structures having controllable stiffness and damping.

The second part of the large structures and control element, precision segmented reflectors, began in FY 1988. It addresses the requirements of advanced, orbiting, scientific instruments (such as the proposed 20-meter large deployable reflector) to have large, extremely precise surfaces on the order of 1-micron average roughness. Such systems would be too large to be placed in orbit by a single launch vehicle. They will also have to be very lightweight to avoid excessive launch costs. Consequently, reflecting surfaces, supporting structures, and appendages (such as a floppy sun shade) will have to be constructed in space, and precise alignment and vibration suppression will be accomplished largely by active control concepts. The technology developed under this activity will be validated/demonstrated at the end of FY 1991 in a multi-panel testbed system. Major accomplishments for FY 1988 will be the design of a multipanel alignment control system, conceptual development of an erectable/deployable backup truss structure, and fabrication of a 1-meter reflecting panel with 10-micron surface accuracy.

BASIS OF FY 1989 ESTIMATE

During FY 1989, the revised COFS I structural flight hardware will be developed in preparation for a 1991 space experiment (requiring a 1990 delivery to Kennedy Space Center). Control sensors and actuators will be integrated into the structure, and ground tests will be conducted to establish control/structure response characteristics and for comparison with analytical predictions.

The CSI technology activity will continue to develop integrated control/structure analysis and design methodology and test methodology focused on selected structures, including the COFS I flight article. This will be a multicenter activity involving Langley Research Center, Marshall Space Flight Center, Goddard Space Flight Center, and the Jet Propulsion Laboratory and will be directed toward developing a NASA-wide approach to accelerate the design, development, and qualification of future large space structures. During FY 1989, a global control concept and piezoelectrically activated structural members will be developed and demonstrated to control shape and dynamic characteristics of large flexible structures. Also, analytical and ground test methods will be validated for predicting the on-orbit characteristics of flexible structures, including the COFS I flight article, and a COFS III generic pathfinder model will be developed.

The precision segmented reflector activity will develop a component-level system to control panel alignment, and a control law will be demonstrated by simulation. Several 1-meter honeycomb construction reflector panels will be fabricated with 3-micron surface accuracy, demonstrating both precision and reproducibility. Also, an initial erectable/deployable backup truss design having millimeter-level precision will be fabricated and demonstrated.

CSTI - HIGH-CAPACITY POWER

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
High-capacity power.....	---	12,800	12,800	14,000

OBJECTIVES AND STATUS

The objective of this program is to develop the technology base for a nuclear power system capable of supplying high-capacity, long-life power for potential future sustained lunar and planetary base operations and any future evolutionary developments to the space station, and to supply power to electric propulsion systems for interplanetary cargo transfer vehicles. This is a joint activity with the Department of Energy (DOE) and the Department of Defense (DOD). The NASA program emphasis is on thermal-to-electric conversion, heat rejection, and power management and distribution subsystems. Higher conversion efficiencies in conjunction with improved thermal and power management and distribution systems materials and design innovations can enable a fivefold increase in the electrical power that can be delivered from the available thermal output of the SP-100 reactor, while more than doubling the system power-to-weight ratio. In FY 1988, NASA will support the joint-agency SP-100 ground engineering systems (GES) program to maintain the momentum of this priority national ongoing activity. The space nuclear reactor technology being validated in the SP-100 GES demonstration program is an essential first step in the process that will lead to the successful development of high-capacity power systems. Revised plans were generated that essentially delayed startup and/or completion in the out-years of selected activities. Realignment to increase the NASA contribution for SP-100 in this CSTI high-capacity power program has resulted in a scale down of the FY 1988 advanced conversion technology activity. In FY 1989, the NASA contribution for SP-100 is budgeted in the operations technology element of Pathfinder.

Dynamic conversion system technology with thermal-to-electric conversion efficiency of at least 25 percent has been demonstrated in a 25-kilowatt electric (kwe) initial demonstrator engine. Tests of the 12.5 kwe free-piston Stirling engine configuration with advanced heat transport and bearing components are underway to evaluate performance and endurance characteristics. The ultimate goal is a refractory metal Stirling engine that will he capable of operating at 1300 degrees Kelvin (K) delivered by the reactor thermal 'source. As an intermediate step, a full-scale Stirling space engine is being designed to be

fabricated of superalloy material for tests to be conducted at 1050 degrees K to investigate critical performance and reliability issues. In the thermoelectric static converter area, laboratory characterization of potentially stable, higher efficiency silicon germanium/gallium arsenide phosphide (GAP) junction materials has been concluded. Improvement over the baseline silicon germanium material is two- to threefold in terms of couple efficiency. The technology target of the silicon germanium thermoelectric effort is to achieve a figure of merit of greater than 1.0, as compared to the current level of 0.7. Material characterization and development of several even higher efficiency rare earth chalcognide junction material candidates (potentially providing a figure of merit as high as 1.4) have been completed with establishment of respective physical, thermal, and electrical properties.

Alternate waste heat radiator concept studies have been initiated to identify promising candidates. In parallel with this activity, supporting research and technology efforts in heat pipe modeling and analyses were conducted. New high-temperature composite materials were developed, manufactured, and characterized in this period. Tungsten fiber-reinforced niobium composites and also graphite fiber-reinforced copper composites exhibited improved creep strength at the high temperatures of interest, resulting in potential mass savings on the order of 10 percent. Joining and fabricating techniques for high-temperature intermetallic compounds used in building thermal systems were developed. Techniques have also been developed to texture the surfaces of these materials to achieve thermal emittance greater than 0.8 at 1300 degrees K.

Tests are continuing with a new family of semiconductors based on silicon, deep injection, double-dopant materials which result in inherently high tolerance to high levels of radiation exposure. Two orders of magnitude improvement in radiation tolerance over current systems at increased operating temperatures (400-500 degrees Centigrade range) have been measured. In addition, laboratory-scale demonstrations of advanced switches, inverters, converters, and distribution concepts were initiated. Fault-survivable power distribution concepts are being defined and assessed in this latter activity.

BASIS OF FY 1989 ESTIMATE

During FY 1989, preliminary design of the Stirling space engine will be completed, After design review and approval, the detailed design efforts for the test engine(s) will be initiated, as well as test planning. N-leg silicon-germanium/GAP material characterization and development, increasing the figure of merit to 0.85 for the thermoelectric converter, will be nearing completion. The program has optimized the thermal and electronic properties of the N-type thermoelectric converters. Research on P-leg configurations with similar materials will continue.

The waste-heat radiator configuration is the major mass contributor in the high-capacity power system. Advanced heat radiator concept definition studies will have been completed. Parallel studies of selected concepts will be initiated addressing feasibility assessment at the component level. Technology development efforts for the power management and distribution system components will be increased, and a definition and assessment effort directed at fault-survivable power system concepts will be initiated in FY 1989. Research and technology tasks addressing the space environmental effects and interactions will also be conducted.

BASIS OF 1989 FUNDING REQUIREMENTS

PATHFINDER PROGRAM

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
		(Thousands of Dollars)			
Exploration technology	---	---	---	17,000	
Operations technology	---	---	---	41,000	
Humans-in-space technology	---	---	---	13,000	
Transfer vehicle technology	---	---	---	14,000	
Mission studies	---	---	---	15.000	
Total	---	---	---	100,000	

Project Pathfinder is an important new program through which NASA will develop a broad set of technologies that will enable decisions on future space missions. Project Pathfinder is the critical next step, augmenting CSTI, in strengthening the technology foundation of the civil space program and the nation's technology leadership. Moreover, Pathfinder is an essential prerequisite to any future decision by the nation's leadership to go forward with ambitious civil space missions. Pathfinder is organized into four technology areas: exploration, operations, humans-in-space, and transfer vehicles. In addition, mission studies will be conducted to support the detailed formulation of mission requirements and technology options. The technologies included in the exploration element are related to the gathering of scientific knowledge and technical understanding at mission sites on the Moon and Mars. The space operations element will address critical technologies for in-situ materials processing, fabrication, and assembly and repair of massive and complex systems in Earth orbit and at lunar and Martian orbits and surfaces. The humans-in-space program will address the technology for improving astronaut productivity, maintenance or health, and minimal or no dependence on resupply of expendables. The transfer vehicle element will support transportation to and from geostationary Earth orbit, the Moon, Mars, and other planets.

BASIS OF FY 1989 FUNDING REQUIREMENTS

EXPLORATION TECHNOLOGY

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Planetary rover	---	---	---	10,000
Surface power	---	---	---	3,000
Optical communications	---	---	---	2,000
Sample acquisition, analysis, and preservation	---	---	---	2.000
Total	---	---	---	17.000

OBJECTIVES AND STATUS

In the exploration technology area, development of the critical technologies necessary for the gathering of scientific knowledge and engineering understanding at mission sites on the Moon, Mars, and other planets in the solar system will be initiated. Specific objectives include the capabilities for robotic exploration missions ultimately capable of autonomous surface exploration; site characterization; and sample collection, analysis, and return. This capability would enable the resolution of many scientific questions related to the geology, biology, and surface chemistry of sites without an in-situ human presence. It would also greatly augment the capabilities of humans when they eventually are on site. Also to be initiated is the development of specialized surface power systems that are capable of providing the power requirements necessary for sortie, piloted missions, and for the interim period while base power systems are being established. All systems will be required to survive exposure to the extreme dust and temperature environments of the Moon and Mars. Optical communications technology will be developed to support the high-volume high-rate information transfer that is associated with both the high levels of surface activity and the collection of extensive scientific and engineering data.

BASIS OF FY 1989 ESTIMATE

The essential technologies for the future robotics and piloted exploration of the solar system are grouped into four separate elements: planetary rover; sample acquisition, analysis, and preservation; surface power; and optical communications. The planetary rover element will focus on the development and integrated testing of technologies for mobility, navigation, site identification, and portable power. The sample acquisition, analysis, and preservation element will focus on the methodology for sample identification and selection, chemical and physical analysis, the development of special tools for sample acquisition, and sample preservation techniques. The surface power element will perform research leading to high power-to-weight, photovoltaic arrays, and regenerative fuel cells that are resistant to the dust, chemical reactants, and temperature environments ambient to the Moon and Mars. Optical communications hardware will be developed to support a subsequent flight demonstration at interplanetary distances.

In 1989, the planetary rover element will be focused on designing the local navigation and mobility testbeds and awarding contracts for their implementation; selecting and developing the technologies to be incorporated into the testbeds; and carrying out the second year of a university grant rover development activity. The preliminary testbed objectives will include semi-autonomous traversal of a simulated Martian terrain using stereo correlation and onboard planning; evaluation of a demonstration of autonomous control of multiple arms; and fabrication of the university rover including integrated planning and perception. In addition, integrated rover power systems architectures will be demonstrated. These proof-of-concept demonstrations will enable decisions on projects targeted for the late 1990's. In the late 1990's, all critical technologies will be integrated into a testbed €or demonstration of a full planetary rover capability.

Technology for sample acquisition, analysis, and preservation has not advanced very much since the Apollo and Viking missions. In FY 1989, work will be initiated to define systems requirements for sample detection/imaging/handling, physical/chemical analysis, and preservation/containment/transporting. Consideration will be given to an optimum division of tasks between the rover and the lander. Specialized tools will be developed for surface and subsurface sample collection. Baseline development will be initiated in the areas of terrain imaging, elemental analysis, water detection, minerology, volatile analysis, meteorology, and geophysics. Systems will be made rugged to survive the accidental impacts and extended exposure to harsh environments, yet also be compact and lightweight. Concepts will be developed for sample containers to preserve returned samples in pristine condition. These activities will be performed in close cooperation with the planetary rover development and will be integrated into the rover testbed.

The surface power element will develop technology required for short-term power and storage to enable human lunar surface operations prior to startup of main base power and Mars surface operations during one-month human visits. Potential candidates for the 25-kilowatt system include amorphous silicon and gallium arsenide photovoltaic systems. They will be compared as candidates for the energy generation system. Both candidates will be designed, fabricated, and tested with the goal of achieving 300 watts/kilogram. A regenerative fuel cell with minimum structure, higher operating efficiency, improved cell separators, and solid electrolyte will demonstrate a goal of 1000 watt-hours per kilogram. The power subsystems will be demonstrated in a flight test and a substantial life test in a simulated Mars environment.

Optical communications will reduce the size of transmitter/receiver antennas by over a factor of 10, offer multigigabit per-second data rates, high-reliability solid-state components, and high directivity with reduced interference problems and power requirements. The program will develop optical communications technology for NASA-unique mission applications. Work will begin on the necessary components to build an experimental package that could increase the data return from a potential mission to Saturn by two orders of magnitude. The optical communications element will be focused in FY 1989 on a systems study of an optical transceiver terminal for inclusion onboard the Shuttle. The transceiver will be the low Earth orbit link for a space-to-ground laser experiment to demonstrate the necessary technology for a deep space mission.

BASIS OF FY 1989 BUDGET REQUIREMENTS

OPERATIONS TECHNOLOGY

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Rendezvous and docking.....	---	---	---	1,000
Resource processing pilot plant.....	---	---	---	1,000
In-space assembly and construction.....	---	---	---	2,000
Cryogenic fluid depot.....	---			7,000
Space nuclear power (SP-100).....	---	---	---	30,000
Total.....	---	---	---	41.000

OBJECTIVES AND STATUS

The space operations thrust will provide the critical technologies required for logistical support of human activites. For Earth orbit operations, this program will greatly extend our capabilities to maintain the infrastructure and to support major new science missions. For lunar and Mars missions, the critical technologies for preparing to depart Earth orbit, for performing tasks on lunar or Martian surface sites, and for safe return to Earth from those sites will be addressed. The specific program objectives include developing the capability for in-situ lunar materials utilization, development of technology for advanced on-orbit operations, and the development of nuclear power for transportation and sustained lunar and planetary operations. Critical issues, such as the extent to which manned activities can be self-sustaining through processing of extraterrestrial materials, will determine the course of space exploration. The elements of the program include autonomous rendezvous and docking technology, resource processing pilot plant research, in-space assembly and construction, cryogenic fluid depot technology, and space nuclear power technology.

BASIS OF FY 1989 ESTIMATE

The autonomous rendezvous and docking program will develop the necessary strategies, sensors, and guidance software required for such operations in both earth and planetary orbits. In FY 1989, rendezvous and docking requirements for a variety of vehicles will be identified and coordinated. The most suitable strategies, trajectories, and guidance schemes for each mission will be determined and simulated. The laser docking sensor will be improved and will be compared with competing radar and video technologies. Work will begin on technology for a long-range sensor for a possible future Mars mission.

The resource processing pilot plant element will develop basic technologies to utilize extraterrestrial materials. In particular, it will focus on the methodology for production of oxygen, metals, and construction materials from lunar raw materials. During FY 1989, the program will be initiated by identifying and evaluating material collection and separation and production processes. Such processes will be evaluated based on their energy efficiency, complexity, and initial and life cycle costs.

The in-space assembly and construction element will focus on methods that will enable large, complex structures to be built in space. This will include methods to precisely manipulate large objects using lightweight flexible arms and to hold them close together; to weld or bond structural members; and methods to construct large surfaces and enclosed volumes. The FY 1989 focus will be on the analytical and experimental evaluation of high-capacity joint concepts, automated methods for producing structural welds and bonds, and methods to manipulate large masses precisely by means of rigid robotic arms.

An important aspect of the permanently manned space infrastructure is the capability to refuel on orbit. The cryogenic fluid depot element of the program will validate the data base for design of such a depot which will include liquid production, conditioning, storage, and transfer. Basic technologies of the component subsystems will be initiated. Development of flowmeters for liquid and gaseous hydrogen and development of cryogenic relief valves will be completed. Validation of the integrated analytical model of the fluid depot in Earth gravity will begin.

Space nuclear power technology is being developed under the tri-agency (NASA/DOD/DOE) SP-100 program, which includes performance tests, life models, and accelerated tests to validate life models of a nuclear reactor ground engineering system. In FY 1989, emphasis will be placed on the continuing development of fuel pellets and cladding materials for the nuclear reactor, the electromagnetic pump for the liquid lithium coolant, thermoelectric couples for the energy conversion, and heat pipes for the radiator.

BASIS OF FY 1989 FUNDING REQUIREMENTS

HUMANS-IN-SPACE TECHNOLOGY

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
EVA/suit	---	---	---	2,000
Human performance	---	---	---	5,000
Closed-loop life support	---	---	---	6,000
Total	---	---	---	13,000

OBJECTIVES AND STATUS

The objectives of this portion of the Pathfinder program are to enable: (1) on-demand, extended surface extravehicular activity (EVA) with mobility, dexterity, simple servicing and maintenance, and long-life systems; (2) productive cognitive and physical performance over long self-sufficient missions in different gravity environments and with protection from space radiation; and (3) self-sufficiency and significant reduction in life-support expendable weight and transport requirements for long missions (greater than one year). Existing technologies for these functions cannot be scaled to meet human performance and life-support requirements over long, self-sufficient missions. Furthermore, technology identification and advancement cannot effectively proceed without the determination of human performance and support requirements. This program will be conducted jointly with the Office of Space Science and Applications (OSSA). OSSA will determine the biomedical requirements and implement the life sciences portion of the program.

The objective of the EVA/suit program is to provide technology for a highly mobile, lightweight, rugged pressure suit and portable life support system that will allow safe and efficient EVA work during planetary missions. The system concept includes five major research areas: suit concept and space serviceability; portable life support system (PLSS) concept with a regenerable air and thermal capability; human performance models, including task and information requirements, personal hygiene, microbial growth control and human comfort requirements; mechanical, electrical, and power components, such as joints, bearings, seals, lighting, ventilation, and mobile power supply capabilities; and tools, gloves, and end

effectors for mobility and maneuverability requirements. Advanced orbital suit designs and test prototypes currently offer promise of high working pressure and modular design; however, EVA suits and systems for lunar and Mars missions must address a different set of working requirements. Concepts and technology must be developed for in-transit/surface suit compatibility, reduced weight of the PLSS, simple and expeditious regenerability of the PLSS, materials and joint resistance to surface dust abrasion and corrosion, simple serviceability, and extended-duration mobility concepts.

The objectives of the human performance program are to determine human capabilities, limitations, and adaptability for individual and group work during long-duration missions and to develop supporting human-machine interface technologies. The program consists of seven subelements: (1) physical performance model; (2) cognitive performance model and human-machine interface; (3) teamwork model; (4) application of computer-aided design tools to develop vehicle designs for crew habitability and space radiation protection; (5) small group behavioral model and analysis of simulated mission environments and authentic analog environments (e.g., Antarctica and North Sea platforms); (6) artificial gravity effects on human physiology and physical and cognitive performance; and, (7) space radiation protection requirements, materials, and vehicle configurations. The program supports determination of performance factors and requirements, and development of strategies, technologies, and procedures that will meet these requirements and accommodate the effects of weightlessness and gravity readaptation on human performance. Prior research established that highly automated, confined, or remote environments induce poor productivity, human error, and other unproductive behaviors. A systematic collection and evaluation of experiences from astronauts and cosmonauts was initiated in FY 1988 to provide a human performance data base, including effects of prolonged weightlessness, isolation, social withdrawal, sleep disturbances, and other behavioral and social problems. Some experiments reveal deleterious effects on human perceptual processes due to artificial rotational gravity. Research results from human factors studies of strength capabilities and limitations in weightless conditions provided insights on human performance useful for the design of crew stations and crew tasks. Performance of small groups has identified important variables associated with leadership effectiveness, group cohesion, and performance under stressful conditions (i.e., decision-making under uncertainty).

The objective of the closed-loop life support program is to provide a high degree of closure in the crew life support system for long-duration space missions to provide air revitalization, water reclamation, and waste treatment. Based on physical and chemical processes, highly efficient subsystems will be developed and integrated into a total life support system which will minimize the requirements for stored consumables and spares and eliminate the need for resupply. In the past, the physical-chemical life support research and technology program was focused on providing the air revitalization and water reclamation systems for use in low Earth orbit and, most recently, for Space Station. The life support

system proposed for the Space Station will include an air revitalization system which is largely a closed system and partial water reclamation from wash water and urine. All wastes and trash will be transported back to Earth for disposal. Food, spares, and make-up oxygen and water will be resupplied to the Station on a periodic basis. Much longer duration missions in which resupply will not be frequent or practical will require significant technological improvements. To date, all physical-chemical life support subsystems, including subsystem integration, have been developed experimentally. Work has been initiated to begin the analysis and simulation modeling of physical-chemical processes for air, water, and waste treatment subsystems to guide selection of candidate processes prior to experimental evaluation. To date, no U.S. manned space flights have depended on onboard plants or biological subsystems for life support. The current research program dealing with controlled ecological systems has focused on the growth dynamics and support requirements of candidate plant systems and on demonstrating a proof-of-concept system which would then permit both specific applications of biological subsystems to be examined and a realistically sized breadboard closed-loop system to be designed. In this program, the feasibility of biologically based systems will be examined for enabling such functions as habitability enhancement, waste processing, food production, and oxygen/carbon dioxide/water exchange. As appropriate, biological subsystems will be integrated with physical-chemical subsystems to evaluate biologically based closed-loop systems.

BASIS OF FY 1989 ESTIMATE

The FY 1989 effort will provide EVA systems concepts and reliable forecasts of the technology needed for high-pressure, high-mobility, readily serviceable suits, and compact fully regenerable PLSS capable of sustaining an astronaut in healthy and comfortable conditions for many hours during planetary EVA. Four major milestones are projected: (1) development of an EVA systems concept compatible for both in-transit and surface use; (2) identification of surface suit components, including task, information, and biomedical requirements affecting suit design; (3) identification of portable life support system requirements; and, (4) definition of requirements for surface mobility and dexterity. Early identification of materials for lightweight, rugged abrasion/corrosion-resistant suits and design of a fully dexterous hybrid glove are planned. Automated and/or simplified servicing concepts for maintenance and quality control of the suit will be pursued. Efficient materials and processes for the provision of breathable air, removal of carbon dioxide from expired air, and the onboard regeneration of the removal subsystem will be identified. Development of the EVA display and control system concepts to allow the suited astronaut to manage the unique planetary information and to carry out surface operations safely and easily will be initiated.

Development of working models of physical, cognitive, psychosocial teamwork performance will be initiated, and studies of small isolated groups who perform mission-equivalent tasks will be started to provide mission and system designers with preliminary data on human performance. Strategies for applying to and integrating models of human performance and behavior into design guidelines will be developed, including the identification of system and technology requirements for computer-aided design. Preliminary system definition and technology requirements for space radiation protection and for rotating systems to produce artificial gravity will be identified. Ground-based experiments and studies of zero-gravity countermeasures will be started, using bed rest, water immersion, and slow-rotation rooms. A program will be preliminarily defined for on-orbit experimental validation of ground-based predictions of human performance in these environments.

In FY 1989, subsystem models of some physical-chemical life support processes will be available, although not completely validated. Efforts to analytically model candidate processes for waste treatment and reclamation of water from wastes will begin. Experiments to provide data to validate the subsystem models will be defined. These models will be used for selecting candidate air, water, and waste processes for further development and integration into a breadboard life support system. Revolutionary advances in technologies for portable life support subsystems for EVA will continue to be pursued to obtain maximum performance of the air revitalization and water removal systems at minimum volume, weight, and power levels.

An initial reference concept of a biologically based controlled ecological system will be used with proof-of-concept test results to develop strategies for research, in-space validation, and evolving operational use of biological subsystems to fulfill human support functions.

BASIS OF FY 1989 FUNDING REQUIREMENTS

TRANSFER VEHICLE TECHNOLOGY

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Chemical transfer propulsion.....	---	---	---	6,000
Cargo vehicle propulsion.....	---			2,000
High energy aerobraking.....	---			2,000
Autonomous lander.....	---	---	---	1,000
Fault-tolerant systems.....	---	---	---	3.000
Total.....	---	---	---	14,000

OBJECTIVES AND STATUS

Transfer vehicle technology addresses reusable transportation to and from geostationary Earth orbit, the Moon, Mars, and other destinations in the solar system. This thrust provides the technologies for a significant reduction in mission costs by reducing the mass required to be launched into low Earth orbit and in transit, as well as reductions in the transit time. The broad objectives toward these goals include research into higher performance, reusable, reliable, space-based transfer vehicles that have low operational cost. The efforts which support the objectives include chemical transfer propulsion, chemical vehicle propulsion, high-energy aerobraking, autonomous lander, and fault-tolerant systems technology.

The objective of the chemical transfer propulsion technology element is to provide demonstrated advanced design concepts and validated analytical techniques that will allow the design and development of advanced expander cycle liquid oxygen (LOX)/hydrogen engines capable of meeting the demanding requirements of Mars and lunar transfer and lander vehicles. Capabilities include high performance to reduce the quantity of propellant required to perform transfer and lander missions, reusability to reduce mission costs, and space-basing to eliminate the need for returning vehicles to earth after every mission for refueling, inspection, checkout, and relaunch. This class of engine can provide the deep throttling capability required for Mars and lunar hovering and landing. Critical technologies include long-life heat-transfer combustor designs, development of turbomachinery technologies that will provide high efficiencies over a

wide flow range of operating conditions, integrated diagnostic sensors, and technologies for enabling space-based maintainability and automated operations. To date, design approaches that will achieve these technology advances have been identified in the research and technology base program and demonstrated in laboratory and rig testing.

The cargo vehicle propulsion technology element addresses extremely efficient electric propulsion (specific impulse 10 times better than the best chemical). Use of an electric propulsion system and a megawatt-level nuclear power source could save the expense of up to 4 expendable launch vehicles per mission. The best electric thruster candidates are ion and magnetoplasmadynamic (MPD) propulsion systems. Small ion systems have been tested. Larger size, higher power units will minimize the number of components and increase reliability for megawatt-level systems. MPD systems are at an earlier technology state, but offer the ability to process high power in a small thruster with a very simple design. MPD units have had limited testing. Erosion of the central electrode during MPD operation is a serious problem needing study.

The high-energy aerobraking element develops aerobraking/aeromaneuvering technology that will enable lightweight, space-based orbital transfer vehicles for future planetary missions. Critical technologies to be addressed include examining and defining the effects that long-term exposure to the space environment will have on the thermal protection system. Designs that will accommodate very high velocity and enthalpy flow conditions must be developed. The ability to handle "new" atmospheric constituents must be developed through gas chemistry models which will provide accurate prediciton of aerodynamic and aerothermal loads in the Martian environment. High-speed Earth and Mars entry conditions must be better defined and understood. Finally, fault-tolerant, real-time adaptive guidance, navigation, and control systems must be defined and developed.

The autonomous lander element provides the technology to safely land, without real-time human control, a planetary exploration spacecraft close to an intended target even though the target includes surface hazards such as slopes and rocks. This capability is needed to improve the operational reliability of robotic missions where the round-trip communication time prevents remote human control of landing and where scientifically interesting areas are expected to be hazardous. It will also be important for landings of unpiloted supply spacecraft that form part of any future piloted Mars mission or lunar base supply operation and as a crew aid during piloted landings.

The fault-tolerant systems element will rely heavily on, and provide a major advance in, the technology of photonics. Photonics has the potential to surpass electronics in important areas of computation. The high throughput of analog photonic data processing reflects the enormous information capacity of light waves and the inherently concurrent nature of wavefront operations. Photonic flight systems will be more fault-tolerant and reliable than comparable electronic systems; will have fewer discrete active components and physical interconnections; and their architectures will be inherently more resistant to single-component failures. The goal of the program is to provide photonic or hybrid photonic/electronic components and sub-systems and overall system architectures that, for selected flight data-system functions important to missions that require one or more supercomputers of the Cray class (1 to 10 billion operations per second), can deliver a substantial savings (10 to 50 percent) in weight, volume, and power over all electronic systems with significant increases in reliability.

BASIS OF FY 1989 ESTIMATE

The chemical transfer propulsion effort will apply the design concepts and analytical methods developed to date in the base program to the design of full-scale enhanced heat transfer combustors, variable-flow turbo-pumps, and controls. Appropriate diagnostic sensors will be incorporated into the component hardware. Component performance and operation, including the diagnostic sensors, will be demonstrated initially. The components will be developed for assembly into an integrated component test configuration to validate high-pressure expander cycle engine performance and operation. Ultimately, the engine will evolve to a near prototype configuration in which fault-tolerant engine operation will be demonstrated, and component design margins will be established.

Technology for MPD systems will be emphasized in the cargo vehicle element. Megawatt pulse testing will be continued with emphasis on understanding the cathode erosion that occurs at very high current flow. The power level of the sustained MPD operation will be raised to 100,000 watts to more nearly simulate high-power operation, and equipment to operate at 250,000 watts will be designed and installed. Externally applied magnetic fields will be imposed on an MPD unit to determine whether this field, added to the self-induced magnetic field, may raise the thrust efficiency above the current 35-50 percent.

The 50-cm-diameter ion system will be assembled and operated at increasing power levels up to 100,000 watts. An operational model will be developed to allow prediction of performance under all conditions and to predict the operating life of the various subsystems in order to direct further technology development. A pair of 30-cm ion thrusters, integrated into a prototype of a flight system, will be operated to begin to learn system characteristics.

Initial designs of power supply and management systems will be made and tested under operating conditions including exposure to the type of radiation caused by nuclear power sources.

The initial focus of high-energy aerobraking will be on improving CFD codes for prediction and characterization of the aerodynamic and aeroheating loads for Mars entry and very high-velocity earth reentry conditions. Studies will be initiated to begin the evaluation and selection process for advanced thermal protection materials and designs. New and advanced control algorithms for fault-tolerant guidance and control systems with the ability to adjust in "real time" to atmospheric uncertainties will be developed. In addition, overall vehicle configuration and system design will be analyzed.

Initial work in the autonomous lander element will focus on an unpiloted landing on Mars. An approach to terminal hazard detection will be demonstrated via simulation, capable of detecting hazards in the size range of 0.25-1 meter at a range of 1-5 kilometers during the final 30 to 60 seconds of landing. The necessary prototype instrument development will have been successfully completed in parallel. Approaches to be considered will be based on state-of-the-art image analysis and will include those that use intensity information from passive devices, such as a camera, as well as those that use range information from active devices, such as a scanning laser or millimeter wave radar.

The fault-tolerant systems element will research and develop breadboard photonics processors to perform necessary functions for future NASA missions. A breadboard robotic vision system capable of quickly recognizing new images in real time will be built. Component technology work will produce spatial light modulator test samples with improved, faster, information-shaping characteristics. Spectral analyzers will be built and tested in the laboratory, reducing by up to several orders of magnitude the quantity of support electronics needed.

MISSION STUDIES

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Mission studies.....	---	---	---	15,000

OBJECTIVES AND STATUS

Using the exploration scenarios identified in Dr. Sally Ride's report, Leadership and America's Future in Space, as a starting point, the mission studies will: (1) identify other viable scenarios to be considered; (2) develop a more detailed definition of each of the candidate scenarios; (3) conduct trades and analyses of the scenarios to begin the process of narrowing down viable and desirable candidates; and, (4) identify the prerequisites (technology, infrastructure, and precursor missions) for conducting such missions. Of particular criticality are the long-lead technologies and infrastructure elements. Special emphasis studies will be conducted to investigate the high-leverage elements to identify the high-payoff options and critical technologies associated with these elements. These mission studies will serve to continually refine the Pathfinder technology program, ensuring that the critical and enabling technologies are receiving proper attention.

During FY 1988, an in-house team was assembled to initially manage and develop the process and the initial data base. This team will conduct a search for all viable scenarios and perform the initial screening and consolidation of these scenarios.

BASIS OF FY 1989 ESTIMATE

Two-year parallel contracts of the more viable scenarios will be conducted focusing on conceptual design and definition studies. FY 1989 will be the first year of these contracts. These parallel studies will define end-to-end mission scenarios and perform first-order systems trades, including mission unique functions, infrastructure (transportation, Space Station, and operating systems), and prerequisites (technology, science research, and precursors). In addition to the current infrastructure and programs of NASA, including planetary surface systems, planetary space transfer systems, human systems, and planetary lunar orbital modes, there will be studies concentrating on the more detailed definition of unique systems and functions.

Finally, special emphasis studies will be developed through academia, industry, and other government agencies for definition of critical issues. Included will be identification and development of potential innovations, as well as detailed assessments of known problem areas such as: (1) initiative cost analysis methodology, (2) in-situ resource utilization, (3) lunar resource processing analysis techniques, (4) space cryogenic reliquification systems, (5) on-orbit assembly feasibility, and (6) artificial gravity systems.

SYSTEM RELIABILITY
AND QUALITY
ASSURANCE

RESEARCH AND DEVELOPMENT

FISCAL YEAR 1989 ESTIMATES

BUDGET SUMMARY

OFFICE OF SAFETY, RELIABILITY, MAINTAINABILITY AND QUALITY ASSURANCE

SAFETY, RELIABILITY AND QUALITY ASSURANCE PROGRAM

SUMMARY OF RESOURCES REQUIREMENTS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
		(Thousands of Dollars)			
Safety, Reliability, Maintainability, and Quality Assurance.....	12,000	14,100	14,100	22,400	RD 16-2
Distribution of Program Amount by Installation					
Johnson Space Center.....	746	1,090	770	900	
Kennedy Space Center.....	140	100	100	100	
Marshall Space Flight Center.....	685	415	415	425	
Goddard Space Flight Center.....	888	1,363	838	1,188	
Jet Propulsion Laboratory.....	2,225	2,350	2,050	2,250	
Ames Research Center.....	415	---	400	450	
Langley Research Center.....	2,093	969	969	1,293	
Lewis Research Center.....	173	150	1,295	1,500	
Headquarters.....	4.635	7,663	7,263	14,294	
Total.....	12.000	14,100	14,100	22,400	

OFFICE OF SAFETY. RELIABILITY, MAINTAINABILITY AND QUALITY ASSURANCE

SAFETY, RELIABILITY AND QUALITY ASSURANCE PROGRAM

PROGRAM OBJECTIVES AND STATUS

The Safety, Reliability, Maintainability, and Quality Assurance (SRM&QA) program supports NASA's overall goals through activities in safety, reliability, quality assurance, maintainability, systems engineering, and program practices through independent assessment activities which reduce program risk. Specific objectives of the program are to:

- Identify and provide independent assessment of issues that have potential impact on mission success.
- Support in-depth reviews, studies and analyses of issues and problems for readiness to launch.
- Conduct major tests and provide a viable problem reporting, corrective action, and trend analysis program throughout NASA.
- Perform radiation characterization on emerging technologies and complement the Air Force program for testing on-orbit radiation effects.
- Upgrade existing software standards, guidebooks, and training; and identify software management product assurance and automated work stations.
- Develop product assurance methodology for procuring reliable, custom large scale integrated (LSI) and very large scale integrated (VLSI) circuit components.
- Upgrade technology and emphasize the safety, reliability and performance of NASA's aerospace battery power systems.
- Plan, document, and establish policy for a NASA wide SRM&QA Information System.
- Increase the safety of high hazard operations and develop safety risk management policy and guidance for all NASA programs.

- Support industrial, aviation, fire protection, and ground operations safety activities

- Provide policies, procedures and surveillance for all agency safety, quality, maintainability, and reliability activities.

OBJECTIVES **AND STATUS**

In concert with the NASA Centers and industry, efforts continue in the areas of materials treatments and processes; integrated circuit product assurance; microcircuit radiation effects evaluation; aerospace and system safety related matters; and other areas in support of NASA-wide programs. The Non-Destructive Evaluation (NDE) Program places special emphasis on developing NDE techniques for assessing the quality of Solid Rocket Motors. Development of qualitative and quantitative inspection and quality control techniques for microcircuits and semiconductors is being promoted. The Software Management and Assurance Program will continue to develop standards, specialized training, distributed software, corporate memory data bases, and guidebooks to facilitate improved software business practices. A Maintainability Program has been formalized and a study completed resulting in the definition of maintainability requirements appropriate for NASA programs.

In response to the findings and recommendations contained in the Report of the Presidential Commission on the Space Shuttle Challenger Accident (Rogers' Commission), a system has been developed to address the reporting and documentation of significant problems, assessment of problem resolutions, and analysis of trends. Goals have been defined for the system to achieve.

The NASA Safety Program is focused on developing specific programmatic system safety management procedures and providing independent system safety reviews at Headquarters. The program will conduct assessments and develop requirements €or hazardous systems such as radio frequency interference, ionizing radiation, toxic chemicals and propellants, and propulsion, ordnance and electrical systems. The assessment of Space Transportation System (STS) System Safety Management procedures and the development of specific programmatic system safety procedures will be completed in FY 1989. System safety management procedures for Level I independent safety reviews, hazard analyses procedures and prioritization methods, system safety methodology development for flight critical software, and safety risk acceptance criteria recommendations are underway.

BASIS OF FY 1989 ESTIMATE

In FY 1989, the SRM&QA program will continue to conduct activities in support of the objectives of the Agency. This funding level will provide for enhanced capabilities which will implement the reporting and documentation of significant problems, assess problem resolutions and analyze trends, and other safety

systems as required. The Agency will develop a data base of failures, anomalies, and unsatisfactory conditions for analysis and assessment of remedial and preventive actions. Trend analysis of flight and critical ground hardware problems will be conducted, as well as for certain generic program hardware.

Problem reporting requirements, hazards analysis, and failure modes and effects analyses, accessible through an Agency-wide tracking and reporting system, will continue to be supported in the STS program through the Program Compliance Assessment Status System (PCASS) effort. PCASS will provide commonality throughout the STS program and NASA centers. The Intercenter Problem Reporting and Corrective Action (PRACA) data base for non-conformance data will be established. The NASA Headquarters SRM&QA management information center will be linked to both the Intercenter PRACA and the PCASS systems. A NASA wide SRM&QA information system will be established. This system will control the proliferation of data bases, assure appropriate informational content and provide standardized access and reporting throughout the Agency.

Integrated engineering standards and practices will be implemented and a data base brought on-line. Standards for fracture control, atmosphere, and environment programs will be expanded. Emphasis will be placed on updating and consolidating engineering standards for use in space station development. Engineering policies and standards for system engineering, configuration management, and drawings will be developed.

The Aerospace Flight Battery Systems program will provide a better understanding of critical performance parameters; provide improved capability of existing chemistry applications, and test and evaluate newly developed chemistry applications for flight.

The NASA safety program will increase the safety of hazardous operations, develop a better understanding of the failure modes of highly stressed wind tunnel components and pressure systems, and quantify the hazard potential of new, exotic propellants, existing cryogenic propellants, and new composite materials. Policies, procedures, practices, regulations, guidelines, and directives will continue to be developed. Independent assessments of hazardous systems such as radio frequency, ionizing radiation, toxic chemical and propellant, propulsion, ordnance, and electrical systems will be continued.

The Independent Systems Assurance Assessments program will develop between use of numerical techniques for reliability analysis and risk assessment.

The Non-Destructive Evaluation (NDE) measurement assurance program will continue to provide state-of-the-art quantitative advanced inspection techniques for solid rocket motors, composites and ceramics and will explore inspection techniques such as microfocus x-ray, fiber optics, acoustic emission, computer tomography, and laser thermography.

TRACKING AND DATA
ADVANCE SYSTEMS

RESEARCH AND DEVELOPMENT

FISCAL YEAR 1989 ESTIMATES

BUDGET SUMMARY

OFFICE OF SPACE OPERATIONS

TRACKING AND DATA ADVANCED SYSTEMS

SUMMARY OF RESOURCES REQUIREMENTS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
	(Thousands of Dollars)				
Advanced systems	17,100	17,900	17,900	18,800	RD 17-2
Total	17,100	17,900	17,900	18,800	
Distribution of Program Amounts by Installation					
Goddard Space Flight Center	5,000	5,300	5,300	5,800	
Jet Propulsion Laboratory	11,841	12,600	12,600	13,000	
Headquarters	259	---	---	---	
Total	17,100	17,900	17,900	18,800	

BASIS OF FY 1989 FUNDING REQUIREMENTS

ADVANCED SYSTEMS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Advanced systems.....	17,100	17,900	17,900	18,800

OBJECTIVES AND STATUS

The objective of the Advanced Systems Program is to perform studies and provide for the development of tracking and data systems and techniques required to obtain new, higher performance tracking and data handling capabilities that will address planned future mission requirements and also improve the cost effectiveness and reliability needed for overall support of the total mix of spaceflight missions.

This activity is a small but vital part of the total Space Tracking and Data Systems Program. Advanced programs continue to focus on assessing and making use of technological advances in telecommunications, electronic micro-circuitry and the computer sciences. Such effort is essential for the cost-effective application of new technology and for planning future support capabilities. Ongoing work includes the investigation of the total data transfer and processing needs of upcoming missions and studies of ground systems and telecommunication links to determine design approaches, and overall tradeoffs for the lowest life cycle costs to support future space missions.

BASIS FOR FY 1989 ESTIMATE

Activities planned for FY 1989 include efforts to obtain location accuracies at the decimeter level for Earth-orbiting spacecraft which would make possible a new class of high precision Earth observatory missions on the Shuttle, Space Station and on free-flying spacecraft. The techniques being analyzed for particular application include the Department of Defense's Global Positioning System and the use of Very Long Baseline Interferometry. Work will continue on the development of extremely precise radiometric techniques for determining angular direction of future planetary missions to an accuracy of five nano-radians. Such improvements typically lead to improved spacecraft navigation and the conduct of science experiments not previously possible. Studies will continue on ground-based navigation strategies, analyses, and demonstrations for Galileo, Ulysses, and Mars Observer.

Efforts to improve communications between the ground and spacecraft will continue in such areas as the use of millimeter wave frequencies on large diameter antennas; development of more efficient transmitters and highly reliable, low noise telemetry receivers; development of a K-Band terminal for TDRSS-user spacecraft; and, antenna feed systems capable of multiple frequency operation, including millimeter waves. Such improvements in space-to-ground communications can benefit future missions by increasing the amount and quality of the data returned. Optical tracking and communications technology to meet telecommunications needs in the decades ahead will also be investigated both for its cost-performance advantages over microwave technology and for its potential in space data relay applications.

The use of high density magnetic tape and optical disk storage with automated quality control of recorded data is being investigated to meet future high-rate image data processing requirements as the data handled from Earth-orbital missions increases from a current peak of 50 megabits per second to the TDRSS design limit of 300 megabits per second. These future requirements result from high resolution sensors, such as multispectral scanners and synthetic aperture radars, which will be capable of transmitting more data than previous scanning and radar instruments. New techniques and systems will be developed for the transfer and processing of these high data rates. These developments include new techniques for signal coding and decoding of data; optical disk buffering and storage to handle TDRS data transfer rates; automated distribution and processing of high volume data, improved man-machine interfaces, and a communications network using an optimal mix of fiber optics, satellites, and local area networks to distribute data to processing centers and users.

Investigations will continue on achieving a more efficient operation of the mission control facilties and providing for the necessary real-time interaction between the spacecraft experimenters and their experiments. Other investigations are being carried out in the area of expert systems applications, greater use of distributed command terminals, and the performance of orbit and attitude computations on board the spacecraft.

SPACE FLIGHT
CONTROL AND DATA
COMMUNICATIONS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

SPACE FLIGHT, CONTROL AND DATA COMMUNICATIONS

FISCAL YEAR 1989 ESTIMATES

GENERAL STATEMENT

The objective of the National Aeronautics and Space Administration program of space flight, control and data communications is to provide for the operational activities of the Space Transportation System and tracking and communication system support to all NASA flight projects. This objective is achieved through the following elements:

SHUTTLE PRODUCTION AND OPERATIONAL CAPABILITY: A program to provide a fully capable fleet of Space Shuttle orbiters, main engines, launch site and mission operations control requirements, initial spares, production tooling, and related supporting activities.

SPACE TRANSPORTATION OPERATIONS: A program to provide the standard operational support services for the Space Shuttle and the expendable launch vehicles. Within Shuttle operations, external tank and solid rocket booster flight hardware is produced; operational spare hardware is provisioned, overhauled and repaired; and manpower, propellants, and other materials are furnished to conduct both flight and ground (launch and landing) operations.

SPACE AND GROUND NETWORK. COMMUNICATIONS AND DATA SYSTEMS: A program to provide vital tracking, telemetry, command, and data acquisition support to meet the requirements of all NASA flight projects. This support is currently provided by a worldwide network of NASA electronic ground stations interconnected by a communications system using ground, undersea, and satellite circuits. The Tracking and Data Relay Satellite System (TDRSS) will become the primary system for supporting upcoming Earth orbiting missions.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

SPACE FLIGHT, CONTROL AND DATA COMMUNICATIONS

FY 1989 BUDGET ESTIMATES

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Millions of Dollars)		
Shuttle production and operational capability	3,408.1	1,217.3	1,088.3	1,400.5
Space transportation operations	1,746.0	1,838.0	1,838.0	2,405.4
Space and ground networks, communication and data systems	845.4	939.4	884.4	1.035.3
Total	5.999.5	3,994.7	3.810.7	4.841.2

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
PROPOSED APPROPRIATION LANGUAGE

SPACE FLIGHT, CONTROL AND DATA COMMUNICATIONS

For necessary expenses, not otherwise provided for; in support of space flight, spacecraft control and communications activities of the National Aeronautics and Space Administration, including operations, production, services, minor construction, maintenance, repair, rehabilitation, and modification of real and personal property; tracking and data relay satellite services as authorized by law; purchase, hire, maintenance and operation of other than administrative aircraft; [$3,908,309,000] *$4,841,200,000,* to remain available until September 30, [1989, including not to exceed $28,000,000 for expendable launch vehicles which shall be available only for the purchase of two Delta II vehicles for the launch of the Roentgen satellite (ROSAT) and the Extreme Ultraviolet Explorer (EUVE)] *1990. (Department of Housing and Urban Development-Independent Agencies Appropriations Act, 1988; additional authorizing legislation to be proposed.)*

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

SPACE FLIGHT, CONTROL AND DATA COMMUNICATIONS

REIMBURSABLE SUMMARY
(In thousands of dollars)

	Budget Plan		
	FY 1987	FY 1988	FY 1989
Shuttle Production and Capability Development	115,828	92,700	98,870
Space Transportation Operations	-179,000	---	12,400
Expendable Launch Vehicles	217,184	147,540	118,210
Tracking and Data Acquisition	37.245	42,500	36.000
Total	191.257	282.740	265,480

NATIONAL AERONAUTICS AND SPACE ADMINSTRATION

FISCAL YEAR 1989 ESTIMATES

DISTRUBTION Of SPACE FLIGHT CONTROL AND DATA COMMUNICATIONS BUDGET PLAN BY INSTALLATION AND FISCAL YEAR

(Thousands of Dollars)

Program		Total	Johnson Space Center	Kennedy Space Center	Marshall Space Flight Center	National Space Tech Lab	Goddard Space Flt Center	Jet Propulsion Lab	Ames Research Center	Langley Research Ctnttr	lewis Research Center	NASA HQ
Space Transportation Sys	1987	5,154,100	2,337,900	642,100	1,533,800	15,800	1,900	1,700	4,500	100	5,100	611,200
	1988	2,926,300	870,700	709,100	1,176,200	18,500	27,400	1,700	5,000	100	3,500	114,100
	1989	3,805,900	980,300	816,300	1,412,500	20,200	50,800	1,800	6,300	23,700	125,700	368,300
Shuttle Production	1987	3,408,100	1,831,000	153,500	986,400	14,200	200	1,700	0	0	3,100	418,000
	1988	1,088,300	308,200	132,400	536,200	16,500	200	1,700	0	0	3,500	89,600
	1989	1,400,500	348,300	186,000	538,300	18,000	0	1,800	0	0	5,700	302,400
Space Transporation Ops	1987	1,746,000	506,980	488,600	517,400	1,600	1,700	0	4,500	100	2,000	193,200
	1988	1,638,000	562,500	576,700	640,000	2,000	27,200	0	5,000	100	0	24,500
	1989	2,405,400	632,000	630,300	871,200	2,200	50,800	0	6,300	23,700	120,000	65,900
Tracking And Data Acqui	1987	845,400	5	0	46,285	0	415,003	122,622	11,800	0	0	249,685
	1988	884,400	0	0	51,100	0	440,700	129,200	10,300	0	0	253,100
	1989	1,035,300	0	0	49,100	0	572,900	140,200	11,900	0	0	261,200
TOTAL BUDGET PLAN	1987	5,999,500	2,337,905	642,100	1,580,085	15,800	416,903	124,322	16,300	100	5,100	860,885
	1988	3,810,700	870,700	709,100	1,227,300	18,500	468,100	130,900	15,300	100	3,500	367,200
	1989	4,841,200	980,300	816,300	1,461,600	20,200	623,700	142,000	18,200	23,700	125,700	629,500

SPACE
TRANSPORTATION
SYSTEMS

FISCAL YEAR 1989 ESTIMATES

BUDGET SUMMARY

OFFICE OF SPACE FLIGHT

SPACE TRANSPORTATION SYSTEM PROGRAM

SUMMARY OF RESOURCES REOUIREMENTS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
Shuttle production and operational capability	3,408,100	1,217,300	1,088,300	1,400,500	SF 1-1
Space transportation operations	1,746,000	1.838.000	1,838,000	2.405.400	SF 2-1
Total	5.154.100	3,055,300	2.926.300	3,805,900	

Distribution of Program Amounts By Installation

Johnson Space Center	2,337,900	836,600	870,700	980,300
Kennedy Space Center	642,100	578,200	709,100	816,300
Marshall Space Flight Center	1,533,800	1,205,700	1,176,200	1,412,500
National Space Technology Laboratories	15,800	13,900	18,500	20,200
Goddard Space Flight Center	1,900	27,200	27,400	50,800
Jet Propulsion Laboratory	1,700	1,500	1,700	1,800
Lewis Research Center	5,100	3,000	3,500	125,700
Langley Research Center	100	100	100	23,700
Ames Research Center	4,500	5,500	5,000	6,300
Headquarters	611.200	383,600	114.100	368.300
Total	5,154,100	3.055.300	2.926.300	3.805.900

OFFICE OF SPACE FLIGHT **SPACE TRANSPORTATION SYSTEM PROGRAM**

PROGRAM OBJECTIVES

The primary program objective of the current activity in the Space Transportation System is to complete the safe return to Space Shuttle flight activities. The Space Shuttle is the key element of a versatile Space Transportation System (STS) that is available to a wide variety of national users and certain international users. The Space Shuttle is the first reusable space vehicle and is configured to carry many different types of space apparatus, spacecraft scientific experiments, and national security payloads. In addition to transporting materials, equipment and spacecraft to orbit, the Shuttle offers unique capabilities that cannot be achieved with Expendable Launch Vehicles (ELV): retrieving payloads from orbit for reuse; servicing and repairing satellites in space; transporting to orbit, operating, and returning space laboratories; and performing rescue missions.

Shuttle Production and Operational Capability provides for the national fleet of Shuttle orbiters including the replacement orbiter which was fully funded in FY 1987. This budget element also provides for the launch site facilities, initial spares, production tooling, and related support activities. In addition, there is also included the design, test, analysis and certification associated with the recovery actions necessary, as a result of the Challenger accident, to verify the flight hardware and mission support processes necessary for returning to flight.

This line item contains five subdivisions: Orbiter Operational Capability, Orbiter Replacement, Propulsion, Launch and Mission Support, and Changes and Systems Upgrades. Orbiter Operational Capability includes orbiter design modifications and system improvements, mission kits, procurement of a spares inventory for the operational orbiter fleet, necessary safety modifications identified by the NASA investigation and the Rogers Commission during the post-Challenger accident review process, initiation of a new set of structural spares to maintain the capability to produce orbiter vehicles, and continuation of work started in FY 1988 on an Extended Duration Orbiter capability (EDO). Orbiter replacement will provide a replacement Orbiter for Challenger which is necessary to restore a significant element in the Nation's space launch capability. Propulsion Systems provides for Space Shuttle Main Engines (SSME), External Tank (ET), and Solid Rocket Booster (SRB) design improvements, safety modifications, capability investments, rate tooling and development of an Advanced Solid Rocket Motor (ASRM). Launch and Mission Support provides the Johnson Space Center (JSC) mission operations capability development, equipment provisioning of the facilities for launch and landing at the Kennedy Space Center (KSC) and the initial lay-in of spares and ground support equipment. Changes and Systems Upgrade provides funding for potential changes and systems modifications as well as for unanticipated new requirements not covered elsewhere.

Space Transportation Operations provides the standard operational support services for the Space Shuttle and Expendable Launch Vehicle's for NASA payload requirements. Within Shuttle Operations, flight hardware is produced, refurbished and repaired; and manpower, propellants, and other materials are furnished to conduct and support both flight and ground operations. The Shuttle Operations program provides for the launch of NASA missions, DOD, other U.S. Government and certain commercial and international missions on a reimbursable basis. The launch schedule calls for one flight in FY 1988 (the first launch is scheduled for late summer 1988), seven flights in FY 1989, and ten flights in FY 1990.

The Shuttle provides launch services to non-NASA users on a reimbursable basis to satisfy Department of Defense and civil government requirements. A limited number of foreign and commercial launches are planned following the resumption of flights based on Administration policy decisions.

The Expendable Launch Vehicle/Mixed Fleet plan provides launch services for unmanned civil U.S. government space missions not requiring the Space Shuttle's unique capabilities. Initially, expendable launch vehicle services will be procured, for selected high priority missions previously manifested on the Space Shuttle. Consistent with the Competition in Contracting Act, expendable launch vehicle services will be acquired from the U.S. private sector, where possible.

STATUS

The Shuttle Production and Operational Capability budget provides funding in four areas: Orbiter Operations Capability, Propulsion, Launch and Mission Support, and Changes and Systems Upgrades. The primary thrust of the current effort in orbiter operational capability is to complete the review, evaluation, production and installation of orbiter modifications to enable a safe return to flight. In addition, the logistics program continues to procure lay-in and rate spares and establish a centralized depot repair capability to fully support the flight program. Improvement programs for the orbiter which were initiated prior to the Challenger accident are well on the way to completion. Work continues on the Remote Manipulator System to upgrade a test article to flight status, on flight software to incorporate all required changes for return to flight and introduction of the upgraded computers. Initial work on systems to extend the orbiter on-orbit stay time from 7-10 to 14-16 days will be funded within the Research and Development FY 1988 Appropriation consistent with Congressional direction. Continuation of this work in FY 1989 is included in Orbiter Operational Capability.

A contract was signed with Rockwell International on August 1, 1987, to produce a replacement orbiter for Challenger utilizing the existing structural spares. This replacement orbiter is needed to restore the Shuttle fleet to a full operational level and to help fly off the backlog of national security, certain international and civil missions.

At KSC, modifications to major facilities and launch site equipment are continuing to provide for more efficient and reliable launch processing. For example, the Launch Complex 39 permanent weather protection modifications on Pad A will be completed in FY 1989. Equipment continues to be procured for installation into the Orbiter Modification and Refurbishment Facility (OMRF) which will provide a safing and disservices capability. Other efforts underway include continued development of the Digital Operational Intercom System (OIS-D), extension of the Launch Equipment Test Facility (LETF) to support testing of the facility modifications, and incorporation of fiber optics to improve KSC on-site communications between facilities.

At JSC, modifications to on-going activities have been approved to satisfy post-Challenger accident program requirements. Weather prediction and reporting capabilities are being expanded and runway end barriers are being developed for installation at the primary and contingency landing sites, with the latter being expanded in number as well as capability. Readiness of those landing sites associated with polar orbit missions have been deferred consistent with the deferral of the Vandenberg launch site activation. In addition, fidelity and reliability improvements to the training simulators are being given high priority with replacement of the host computers and selected software models underway.

Development and life certification of the Space Shuttle Main Engine (SSME) is continuing in support of the flight and ground test program. Design modifications on the high pressure pumps and the hot gas manifold are directed at increasing the SSME operating margins, reducing the SSME operating costs, and determining the hardware life and replacement requirements through a certification extension test program. A major near-term effort is to continue to develop design improvements to the high pressure turbopump blades and bearings to enhance the operating margins and extend their operational life. The long range plan is to replace the high pressure turbopumps with redesigned pumps from an alternative source. A contractor was selected in August 1986 for this effort. Redesign of the hot gas manifold is continuing with the design goal of improving flow conditions which will extend engine life by decreasing systems resistance and reducing pump loads. These manifold changes and the alternative source turbopumps will be introduced into the fleet during the early 1990's. The SSME program also includes an advanced technology effort which will provide a technology test bed for detailed SSME environment characterization, and will evaluate potential SSME component and system level improvements, as well as evaluate technical advances arising from the Office of Aeronautics and Space Technology's Space Research and Technology program.

The redesign of the solid rocket motor to resolve deficiencies in the prev ous design will be completed in FY 1988. Evaluation of flight data, inc uding detailed analysis, will be continuing in FY 1989 to thoroughly assess the redesign. In FY 1989 development of an Advanced Solid Rocket Motor (ASRM) will be initiated. The ASRM will enhance reliability and safety by eliminating the redesigned SRM constraint of maximizing utilization of existing hardware. Changes in configuration, design details, and materials may be employed to meet more stringent design requirements and enhance safety margins. Production processes will be examined to use the latest applicable technology and automation to enhance reliability and producihility. Significant performance increases are also expected with the ASRM.

Tooling and production streamlining activities are continuing on the solid rocket booster. No major design changes are anticipated in the external tank as the result of extensive reviews following the Challenger accident.

The Shuttle Operations budget provides funding in three principal areas: Flight Operations, Flight Hardware, and Launch and Landing Operations. Flight Operations includes training, mission control, flight operations planning, payload and systems analytical integration, mission analysis, post-flight anomaly resolution, sustaining engineering and launch support services. The period prior to resumption of flight is being utilized to correct deficiencies identified either by previous experience or by the accident investigation and redevelopment analyses. Training exercises continue for first flight and sustained flight rate.

Flight Hardware includes the replenishment of orbiter spares and refurbishment of flight hardware, SSME spares and refurbishment, external tanks and the interface hardware with the orbiter, solid rocket motors and booster hardware, and propellants; engineering and logistics support for external tank/solid rocket booster/main engine hardware elements; and maintenance and operation of flight crew equipment. The funding for the ET and solid rocket motors and boosters includes long lead procurements of raw materials, subassemblies, and subsystems required to sustain production as the flight rate increases.

The Launch and Landing Operations budget provides funding for processing the elements of shuttle flight hardware as they flow through the ground processing stations at KSC. The Shuttle Processing Contractor (SPC), in conjunction with the Base Operations Contractor (BOC), provides all Shuttle vehicle testing, check-out, servicing, and launch processing functions. The Payload Ground Operations Contractor (PGOC) provides processing for all STS payloads from their arrival at KSC through shuttle integration.

The Expendable Launch Vehicles/Mixed Fleet plan has been developed as a result of an assessment of NASA's Space Transportation requirements after the January 1986 Challenger accident. This assessment concluded that U.S. Civil Government spacecraft be launched on a mixed fleet in order to provide increased access to space, to assure continuity of space operations, and to enhance mission flexibility. The plan is being procured in phases. First, NASA plans to procure launch services through directed procurement for missions which require launching by 1991. The missions, under this first phase, are selected high priority missions previously manifested on the Space Shuttle. After the initial phase, the plan is to procure launch services on a competitive basis for identified future requirements.

PRODUCTION
AND OPERATIONAL
CAPABILITY

BASIS OF FY 1989 FUNDING REOUIREMENTS

SHUTTLE PRODUCTION AND OPERATIONAL CAPABILITY

	1987 Actual	1988 Revised Budeet	1988 Current Estimate	1989 Budget Estimate	
		(Thousands of Dollars)			
Orbiter operational capability.....	448,100	403,200	328,600	320,000	SF 1-4
Orbiter replacement.....	2,000,000	---	---	---	SF 1-7
Launch and mission support.....	151,200	240,800	164,800	343,700	SF 1-8
Propulsion systems.....	808,800	548,300	594,900	711,800	SF **1-10**
Changes and system upgrading.....	---	25.000	---	25.000	SF 1-14
Total.....	3,408,100	1,217,300	1.088.300	1.400.500	
Distribution of Program Amounts by Installation					
Johnson Space Center.....	1,831,000	344,800	308,200	348,300	
Kennedy Space Center.....	153,500	122,900	132,400	186,000	
Marshall Space Flight Center.....	986,400	435,400	536,200	538,300	
National Space Technology Laboratories...	14,200	13,400	16,500	18,000	
Goddard Space Flight Center.....	200	--	200	--	
Jet Propulsion Laboratory.....	1,700	1,500	1,700	1,800	
Lewis Research Center.....	3,100	3,000	3,500	5,700	
Headquarters.....	418.000	296,300	89.600	302.400	
Total.....	3,408,100	1.217.300	1.088.300	1.400.500	

OBJECTIVES AND STATUS

The objectives of this program are to provide for the completion of the modifications required to return the Space Transportation System to a safe flight status, the completion of the national fleet of Shuttle orbiters, including building a replacement orbiter for the Challenger; the development and production of the propulsion systems; the development of launch site capabilities; and the potential changes and upgrading of the Space Transportation System (STS). Also included is the development of the Extended Duration Orbiter (EDO) and the Advanced Solid Rocket Motor (ASRM).

With the loss of Challenger in January 1986, the orbiter fleet was reduced to three vehicles until a replacement orbiter, which was approved by Congress in 1986, can be delivered. The current orbiter fleet includes Columbia, the orbiter developed and flown on four test and evaluation flights, and two orbiters of a lighter-weight configuration, Discovery and Atlantis. The budget provides funding for necessary improvements, hardware fixes and mission kits for the orbiter fleet to satisfy flight requirements, In addition, the provisioning of orbiter spares at the Kennedy Space Center is an on-going activity for the initial lay-in of spares to support the flight rate buildup. The EDO development is also included to increase on-orbit stay time in order to improve the Shuttle capability to support payload requirements.

Launch and Mission Support provides for the required investment in Launch Operations and Flight Operations capability to meet STS program objectives, which include returning safely to flight and supporting the flight rate. At KSC, the second line of facilities allow simultaneous processing and checkout of orbiters and associated flight hardware from landing through launch. At JSC, mission support provides collateral hardware, principally the extra-vehicular maneuvering units (EMU) while mission operations capability provides for improvements in the flight support systems. The flight support systems funded by this budget include training and carrier aircraft, additional landing aids and runway end barriers at the primary and contingency landing sites, and replacement/upgrade of equipment in the mission support complex such as the Shuttle Mission Simulator and the Mission Control Center.

Propulsion systems provide for the production of the Space Shuttle Main Engines (SSME) and the development of the capability to support operational requirements established for the SSME, SRB, and ET. The SSME program includes: production of main engines necessary for the orbiter fleet and to establish a spares inventory, ground testing in support of engine development, anomaly resolution, and product improvement and advanced development efforts to improve operating margins.

The SRB production and capability development activities include: the reclamation of production verification and 51-L configuration solid propellant motors; investigation of returned flight hardware; procurement of contamination control tooling and equipment to support flight rate; and selected studies to continue investigative, analytical, and problem solving activities. The development of an ASRM is included in this budget.

Changes and Systems Upgrading provides funding for potential changes and system modifications as well as unanticipated new requirements not covered in the budget estimates for the above activities and other program elements.

BASIS OF FY 1989 FUNDING REQUIREMENT

ORBITER OPERATIONAL CAPABILITY

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Orbiter	272,900	241,200	206,700	191,000
Systems integration	25,500	4,100	34,000	17,700
Orbiter spares	149.700	157.900	87.900	111.300
Total	448.100	403.200	328.600	320.000

OBJECTIVES AND STATUS

Our primary objective is to continue return of the three orbiter fleet to safe flight status in FY 1988. This will provide safe and reliable access to space for NASA, the Department of Defense and certain domestic and international users of space. In support of this objective, orbiter production activities include the necessary safety modifications identified by the Rogers Commission and the post-Challenger accident review process and the development and installation of necessary hardware, software and procedural modifications. Also, work continues on improvements to achieve greater operational capabilities, reduce operational costs, and meet system requirements. These improvements include upgrading the general purpose computers (GPC), inertial measurement units (IMU), auxiliary power units (APU), and provision of a crew escape system during Orbiter controlled gliding flight. The brake and the nose wheel steering systems are undergoing modifications to improve landing performance. In concert with these major improvements to the hardware, there are modifications to the flight and ground software. In addition to these system changes, there are numerous mission and modification kits requested for specific flights and payloads. Also included will be the work necessary to continue work on an extended duration orbiter (EDO) capability.

The structural spares program initiated in FY 1983 provided the foundation for the production of a replacement orbiter with a delivery date planned for mid-1991. A new set of structural spares will be initiated in FY 1989. This new effort will sustain the capability to produce another vehicle in addition to providing additional spares for inventory. Structural assemblies include the wings, aft thrust structure, engine compartment, crew module (including the nose and cockpit), mid and aft fuselage sections, payload bay doors, vertical tail, and the orbital maneuvering system pods.

The procurement and fabrication of the orbiter spares inventory is ongoing. A concerted effort has been made to better define the spares requirements and production capability at various vendors. A logistics

depot has been established at KSC for repair and maintenance of orbiter parts. The on-site depot will reduce repair costs and shorten turnaround time. The depot is currently repairing and maintaining minor line replaceable (LRU) and shop replaceable units (SRU) and is scheduled to transition to major repair activity and become fully operational by FY 1991.

CHANGES FROM FY 1988 REVISED BUDGET

FY 1988 funding for orbiter operational capability activities decreased $74.6 million. Additional funding required for mandatory return to flight and systems integration activities was offset by deferring for one year the initiation of a replacement set of structural spares as well as the deferral of important but non-mandatory hardware modifications and tasks.

BASIS OF FY 1989 ESTIMATE

Orbiter funds provide for the procurement of a logistics capability including an inventory of spares to support operations requirements, the continuation of previously approved systems improvement programs, necessary safety modifications identified as a result of the Challenger accident review process, initiating the manufacture of a replacement set of structural spares, and the engineering analysis and integration support for the flight rate. Orbiter funding also provides for orbiter support activities such as the remote manipulator system, the on-board flight software, and implementation of a crew escape system during orbiter controlled gliding flight. Starting in FY 1989, work on the Extended Duration Orbiter (EDO) will be continued under the orbiter program. In FY 1988, Congress appropriated funds in Research and Development to initiate the EDO.

The orbiter logistics capability program in FY 1989 is continuing the lay-in of LRU's, SRU's, and repair parts to support the flight rate buildup. The funding covers flight hardware spares, ground equipment spares, scheduling, provisioning documentation, and maintenance training. In addition, funding is included to provide maintenance test equipment and special test equipment for the centralized depot and selected vendor repair sites.

The development, qualification and production of flight units for an improved auxiliary power unit (APU) and the upgrade of the general purpose computers (GPC) will continue. The improved APU will have longer life and higher reliability and will require substantially less ground servicing. This configuration will preclude recurrence of problems which have occurred on prior flights such as the formation of wax due to the mixing of lube oil and fuel. The new GPC will add memory and increase operating speed in order to avoid the operational limitations of the current hardware and will result in a more reliable system.

The orbiter funding also covers systems integration of all redevelopment analyses and hardware changes, as well as procuring orbiter support items and capability changes to the on-board flight software. Continuing development of the capabilities of the on-board primary and backup flight software is necessary due to expanding safety requirements and system capabilities.

The EDO provides for the development of a cryogenic pallet kit to extend the on-orbit stay time from 7-10 to 14-16 days in order to provide significantly greater time for payloads to complete their mission objectives. The cryogenic pallet will accommodate four tank sets to supply the fuel cells with additional reactants needed to generate electrical power for the added time on-orbit. The program should be completed in FY 1992 with the modification of an existing orbiter.

BASIS OF FY 1989 FUNDING REOUIREMENT

REPLACEMENT ORBITER

	1987 Actual	1988 Revised Budeet	1988 Current Estimate	1989 Budget Estimate
Orbiter replacement.....	2,000,000	---	---	---

OBJECTIVES AND STATUS

In order to provide assured access to space and to maintain United States preeminence in space, NASA has been directed to procure a replacement orbiter (OV-105), with full funding provided in FY 1987. This replacement orbiter will provide a significant increase in existing National launch capability to fly off the backlog of national security, international, U.S. space industry, and NASA missions resulting from the Challenger accident.

Currently, a set of structural spares is being completed and used as the foundation for the production of OV-105. A contract has been signed with Rockwell International for the production of this orbiter; work began on August 1, 1987 and the OV-105 is planned to be delivered in 1991. Funding includes a full set of new main engines and the necessary ancillary government furnished equipment such as the remote manipulator arm, space suits, galley, etc.

Consistent with the direction in the FY 1988 Continuing Appropriations Bill (PL 100-202), $100 million of replacement orbiter funds have been transferred to Space Station development. In addition, in order to offset a general reduction to FY 1988 Space Flight Control and Data Communications, the appropriation conference report allowed up to $125 million of replacement orbiter funds to be utilized to continue necessary modifications and related work to prepare the Shuttle fleet for operational status. It is anticipated that these funds will be applied to support SRB recovery activities; the FY 1987 operating plan will be updated accordingly.

BASIS OF FY 1989 FUNDING REQUIREMENT

LAUNCH AND MISSION SUPPORT

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
Launch site equipment.....	70,300	56,900	54,400	142,000
Mission support capability.....	31,700	113,200	32,700	93,500
Mission operations capability.....	49.200	70.700	77.700	108.200
Total.....	151.200	240.800	164.800	343.700

OBJECTIVES AND STATUS

This activity supports the development of launch and mission support capabilities, principally at the Johnson Space Center (JSC) and Kennedy Space Center (KSC). The first line of facilities at KSC was developed during the DDT&E program to support launch processing and checkout of one Shuttle vehicle through launch. A "second line" of facilities is provided in the launch site equipment budget to support processing and checkout of up to three orbiters in flow and to sustain the operational launches at KSC. Second line facilities already operational include the second launch pad, the second high bay of the orbiter processing facility, the second mobile launch platform, and two additional high bay areas in the vehicle assembly building. The third mobile launch platform will be completed in FY 1989. The orbiter modification and refurbishment facility (OMRF) will have safing and deservicing capability.

Funding has been included for upgrading landing aids for end of mission and contingency/abort landing sites. Capability improvements have been added for weather prediction and information handling to improve system monitoring, notably for anomaly tracking. Funding for a pre-flight adaptor trainer has also been added to help prepare the crews for a weightless environment. Consistent with the recommendations of the Rogers Commission, improvements in simulation training including new host computers and interface hardware are being made. Critical improvements in simulation fidelity will be accommodated with the expanded capacity of the new hardware. Reliability required for the longer integrated simulations, and associated maintenance cost will also be substantially improved with these replacements. Other activities include implementing required modification and upgrades on the T-38 proficiency aircraft and procuring a fourth Shuttle Training Aircraft and a second Shuttle Carrier Aircraft. Procurement of extravehicular mobility units and associated improvements are also included.

CHANGES FROM FY 1988 REVISED BUDGET

The Launch and Mission Support total has decreased $76.0 million. The launch site equipment decrease of $2.5 million reflects a deferral of Launch Processing System improvements to accommodate return-to-flight modifications and the addition of independent safing and deservicing capabilities within the OMRF.

Mission support capability decreased by $80.5 million reflecting the slow build up of mission related activities in propulsion.

Mission operations capability increased by $7.0 million to continue the required equipment improvements in the training, landing, and mission control facilities.

BASIS OF FY 1989 ESTIMATE

In FY 1989, Launch Site Equipment includes activities to improve the capability to support the flight rate requirements at KSC. These include a digital internal communications system with associated fiber optics cabling, safing and deservicing equipment for installation into the orbiter modification and refurbishment facility, replacement equipment for the launch processing system, extension of the launch equipment test facility (LETF), and installation of equipment at the contingency landing sites. The third mobile launcher platform previously scheduled for readiness in September 1986, has been delayed until FY 1989 consistent with the adjusted flight rate requirements. Identification, replacement and upgrading of obsolete ground processing and support equipment will be accomplished.

Mission support capability requirements continue to establish an inventory of crew equipment, principally extravehicular mobility units (EMU), to support the flight rate. STS operations effectiveness work and other support functions continue to support STS program-wide requirements including flight safety, mission success, and rate capability.

Mission operations capability funding in FY 1989 provides for completion of replacement of the host computers, selected critical items for the Shuttle training simulators and replacement of ADP and other hardware in the Mission Control Center. Continuing projects include improvements to weather prediction, information handling, mission control systems, and contingency landing sites. Also included is the continued development of a preflight adaptor trainer to prepare the crew for a gravity-free environment and procurement of the fourth Shuttle Training Aircraft and a second Shuttle Carrier Aircraft.

BASIS OF FY 1989 FUNDING REQUIREMENT

PROPULSION SYSTEMS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Main engine	432,700	363,800	382,200	511,800
Solid rocket booster	322,100	139,900	179,200	193,000
External tank	51,700	42,200	33,500	7,000
Systems support	2,300	2,400	---	---
Total	808,800	548,300	594,900	711,800

OBJECTIVES AND STATUS

Propulsion Systems provides for the production of the Space Shuttle Main Engines (SSME), the implementation of the capability to support operational requirements, and anomaly resolution for the SSME, Solid Rocket Booster (SRB), and External Tank (ET). The SSME program includes the production of the main engines required for the orbiter fleet, the procurement of spare engines, ground testing operations, development and certification activities to improve operating margins, reliability and durability, and anomaly resolution capability. The SRB program includes the reclamation and refurbishment of hardware produced prior to the Challenger accident, continued replacement of reuseable hardware lost during the 51-L failure and subsequent ground testing of the SRB redesign, continuation of test data analyses and evaluation, completion of SRM tooling modifications, procurement of transportation equipment to support the projected flight rate, and development of the Advanced Solid Rocket Motor. Engineering analysis and modification of booster hardware for certification of a 20 flight reuse capability will continue in FY 1989. Systems support primarily provides for support to the testing of the SSME in the main propulsion test article configuration.

The SSME program has been structured into three major elements under Shuttle Production and Operational Capability: (1) flight engine; (2) development engine; and (3) advanced development. The total SSME experience now exceeds 1,400 tests, totaling approximately 320,000 seconds of test and flight time. This experience includes 285 tests, exceeding 62,208 seconds of operation, at the full power level (FPL).

The flight engine activity includes the production of new engines, retrofit of improved hardware into the fleet, and anomaly resolution activity.

The development engine activity provides for the hardware, propellants, and support for testing, and for testing, and for the development, certification, and flight certification extension of improved hardware including a redesigned hot gas manifold and near-term high pressure turbopump improvements such as improved blades and bearings. The NSTL B-1 test stand for single engine test has been added to the program to meet expanded ground test requirements.

In light of the Challenger accident, the SSME program has delayed all activities associated with the operational use of FPL (109%). Single engine testing at these levels has continued to demonstrate margin and safety for the life certification extension test program. In addition, testing is required to demonstrate capability to support extreme abort modes which require operation at FPL. The NSTL main propulsion test stand capability is being maintained for the FPL test of three clustered engines. This test will provide for a verification of the main propulsion system operations at full power level using the main propulsion system test hardware mounted in the aft end of the simulated orbiter.

The advanced development element includes the alternate turbopump program and the technology test bed. An alternate source for high pressure turbopumps was selected in August, 1986. These alternate pumps will be designed for greater reliability, safety margin, and lower operational costs. The technology test bed will provide an independent means to evaluate the technical advances arising from the development program, the alternate pump effort, and the OAST Space Research and Technology program.

The redesign of the SRB to resolve deficiencies in the previous design will be completed through certification and reflight in FY 1988. Assessment of flight data, including analysis and evaluation, will be continuing in FY 1989. There will be a continuing activity to improve tooling and procedures to enhance process control and product quality. Reclamation of reuseable SRM hardware produced prior to the Challenger accident will be accomplished through static firing and refurbishment. Refurbishment of the case hardware will include modification to the redesigned configuration.

CHANGES FROM FY 1988 REVISED BUDGET

FY 1988 funding requirements in Propulsion increased $46.6 million. The total Propulsion funding requirements increased $171.6 million and $125 million of this requirement will be accommodated through application of FY 1987 funds. The Conference Report (House Report 100-498) accompanying the FY 1988 Continuing Appropriations Bill (P.L. 100-202) provided authority to use $125 million of FY 1987 to fund recovery activities necessary to prepare the Shuttle fleet for operational status. This funding will be applied against these requirements to partially offset the increase. The increase in total requirements is primarily the result of an additional $164.3 million required in the Solid Rocket Booster (SRB). Funding in the SRB has been increased to cover expanded redesign, analysis and testing activities on the

Solid Rocket Motors, increased recertification and instrumentation of the SRB and continuation of the Phase B definition studies for the Advanced Solid Rocket Motor (ASRM) begun in 1987. These increases do not include any potential impact from the recent DM-9 nozzle boot ring test failure. The External Tank decreased $8.7 million reflecting the delay of computer equipment and the deletion of planned support equipment improvements. The Main Engine activities increased $18.4 million in order to support increased design and testing activities of critical flight hardware and systems support was reduced $2.4 million with the deferral of the main propulsion test.

BASIS OF FY 1989 ESTIMATE

Funding for the FY 1989 budget is based upon resumption of the flight program in the late summer of 1988 and the design, test, and certification of the propulsion hardware for flight. Return to flight activities include a complete reassessment of the program and recertification of all flight hardware to assure compliance with flight requirements. The SSME program will continue production of flight hardware and the development programs including necessary improvements to the current configuration and the alternate turbopump programs. The SRB FY 1989 funding will primarily focus upon continued evaluation and analysis of flight data to thoroughly assess the redesign. Modification of booster hardware necessary to obtain 20 flight reuse capability will continue as well. The External Tank program supports the production of tanks with required off-the-shelf equipment.

The Advanced Solid Rocket Motor (ASRM) project is intended to enhance the flight safety, reliability and performance of the Space Shuttle fleet. The ASRM will not be subject to the constraint of maximum utilization of existing hardware that limited changes on the recent SRM design activities. The ASRM may employ changes in configuration, design details, and materials to meet more stringent design requirements and enhance safety margins. Production processes will be examined to utilize the latest applicable technology and process automation to enhance reproducibility and reliability.

During the ASRM definition studies, now being conducted, the contractors will perform preliminary designs on a segmented motor and monolithic motor. Also, they will provide design data on a modern, automated production facility to maximize material and process controls for enhanced re iability. An additional objective of the ASRM is to achieve increased payload capability. The definition studies will examine achieving this objective with the requirement that there be no compromise to flight safety and reliability, and the that the impact to other Shuttle elements be held to an absolute minimum.

The Request for Proposal (RFP) for the development phase will be issued at or near the end of the definition studies. One contractor is to be selected for developing, and the contract start is anticipated during the first half of FY 1989. The development program is anticipated to extend for 4 to 5 years with the first flight in early 1994. The development period is based on the original SRM development. The scope of the development will include modification or acquisition of facilities, the development and test of the new design and production of verification units. The ASRM development is

comparable in scope and complexity to that of the **SRM**, and the technological base is greater than that at the start of the SRM project.

The asbestos-free insulation development program previously included as a separate development will be incorporated into the scope of the **ASRM** development. This requirement is driven by environmental and production safety concerns rather than by technical or performance issues. Costly duplications of qualification tests can be avoided by incorporating this effort into the overall **ASRM** effort. However, if the **ASRM** is not approved or the existing asbestos-based insulation production is stopped before the **ASRM** is available, the separate development will have to be reinstated.

BASIS OF FY **1989** FUNDING REQUIREMENT

CHANGES AND SYSTEMS UPGRADING

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Changes and systems upgrading.....	---	25,000	---	25,000

OBJECTIVES AND STATUS

Management, technical flight experience, and cost reviews of the Shuttle program have stressed the need for providing an allowance for changes and modifications which inevitably are required in a large, complex, and technically demanding space system.

The Changes and Systems Upgrading budget provides for potential changes to improve system reliability, safety and performance.

CHANGES FROM FY **1988** REVISED BUDGET

The $25 million decrease reflects the allocation of all FY 1988 funding to the Shuttle projects for recovery activities as individual tasks were identified. These funds have been applied to the SRB and SSME projects for recovery tasks discussed in Propulsion.

BASIS OF FY **1989** ESTIMATE

The funding for FY 1989 will provide for those changes which are considered to have highest priority. The objectives are to improve reliability, increase operating safety margins, and reduce costs.

OPERATIONS

BASIS OF FY 1989 FUNDING REOUIREMENT

SPACE TRANSPORTATION OPERATIONS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
		(Thousands of Dollars)			
Flight operations	515.000	520.400	583.600	660.100	SF 2-4
Flight hardware	869.200	918.500	776.600	1.035.200	SF 2-7
Launch and landing operations	359.800	371.100	449.800	514.600	SF 2-9
Shuttle operations	1.744.000	1.810.000	1.810.000	2.209.900	
Expendable launch vehicles and services	2.000	28.000	28.000	195.500	SF 2-11
Total	1.746.000	1.838.000	1.838.000	2.405.400	
Distribution of Program Amounts by Installation					
Johnson Space Center	506.900	491.800	562.500	632.000	
Kennedy Space Center	488.600	455.300	576.700	630.300	
Marshall Space Flight Center	547.400	770.300	640.000	874.200	
National Space Technology Laboratories	1.600	500	2.000	2.200	
Goddard Space Flight Center	1.700	27.200	27.200	50.800	
Langley Research Center	100	100	100	23.700	
Lewis Research Center	2.000	---	---	120.000	
Ames Research Center	4.500	5.500	5.000	6.300	
Headquarters	193.200	87.300	24.500	65.900	
Total	1,746,000	1.838.000	1.838.000	2.405.400	

OBJECTIVES AND STATUS

Space Transportation Operations provides launch services to **NASA** payloads utilizing a mixed fleet approach of the Shuttle and Expendable Launch Vehicles. Launch services are also provided, on a reimbursable basis to the Department of Defense, other civil agencies, and certain commercial and international users. The Shuttle program launch schedule is based on a resumption of flight activity in late summer 1988 with one flight in FY 1988, seven in FY 1989, and ten in FY 1990. The ELV planning reflects use of a mix of launch systems based on individual payload requirements.

The Space Shuttle has demonstrated a broad range of capabilities including deployment of spacecraft and their upper stages, satellite repairs, satellite retrieval, operations using the remote manipulator, integral scientific experimentation using Spacelab systems, and extravehicular activity operations. These capabilities provide a unique opportunity to enhance the scientific return of many payloads and the Shuttle will remain the mainstay of **NASA's** launch capability. The major program elements of Shuttle Operations are Flight Operations, Flight Hardware and Launch and Landing Operations. These elements provide for the standard service operation of the Shuttle including pre-flight preparation activities, procurement and refurbishment of flight hardware and maintenance and operation of equipment and facilities necessary to support all phases of the Shuttle flight process.

The Flight Operations activity is divided into three major elements: mission support, integration, and support. Mission support includes training, flight operations activities and a wide variety of planning activities ranging from operational concepts and techniques to detailed systems operational procedures and checklists. Integration includes launch support services and sustaining engineering for orbiter systems, cargo analytical integration, and systems integration. The support element includes systems support activity at JSC such as aircraft operations, engineering support, and support to the NSTS program office. Shuttle system support at Headquarters and the Goddard Space Flight Center is also included.

The Flight Hardware program element provides for: the procurement of external tanks (ET) and solid rocket booster (SRB) hardware including motors, booster hardware, and propellants; spare components and flight support for the Space Shuttle Main Engine (SSME); orbiter spares; ET disconnects, logistics support for the ET, SRB, and SSME flight hardware elements; and maintenance and operations of flight crew equipment. Included in the funding request for tanks and boosters are the long lead time raw materials, subassemblies, subsystems and additional ground testing of the redesigned Solid Rocket Motor (SRM) necessary to sustain and verify the production of elements in a manner consistent with the flight rate requirements.

Launch and Landing Operations provides for the pre-launch preparation, liquid propellants, launch, and landing operations of the Shuttle and its cargo. Total funding requirements for Shuttle Operations are offset by reimbursements for Shuttle launch services received from other U.S. Government, commercial, and

international users to support the operations requirements of the Space Shuttle. There are currently no planned reimbursable funds for Shuttle Operations in FY 1988. It is anticipated that reimbursable funding will resume in FY 1989 and increase as the Shuttle flight rate builds up.

The Expendable Launch Vehicles/Mixed Fleet plan was initiated in FY 1987 as a result of an assessment of NASA's space transportation requirements after the Challenger accident. This assessment showed that U.S. Civil Government spacecraft be launched on a mixed fleet in order to provide increased access to space, to assure continuity of space operations, and to enhance mission flexibility. The missions currently planned for launch on ELV's are selected high priority missions previously manifested on the Space Shuttle for west coast launches and selected east coast launches which do not require the Shuttle's unique capabilities and can transition to ELV's without significant impact to the Spacecraft.

BASIS OF FY 1989 FUNDING REOUIREMENT

FLIGHT OPERATIONS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Mission support.....	158,500	167,000	193,200	215,400
Integration.....	206,500	195,500	226,800	264,100
Support.....	150,000	157,900	163,600	180,600
Total.....	515,000	520,400	583,600	660,100

OBJECTIVES AND STATUS

Flight operations is divided into three major areas of activity: mission support, integration, and support. Mission support includes a wide variety of pre-flight planning, crew training, and operations control activities. The planning activities range from the development of operational concepts and techniques to detailed systems operational procedures and checklists. Tasks include flight planning, preparation of systems and software handbooks, flight rules, detailed crew activity plans and procedures, development and implementation of the mission control center (MCC) and network system requirements for each flight, and operations input to the planning for the selection and operation of Shuttle payloads. Specific flight planning activity encompasses the flight design, flight analysis, and software activities. Flight design products include conceptual flight profiles and operational flight profiles which are issued for each flight as well as support to the crew training simulations and flight techniques. In addition, the flight-dependent data located in the erasable memory (mission-to-mission changes) is developed in the flight design process for incorporation into the orbiter software, Shuttle mission simulator, and MCC systems. Also included are the maintenance and operation of critical mission support facilities including the mission control center, flight simulators, crew training, and flight software reconfiguration and recertification facilities.

Integration includes orbiter sustaining engineering, payload integration into the Shuttle, system integration of the flight hardware elements, orbiter launch support services to the launch site and flight development and verification software. The orbiter sustaining engineering provides all prime contractor engineering activities necessary to re-qualify the orbiter for flight including FMEA/CIL, design changes and certification reviews. The software activities include the development, formulation, and verification support of the guidance, targeting, and navigation systems software requirements in the orbiter.

Support includes base operations support to Shuttle operations and systems level support at the manned space flight centers. Base operations support provides for operation and maintenance of aircraft for flight training, crew proficiency and the ferry requirements; engineering and supporting activities for the orbiter, crew equipment, and flight operations systems; and support to the NSTS program office.

Currently, the resources for Flight Operations are focused upon preparing for resumption of flight, fixing a backlog of system discrepancies and incorporating a large number of changes to ground systems hardware, software, and procedures including those resulting from the ongoing process of analysis and decision-making in the wake of the Challenger accident. Flight preparation, training of ground and flight crews (including system-wide integrated simulations), and other functions are being carried out. These efforts are critical to the safe operation of the Shuttle and significant emphasis is being placed on insuring that the flight products and crew training satisfying revised and more stringent operational requirements.

CHANGES FROM FY 1988 REVISED BUDGET

The Flight Operations direct budget increased $63.2 million in order to support more extensive system design reviews, flight product verification and safety/reliability oversight. Mission support has increased $26.2 million to reflect additional fidelity and verification in the flight design and software reconfiguration activities over previously estimated levels. Integration has increased $31.3 million due to additional manpower required primarily in the orbiter sustaining engineering and systems integration activities. This in response to the Rogers Commission recommendation which requires increased oversight and surveillance by the development contractors to ensure system requirements and specifications are being implemented properly. Also added are increased engineering oversight by NSTS and the program office over the Shuttle projects including the operation of a comprehensive system-wide Shuttle data base which will store and track performance and failure history for each major subsystem within every Shuttle project (e.g. SRM, ET, Orbiter, etc.). Support has increased $5.7 million in order to accommodate increased requirements at JSC and NSTS for information processing and equipment.

BASIS OF FY 1989 ESTIMATE

The Flight Operations portion of the Shuttle Operations budget continues to support that activity predominately associated with the effort at JSC to plan for and conduct STS missions from launch to landing. The functions are essentially the same as in the past: to maintain and operate all the ground facilities necessary for flight preparation and execution, and to instruct the flight and ground controller crews; to maintain and operate aircraft for proficiency, training and orbiter ferry requirements and to perform analyses of and conduct of the mission planning necessary for each mission.

It also includes the sustaining engineering required to integrate all flight and ground elements and to assure systems safety and integrity; the analytical integration of the payloads into the orbiter and the planning to assure compatibility and verification of interfaces; and support of crew operations and training programs. Orbiter engineering manpower continues the required support of procedure and hardware modifications resulting from the FMEA/CIL reviews, in addition to the sustaining engineering activities that ensure maintainability, reliability, and anomaly resolution during operations.

BASIS OF FY 1989 FUNDING REOUIREMENT

FLIGHT HARDWARE

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Orbiter	473,500	273,700	280,900	339,400
Solid rocket booster	144,300	317,800	205,600	382,500
External tank	251.400	327.000	290.100	313,300
Total	869,200	918,500	776.600	1,035,200

OBJECTIVES AND STATUS

The Flight Hardware program element provides for the procurement of External Tanks (ET), the manufacturing and refurbishment of Solid Rocket Booster (SRB) hardware and motors; and operational support to the Orbiter including orbiter spares, ET disconnects, spare components and flight support for the Main Engines (SSME) and maintenance and refurbishment of flight crew equipment. Included in the funding request for tanks and boosters are the long lead raw materials, subassemblies, and subsystems necessary to sustain the production of these elements in a manner consistent with the increasing flight rate. Production phasing of these elements is based on the current flight traffic model and is structured to maintain a smooth and efficient buildup of the production capability. Included also are static test firings of two production type motors a year in order to continue verification and analysis of the SRM redesign. In the ET, production continues at a minimum level of activity necessary to retain manufacturing capability. The Orbiter line element includes Orbiter spares for replenishment of line and shop replaceable units, the manpower for supporting the logistics operation, and the repair capability for flight hardware. SSME includes component and engine overhauls, flight support, and procurement of replacement spare parts. Also included in flight hardware are replaceable spares, field support, and maintenance of crew-related equipment. Some examples of orbiter spare equipment are fuel cells, tiles for thermal protection, tape recorders, leading edge support structures, wheels, brakes and pyrotechnics. The crew-related equipment activities include support to pre-flight training and flight usage of the extravehicular maneuvering unit, emergency portable oxygen systems, radiation instrumentation, survival radios, closed-circuit television cameras, medical support, and food and other galley-related items.

CHANGES FROM FY 1988 REVISED BUDGET

Decreased funding of $141.9 million for flight hardware reflects the savings which accrued from the reduced traffic model somewhat offset by increased requirements in the Orbiter projects. Orbiter has increased $7.2 million due to increased engine support manpower and critical item analysis. Orbiter logistics has also been increased to restore inventory levels and to accommodate more repairs at vendor locations as preparations are made for the resumption of flights. The SRB has decreased $112.2 million due to the reduced mission model and deferral of material and subcontract purchases. These reductions in SRB are partially offset by additional hardware modifications generated by the recovery program as well as increased x-ray requirements. The external tank has decreased $36.9 million due to the reduced mission model.

BASIS OF FY 1989 ESTIMATE

Requirements for Orbiter flight spares, crew equipment spares, and logistics are based on projected flight rates, maintenance schedules, operational usage, repair times, and lead times to procure or repair flight hardware. The budget provides replenishment line and shop replaceable units, as well as the manpower to support the overhaul and repair activity for the Orbiter, extravehicular maneuvering unit and other crew equipment. The flight equipment processing contract (FEPC) which was initiated during FY 1986 is continuing its buildup to full capability to support the projected flight rates. Main Engine hardware provides for manufacturing and delivery of overhauled engines, engine component spares and flight support. Flight hardware requirements activity for the SRB and ET include the procurement of the materials and labor required for refurbishment and fabrication of units which will be flown during FY 1989, as well as the support of the production of units which will be flown thereafter. Additionally, two static firing tests of the redesigned SRM will be conducted to monitor the consistency of production characteristics.

BASIS OF FY 1989 FUNDING REQUIREMENT

LAUNCH AND LANDING OPERATIONS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Launch operations.....	322,500	322,a00	402,700	456,600
Payload and launch support.....	37.300	48.300	47,100	58.000
Total.....	359.800	371,100	449.a00	514.600

OBJECTIVES AND STATUS

Launch and Landing Operations provides for the manpower and materials to process and prepare the Shuttle flight hardware elements for launch as they flow through the processing facilities at KSC. Standard service processing and preparation of payloads as they are integrated into the orbiter are also funded by this category as is procurement of liquid propellants for launch and base support. Support to landing operations at KSC and contingency sites, as required, is also provided.

Operation of the launch and landing facilities and equipment at KSC is the primary function of the Shuttle Processing Contractor (SPC). This includes stacking and mating of the flight hardware elements into a launch vehicle configuration, verification of the launch configuration, and operation of the launch processing system prior to lift-off. Support is also provided by the SPC for booster retrieval operations, configuration control, logistics, transportation, and inventory management.

Support to Shuttle processing is provided by the Base Operations Contractor or (BOC). The BOC is responsible for operations support functions such as propellants and life support, railroad maintenance, pressure vessels, Shuttle landing facility and facility and equipment modifications.

Other launch support services included in this budget are maintenance and repair of the central data subsystem, which supports Shuttle processing as an on-line element of the launch processing system; range support provided by the DOD; Shuttle related data management functions such as work control and test procedures; and purchase of equipment, supplies and services not procured under the Shuttle Processing Contractor.

The Payload and Ground Operations Contract (PGOC) is the major contract for the payload processing activities. In Shuttle Operations, the PGOC contractor provides the standard service processing of all

STS payloads into an integrated cargo prior to loading into the Shuttle. PGOC will also be the primary contractor for Spacelab and Space Station payload processing at KSC, funded under their respective budgets.

CHANGES FROM FY 1988 BUDGET ESTIMATE

Direct funding requirements for Launch and Landing Operations reflect a net increase of $78.7 million to provide significantly expanded testing, process engineering, quality control and accountability during Shuttle processing. Extensive studies during FY 1987 concluded that increased support levels were required to improve flight safety and ensure sustained flight rates. These increases will provide improved operational procedures and processing practices, strengthen engineering and quality assurance support to processing, and enhance training to assure discipline and continuity in processing. The slip in the return to flight date has had minimal impact to the funding requirements for launch and landing activities due to the addition of a flight readiness firing and increased hardware modifications and testing requirements

BASIS OF FY 1989 BUDGET

Launch operations funding in FY 1989 provides for manpower and support services necessary for processing launches from KSC. This includes manpower to assemble the **SRB's,** mate the boosters and tanks, process the orbiter, mate the orbiter to the integrated **SRB's** and tank, process and checkout integrated flight elements through launch, retrieve the **SRB's** for refurbishment, and support landing of the orbiter either at KSC or at a contingency landing site when required. Funding also supports the manpower required for sustaining engineering, spares provisioning, logistics, launch processing system operation and maintenance, and maintenance/modification of all other Shuttle-related ground support equipment and facilities. Flight safety will continue to be emphasized through testing, engineering and quality control.

Payload and launch support funding provides propellants for launch operations and base support, and contractor support for the assembly of individual payloads into **a** total cargo. This element includes providing launch rite support managers to payload customers, verifying cargo-to-orbiter interface, and providing operations maintenance and logistic support to cargo support equipment (such as cargo integration test equipment and multi-mission payload support equipment) and to the payload support areas including the Vertical Processing Facility, Operations and Checkout building, and cargo hazardous servicing facilities. Support required for maintaining the Dryden Flight Research Facility as a contingency landing site is also included.

BASIS OF FY 1989 FUNDING REQUIREMENT

SPACE TRANSPORTATION OPERATIONS

EXPENDABLE LAUNCH VEHICLES/MIXED FLEET

	1987 Actual	1988 Revised Budeet	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Expendable launch vehicles and services..	2,000	28,000	28,000	195,500

OBJECTIVES AND STATUS

The Expendable Launch Vehicles/Mixed Fleet plan, initiated in 1987, provides launch services for selected NASA payloads not requiring the Space Shuttle's unique capability. Four performance classes of expendable vehicles are planned in the mixed fleet. A small class capable of launching payloads up to 1,000lbs into low Earth orbit; a medium class capable of launching payloads up to 10,000lbs into orbit; an intermediate class capable of launching payloads up to 30,000lbs and a large class capable of launching payloads of *40,000* lbs or more. NASA plans to utilize competition where possible in the acquisition of expendable launch vehicle services in these performance classes to accommodate a range of spacecraft requirements in FY 1992 and beyond. In the interim, NASA will acquire expendable launch vehicle services for selected high priority missions previously manifested on the Space Shuttle consistent with the Competition in Contracting Act (CICA). In this interim period, two delta II launches, one for the Roentgen Satellite (ROSAT) and one for the Extreme Ultraviolet Explorer (EWE) are being acquired through the Department of Defense (DOD). DOD has also been requested to provide a Titan IV vehicle to be available in 1991 to provide a back-up for either the Magellan, Galileo and Ulysses planetary missions presently manifested on the Shuttle. Titan III vehicles are being evaluated for launch of the TDRS-F and Mars Observer spacecraft in the 1991/92 time period. In addition, discussions are in progress to obtain Atlas/Centaur launch services for the Combined Release and Radiation Effects Satellite (CRRES) as part of a barter in exchange for residual hardware from previous programs. Assuming that CRRES is launched on this vehicle, several of the planned experiments which could not be accommodated on Atlas/Centaur would be launched on Scout vehicles.

Funds provided in FY 1988 are being utilized for procurement the Delta II launch vehicles from the DOD for the ROSAT and EWE missions. In addition, a DELTA vehicle is being prepared for the Cosmic Background Explorer (COBE) mission using funds reimbursed by DOD for residual hardware.

BASIS OF FY 1989 ESTIMATES

Funds are required for continuation of launch vehicle procurements through the DOD for the ROSAT and the EWE missions. In addition, funding is required to initiate work on the Titan 111, Titan IV, Atlas/Centaur and Scout launches described above. Funding is required for medium class vehicles for the Geotail and Wind spacecraft of the Global Geospace Science project. Procurement of launch services for small class vehicles in support of Science & Application missions, planned to be launched at a rate of two per year, will be initiated with these funds.

TRACKING AND DATA
ACQUISITION

SPACE FLIGHT, CONTROL AND DATA COMMUNICATIONS

FISCAL YEAR 1989 ESTIMATES

BUDGET SUMMARY

OFFICE OF SPACE OPERATIONS **SPACE AND GROUND NETWORKS. COMMUNICATIONS AND DATA SYSTEMS**

SUMMARY OF RESOURCES REOUIREMENTS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate	Page Number
		(Thousands of Dollars)			
Space network	404,300	479,300	435,700	538,900	SF 3-4
Ground networks	237,200	255,600	232,200	248,100	SF 3-11
Communications and data systems	203.900	204.500	216,500	248,300	SF 3-20
Total	845.400	939.400	884,400	1035.300	
Distribution of Program Amounts by Installation					
Marshall Space Flight Center	46,285	34,600	51,100	49,100	
Goddard Space Flight Center	415,003	507,700	440,700	572,900	
Jet Propulsion Laboratory	122,622	131,800	129,200	140,200	
Ames Research Center	11,800	10,200	10,300	11,900	
Headquarters	249,685	255,100	253,100	261,200	
Johnson Space Center	5	---	---	---	
Total	845.400	939,400	884.400	1035.300	

OFFICE OF SPACE OPERATIONS **SPACE AND GROUND NETWORKS, COMMUNICATIONS AND DATA SYSTEMS**

PROGRAM OBJECTIVES AND JUSTIFICATION

The purpose of this program is to provide vital tracking, telemetry, command, data acquisition, communications and data processing support to meet the requirements of all NASA flight projects. In addition to NASA flight projects, support is provided on a reimbursable basis for projects of the Department of Defense (DOD), other Government agencies, commercial firms, and other countries and international organizations engaged in space research.

Support is provided for Earth orbital, planetary and solar system exploration missions, research aircraft, sounding rockets and balloons. Included in Earth orbital support are the Space Shuttle, Spacelabs, and scientific and applications missions. The various types of support provided include: (a) tracking to determine the position and trajectory of vehicles in space; (b) acquisition of scientific and space applications data from on-board experiments and sensors; (c) acquisition of engineering data on the performance of spacecraft and launch vehicle systems; (d) reception of television transmissions from space vehicles; (e) transmission of commands from ground stations to the spacecraft; (f) communications with astronauts; (g) transfer of information between the various ground facilities and control centers; and (h) processing of data acquired from the launch vehicles and spacecraft. Such support is essential for achieving the scientific objectives of all flight missions and for executing the critical decisions which must be made to assure the success of these missions.

Tracking and acquisition of data for the space projects is presently accomplished through the use of a worldwide network of NASA ground stations, and by the first of three tracking and data relay satellites in geosynchronous orbit working with a highly specialized ground station. Ground facilities are interconnected by terrestrial and communications satellite circuits linking the spacecraft and their control centers for execution of the missions.

To meet the support requirements levied by the wide variety and large number of flight projects, NASA has three basic support capabilities to meet the needs of all classes of NASA flight missions. These are the Spaceflight Tracking and Data Network (STDN), which supports Earth orbital missions; the Deep Space Network (DSN), which primarily supports planetary and interplanetary flight missions; and the Space Network including the Tracking and Data Relay Satellite System (TDRSS), which will provide all low Earth orbital mission support when it becomes fully operational.

The STDN will provide Earth orbital support until the TDRSS becomes operational. At that time the STDN phasedown will continue with the closure of several ground stations. The DSN, under the management of the Jet Propulsion Laboratory (JPL), provides support to geosynchronous, highly elliptical, and planetary and solar system exploration missions, as well as support to those spacecraft, now in low-Earth orbit, which are not compatible with TDRSS.

Highly specialized computation facilities provide real-time information for mission control; and process into meaningful form the large amounts of scientific, applications, and engineering data which are collected from flight projects. In addition, instrumentation facilities provides support for sounding rocket launchings and flight testing of aeronautical research aircraft.

The Space Flight, Control and Data Communications appropriation includes the Space Network, Ground Networks, and Communications and Data Systems elements of the program, and provides funding for: (a) TDRSS operations, spacecraft production, and launch support; (b) operations and maintenance of the tracking, data acquisition, mission control, data processing, and communications facilities; and (c) the engineering services and procurement of equipment to sustain and modify the various systems to support continuing, new, and changing flight project requirements.

CHANGES FROM FY 1988 REVISED BUDGET

The current estimate for FY 1988 of $884.4 million is $55 million below the revised budget estimate and represents a reduction of $40 million for the TDRSS Replacement Spacecraft and a $15 million general reduction consistent: with Congressional direction. These and other adjustments are addressed in subsequent sections of the program justification.

BASIS OF FY 1989 FUNDING REQUIREMENTS

SPACE NETWORK

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Tracking and data relay satellite system (TDRSS)	285,098	320,900	318,900	313,800
Space network operations	35,700	43,900	42,700	46,700
Systems engineering and support	26,404	25,600	26,700	25,600
TDRS Replacement spacecraft	50,398	75,800	35,800	78,800
Second TDRSS ground terminal	2,700	9,100	7,600	70,000
Advanced TDRSS	4,000	4,000	4,000	4,000
Total	404.300	479.300	435.700	538.900

OBJECTIVES AND STATUS

The Space Network consists of the Tracking and Data Relay Satellite System (TDRSS) and a number of NASA ground elements to provide the necessary tracking, telemetry, command, and communications services to low Earth orbital spacecraft. The TDKSS, when fully operational, will consist of a three satellite constellation, including an on-orbit spare, in geostationary orbit and ground facilities located at White Sands, New Mexico. From the White Sands location, satellite and ground communication links interconnect the NASA elements of the network and any remotely located user facilities.

The FY 1989 request includes funding for: repayment of the loans extended by the Federal Financing Bank for TDRSS development; maintenance and operation of the White Sands complex and other NASA elements of the network; support activities such as systems engineering, documentation and mission planning; equipment modification and replacement; analytical studies to define the spacecraft required for the next generation TDRSS; the development and integration of an additional spacecraft to replace the TDRS lost in the Challenger accident; and the implementation of a second ground terminal at White Sands.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Tracking and data relay satellite system.....	285,098	320,900	318,900	313,800

OBJECTIVES AND STATUS

The Tracking and Data Relay Satellite System's (TDRSS) objective is to provide communications services between spacecraft and ground facilities. The relay satellites provide space-to-space communications to and from user satellites and relay these communications to the ground via the White Sands facilities which are interconnected with the other elements of the network. From their position in geostationary orbit, the TDRS's can provide nearly a six-fold increase in the orbital coverage provided by ground tracking stations and can accommodate extremely high user data rates ranging up to 300 megabits per second.

The TDRS-1 was launched in April 1983, and since that time it has supported Shuttle missions, including Spacelabs, and free flyer satellite missions such as the Solar Maximum Mission (SMM), Earth Radiation Budget Satellite (ERBS), Landsat, and Solar Mesopheric Explorer (SME). The TDRS-2 was destroyed during the Challenger accident in January 1986. The four remaining spacecraft are undergoing modifications to be compatible with Shuttle safety requirements and are in various stages of construction, assembly and retesting. It is anticipated that the launch of the next TDRS will be on the first Shuttle mission when flights resume. The third TDRS had been scheduled for launch in the first quarter of 1989. The launch date is currently under review pending determination of the Shuttle manifest. Once these two spacecraft have been successfully launched, and the system achieves full operational status, TDRS-1 will become the on-orbit spare.

CHANGES FROM FY 1988 REVISED BUDGET

The decrease of $2 million in the FY 1988 revised budget estimate results from a detailed reassessment of support requirements, leading to greater than anticipated savings during the STS standdown period.

BASIS OF FY 1989 ESTIMATE

Under the terms of the TDRSS service contract, loans were extended by the Federal Financing Bank (FFB) to Space Communications Company (SCC), the owner-operator of the TDRSS, for program development. Under the terms of the loan agreement and assignment, NASA repays these loans directly to the FFB. In addition, NASA will make payments to SCC for the operation and maintenance of the White Sands complex and for satellite construction and launch support provided during the year.

Of the amount requested in FY 1989, approximately $227 million is for the FFB loan repayments. The remainder of the request is for continuing spacecraft construction, modification, test, storage, and assembly, launch related costs, and operation and maintenance of the White Sands Ground Terminal.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Space network operations.....	35,700	43,900	42,700	46,700

OBJECTIVES AND STATUS

The objective of Space Network Operations is to provide for the operation and maintenance of the associated NASA ground systems and facilities which, when combined with TDRSS, provide a full array of reliable tracking, telemetry, command, and communications services to user spacecraft in low Earth orbit. Each of these key NASA network elements are designed to function as an integrated operative system and perform specific functions for the Space Network.

The NASA Ground Terminal (NGT) monitors TDRSS performance., provides fault isolation monitoring for the network, and serves as the communications interface between White Sands and all other user facilities. The Network Control Center (NCC) manages and schedules TDRSS services for all user spacecraft, and the Flight Dynamics Facility (FDF) provides orbit determination, trajectory analysis, and position location for flight missions supported by the space network and for selected missions supported by the ground networks.

The overall system has provided services to a variety of missions and effort is continuing to achieve an operational configuration that will be capable of supporting an expanded workload in the early 1990's.

CHANGES FROM FY 1988 REVISED BUDGET

The decrease of $1.2 million in the FY 1988 revised budget estimate results from reduced contractor support required during this period, principally as a result of the STS standdown.

BASIS OF FY 1989 ESTIMATE

The funding request provides for services to operate network facilities 24 hours a day, seven days per week, and for related hardware and software maintenance. Funding is also provided for a variety of support activities such as operational analysis, mission planning, simulations, user compatibility testing, and documentation.

	1987 Actual	1988 Revised Budeet	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Systems engineering and support.....	26,404	25,600	26,700	25,600

OBJECTIVES AND STATUS

The objective of Systems Engineering and Support is to provide the engineering services and hardware required to sustain and modify the NASA elements of the Space Network. Engineering services are supplied primarily through support service contracts.

Preparations continue to assure ground system readiness for the resumption of Shuttle flights including the upcoming TDRS launches and for full network operation once the TDRSS is operational. There is ongoing activity to sustain system reliability for current users and preparations are underway to meet the support requirements of upcoming missions such as the Hubble Space Telescope.

CHANGES FROM FY 1988 REVISED BUDGET

The increase of $1.1 million in the FY 1988 revised budget estimate is for the necessary advanced planning to support the development of Space Station operational concepts, interface definition for data handling and distribution, and support requirements definition.

BASIS OF THE FY 1989 ESTIMATE

Funds are requested to provide systems engineering, hardware and software maintenance, sustaining engineering support, test equipment, and vendor maintenance for specialized equipment and subsystems within the Space Network. Funds are also requested for continued software development and ongoing hardware implementation, replacement and modification for the NCC.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
TDRS replacement spacecraft.....	50,398	75,800	35,800	78,800

OBJECTIVES AND STATUS

A contract has been awarded to TRW, the sub-contractor for the TDRSS space segment, to provide a replacement spacecraft and long-lead parts for an optional spacecraft. The replacement for the TDRS-2 spacecraft lost with the Challenger will maintain the TDRSS until the late 1990's when the Advanced TDRS is planned to become available. The option provides protection against unforeseen launch or deployment failures. Preliminary design studies identified parts and components no longer available and recommended limited design changes to increase spacecraft safety and reliability. The design objective is to provide a satellite functionally identical to the current satellites and fully compatible with the existing system.

CHANGES FROM FY 1988 REVISED BUDGET

The decrease of $40 million in the N 1988 revised budget estimate reflects Congressional action on the NASA N 1988 budget request.

BASIS OF FY 1989 ESTIMATE

The requested funding will provide for continution of the construction phase of the program. This phase will include completing all design activities culminating with critical design review in the second quarter of FY 1989. In addition, fabrication of the spacecraft bus and payload hardware will continue, specifically including the spacecraft structure and control systems, antennas, traveling wave tube amplifiers, and signal processing sub-systems.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Second TDRSS ground terminal (STGT).....	2,700	9,100	7,600	70,000

OBJECTIVES AND STATUS

The objective of this program is to provide a backup to the existing ground terminal at White Sands, New Mexico, to insure continuity of service and to minimize the potential loss of critical space assets, including data. The existing terminal is a single point of failure for the entire Space Network, and a catastrophic failure of this terminal could result in a nearly complete loss of NASA communications and data gathering capabilities for earth orbiting missions. In addition, the present terminal has experienced temporary service outages due to equipment failure which could have been avoided with a backup terminal.

Due to the aging of equipment, replacement of major subsystems and components in the existing terminal will eventually be required, necessitating an alternate means of conducting network operations while the replacement activity is underway. The addition of a second ground terminal will provide the necessary alternative means for continuing operational support while the existing terminal is down during the replacement.

Because the design of the current terminal is limited to full operation of two TDRS spacecraft, a second terminal will also provide the additional flexibility to operate more spacecraft if, as anticipated, mission requirements exceed current capabilities in the mid 1990's.

CHANGES FROM FY 1988 REVISED BUDGET

The decrease of $1.5 million in the FY 1988 revised budget estimate will be accommodated by rephasing of procurement activities planned for FY 1988 into FY 1989.

BASIS OF FY 1989 ESTIMATE

A competitive award for two design study contracts was made in May 1987. A competitive award to a single contractor for implementation is planned for early FY 1989. Funding for the initiation of the implementation phase for the development of hardware and software is included in this request.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Advanced tracking and data relay..... satellites (ATDRS).....	*4,000*	*4,000*	*4,000*	*4,000*

OBJECTIVES AND STATUS

The objective of the program is to develop and competitively procure technologically advanced satellites to sustain Space Network operations. By the mid-1990's, the stock of ground spare spacecraft for the Tracking and Data Relay Satellite System (TDRSS) is expected to be exhausted. The ATDRS will provide the capability to extend network service into the 21st century and to accommodate the future mission requirements projected for this era. Initial low level studies have been initiatied and will be completed by mid-FY 1989. In late FY 1989, definition activities will commence.

BASIS OF FY 1989 ESTIMATE

Requested funding is required to complete the initial studies and to begin competitive definition activities.

BASIS OF FY 1989 FUNDING REOUIREMENTS

GROUND NETWORKS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Spaceflight tracking and data network systems implementation.....	3,a00	3,200	3,200	6,200
Spaceflight tracking and data network operations.....	78,000	84,600	70,100	65,700
Deep space network systems implementation.....	40,000	49,000	46,200	50,100
Deep space network operations.....	87,700	94,100	88,000	99,000
Aeronautics, balloons, and sounding rocket support systems implementation..	11,200	a,400	a,200	9,300
Aeronautics, balloons, and sounding rocket support operations.....	16,500	16.300	16.500	17.a00
Total.....	237,200	255.600	232,200	248.100

OBJECTIVES AND STATUS

The Ground Networks provide support to three broad categories of missions: Earth orbital spaceflight; planetary and solar system exploration; and aeronautics, balloons and sounding rockets. Earth orbital support is provided primarily by the Spaceflight Tracking and Data Network (STDN), a network of eight geographically dispersed ground stations. The Deep Space Network, with ground stations located at three sites approximately 120 degrees apart in longitude, provides support to the planetary and solar system exploration missions as well as Earth orbital missions not compatible with TDRSS. Aeronautics, balloons and sounding rocket research is supported by specially instrumented ranges as well as mobile systems.

Funding €or the Ground Networks provides for operation and maintenance of the worldwide tracking facilities, engineering support, and the procurement of hardware and software to sustain and modify network capabilities as required to support new missions. The workload in FY 1989 will include support to the Space Shuttle, the Voyager-2 encounter with the planet Neptune, and the Magellan spacecraft launch. Magellan will perform radar imaging of Venus during FY 1990. Preparations will be underway for the future

Galileo, Ulysses, and Mars Observer planetary encounter missions, and the Global Geospace Science (GGS) mission. Ongoing missions such as Dynamic Explorer (DE), International Ultraviolet Explorer (IUE), and Solar Maximum Mission (SMM) will continue to receive Ground Networks and/or Space Network support. Aircraft test programs will also be supported.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Spaceflight tracking and data network systems implementation.....	3,800	3,200	3,200	6,200

OBJECTIVES AND STATUS

The Spaceflight Tracking and Data Network (STDN) systems implementation program encompasses the procurement of hardware and attendant engineering services to sustain, modify, and replace existing network capabilities to ensure reliable tracking, command and data acquisition support to NASA's spaceflight missions.

BASIS OF FY 1989 ESTIMATE

The FY 1989 request includes funds for replacement of obsolete and difficult-to-maintain equipment at certain tracking stations and other network facilities. The funds requested also provide for the procurement of major subsystem spares, the replacement of older test equipment, and minor equipment modifications resulting from changes in support requirements.

Funds are also required to upgrade equipment systems and subsystems at those facilities to be retained after TDRSS is operational. These facilities include the Merritt Island, Florida, and Bermuda STDN stations which provide prelaunch, launch, and Shuttle landing support, as well as limited orbital support. Also included is the orbital tracking facility at the Wallops Flight Facility,

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Spaceflight tracking and data network operations.....	78,000	84,600	70,100	65,700

OBJECTIVES AND STATUS

The primary function of the Spaceflight Tracking and Data Network (STDN) system is to support NASA's Earth orbiting spaceflight missions, including the Space Shuttle. This network also provides launch support to NASA planetary missions, and on a reimbursable basis, spaceflight missions of other United States government agencies (NOAA and DOD) and other nations.

The STDN presently consists of eight geographically dispersed ground stations. They are located at: Merritt Island, Florida; Kauai, Hawaii; Guam; Ascension Island; Dakar, Senegal; Bermuda; Santiago, Chile; and Yarragadee, Australia. Each of these stations, with the exception of Yarragadee, have the capability to electronically track spacecraft, send commands for spacecraft and experiment control purposes, and receive and display engineering and scientific data from the spacecraft. In the case of manned flights, they also maintain voice communications for crew operations and safety and other project-related purposes The Yarragadee, Australia station provides only air-to-ground voice communication with the Space Shuttle astronauts.

The STDN will undergo a highly significant change from its current configuration when the Space Network achieves operational status. At that time six STDN stations will cease operations and either close or be transferred to other organizations. These stations are Ascension Island; Guam; Hawaii; Santiago, Chile; Dakar, Senegal; and Yarragadee, Australia. The two remaining stations at Merritt Island, Florida, and Bermuda will provide prelaunch, launch, and Shuttle landing support as well as limited orbital support.

CHANGES FROM FY 1988 REVISED BUDGET

The decrease of *$14.5* million reflects program adjustments that are being made to accommodate a portion of the general reduction specified by Congress and a reallocation of funds for increased communications support requirements.

BASIS OF FY 1989 ESTIMATE

The FY 1989 funding request provides for a full year of operation of the eight STDN stations. In addition to the costs of operating the eight STDN stations, the request includes funding for logistics support, network planning, scheduling, control center operations, engineering, documentation, and software programming support. Logistics support funded under this program is provided to a variety of users such as the Deep Space Network, NASA Communications Network, Wallops Flight Facility, and spacecraft control centers at Goddnrd Space Flight Center (GSFC).

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Deep space network (DSN) systems implementation.....	40,000	49,000	46,200	50,100

OBJECTIVES AND STATUS

The primary role of the Deep Space Network (DSN) is to provide the communication link between each of NASA's planetary and interplanetary spacecraft and the Earth. The DSN is responsible for receiving science and engineering data and providing the navigation, command and control capabilities from the ground to a wide variety of spacecraft across distances ranging from hundreds to over 6 billion kilometers from Earth. The DSN also has support responsibilities for some spacecraft in Earth orbit that are not supportable by the TDRSS.

The systems and facilities required to support spacecraft at the limits of the solar system are highly specialized and include the use of large aperture antennas electronically configured in an array to receive the extremely weak radio signals. The antennas use ultrasensitive, cryogenically-cooled receivers and powerful transmitters. Extremely stable hydrogen maser time standards are required for precise navigation of distant spacecraft. Advanced data handling systems are required at both the DSN Complexes and the Network Operations Control Center.

Since Magellan and Galileo, both planned for launch in 1989, are the first spacecraft to receive the higher X-band frequency, the Deep Space Network is being equipped to transmit commands in this frequency range. Initially, the 34-meter antennas in California, Spain and Australia will have this capability. Not only will Galileo utilize this new frequency for spacecraft telecommunications, but it will also use a new precision tracking capability to perform experiments designed to detect perturbations in the gravity field caused by collapsing quasars. Since other deep space missions such as Mars Observer, with a planned 1992 launch will also utilize X-band, it is planned to implement this capability on most of the remaining antennas in the DSN by FY 1992.

The four major objectives for the DSN in the late 1980's are as follows: (1) to provide communications channels to scientific spacecraft at ever-increasing distances and to provide the capability to receive images at these great distances; (2) to increase the frequency range and data rate capability of the ground network to accommodate new deep space mission requirements; (3) to provide support for a new set of spacecraft which will include non-TDRSS compatible, highly elliptical Earth orbiters, and synchronous Earth orbital missions; and (4) to provide the improved navigation capabilities required for precise spacecraft targeting and probe delivery

These objectives continue to represent a significant challenge to the DSN. The most distant planetary encounter will be with Neptune by Voyager-2 in August 1989. This encounter will occur some 4.5 billion kilometers from Earth. At that time, Voyager-2 is expected to transmit the first high resolution images ever received from a spacecraft at that distance. To meet the challenge, an expansion of the 64-meter antennas to 70-meters will be completed by mid-1988. This expansion, along with multiple antenna arraying (signal combining) of DSN antennas and non-NASA radiotelescopes in New Mexico and Australia, will provide the increased signal capturing capability for our first look at Neptune. This technique was previously used successfully by the Canberra-Parkes, Australia array during the Voyager encounters with Saturn and Uranus.

The Magellan spacecraft is planned for launch in April 1989 and will be placed in orbit around Venus during July 1990. Radar mapping of Venus will be performed over the course of one Venusian year. Atmospheric dynamics of the Venusian atmosphere will also be measured.

The Deep Space Network will also support the two landers of the U.S.S.R's Phobos mission in FY 1989 This Soviet mission consists of two spacecraft, each of which will place a lander on the Martian moon Phobos. Future deep space missions to be supported by the DSN include Galileo, Ulysses, and Mars Observer.

CHANGES FROM FY **1988** REVISED BUDGET

The decrease of $2.8 million in the FY 1988 revised budget estimate reflects the decision to defer various system upgrades.

BASIS OF FY **1989** BUDGET ESTIMATE

Funding in the FY 1989 request provides for continuing the evolution of the DSN, taking advantage of the latest technologies to meet increasingly complex support requirements. Included are new capabilities needed to meet the more stringent navigation and spacecraft-ground telecommunications requirements.

Funds are included in the FY 1989 budget to implement the new capabilities required for the Magellan and Mars Observer missions. These capabilities include telemetry system modifications to handle the high data rates and extensive changes to the receiver system required by spacecraft signal dynamics. Funds have also been included to support the microwave observing project which will analyze microwave signals in space for evidence of advanced life elsewhere in the galaxy.

The band transmission capability being implemented at the new 34-meter sites require modifications to the antenna feed systems and the addition of a transmitter to the antennas which are currently in a "listen only" configuration. Extensive improvements to the ground tracking systems are required in FY

1989 to provide the navigation accuracy necessary for the Galileo probe release. This mission event requi.res that the position of the spacecraft be precisely known in order that the probe, when released, will follow the correct ballistic trajectory into the Jovian atmosphere.

Work will continue in FY 1989 in preparation for the Voyager-2 spacecraft encounter with Neptune in August 1989. This activity consists of implementation of a X-band receive capability for the Very Large Array radiotelescope at Socorro, New Mexico (which will be arrayed with Goldstone, California antennas) and the 64-meter radio telescope antenna at Parkes, Australia (which will be arrayed with the DSN antennas at Canberra, Australia).

This program also includes funds for sustaining activity in the DSN such as reliability modifications, operational improvements, and replacement of obsolete equipment at the the three DSN complex signal processing centers and at the Network Control Center at Pasadena, California.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Deep space network operations..	87,700	94,100	88,000	99,000

OBJECTIVES AND STATUS

The three Deep Space Network (DSN) complex locations--Goldstone, California; Canberra, Australia; and Madrid, Spain--are approximately 120 degrees apart in longitude to permit continuous viewing of planetary spacecraft. After completion of the project in FY 1988 to expand the diameter of the 64-meter antennas to 70 meters, each complex will have four antennas: one 70-meter, two 34-meter and one 26-meter. A centralized network control center is located at the Jet Propulsion Laboratory (JPL) in Pasadena, California.

The Voyager-2 spacecraft encounter with Uranus in January 1986 provided the first detailed information on that distant planet. Voyager-1 is now nearly 5 billion kilometers from Earth on a trajectory that will take it out of the solar system. The Pioneer-10 spacecraft is beyond the orbit of Neptune, and is the first man-made object to leave the solar system. It now takes eleven and one-half hours for a radio signal, traveling at the speed of light, to make the round trip between Earth and Pioneer-10. The Pioneer-11 spacecraft, some 3.8 billion kilometers from Earth, continues to be tracked. The Pioneer-6 through 8 spacecraft are provided support periodically, and especially during solar conjunctions and gravity wave experiments.

The DSN facilities are also used for ground based measurements in support of experiments in planetary radar mapping and in the field of radio astronomy. The ultrasensitive network antennas are being used in an attempt to learn more about pulsar high energy sources, quasars, and other interstellar and intergalactic phenomena.

CHANGES FROM FY **1988** REVISED BUDGET

The decrease of $6.1 million in the FY 1988 revised budget estimate reflects a reallocation of funds for increased communications support requirements and rephasing of activities to accommodate a portion of the general reduction.

BASIS OF FY **1989** ESTIMATE

The DSN operations funding provides for the maintenance and operation of network facilities and the support and engineering effort required for continuing operation of the network. The expected DSN workload in FY 1989 consists of support for the Voyager-2 spacecraft and its encounter with Neptune, Voyager-1, the six ongoing Pioneer spacecraft (Pioneer-6, 7, 8, 10, 11 and Pioneer-Venus), Magellan, Phobos, preparations for Galileo launch, Active Magnetospheric Particle Tracer Explorer, International Cometary Explorer, Nimbus-7, and Dynamics Explorer. The DSN will also provide emergency and backup support for the Space Shuttle, TDRSS and Hubble Space Telescope.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Aeronautics, balloons and sounding rocket support systems implementation.	11,200	8,400	8,200	9,300

OBJECTIVES AND STATUS

The facilities of the Aeronautics, Balloon and Sounding Rocket (AB&SR) Program encompass the ground support capabilities required to capture the scientific and engineering data from aircraft, balloons, sounding rockets and some Earth orbiting vehicles engaged in scientific research. The primary fixed facilities are located at the Wallops Flight Facility (WFF), the Ames Research Center (ARC) and the Dryden Flight Research Facility (DFRF).

The Wallops Flight Facility, under the management of Goddard Space Flight Center (GSFC), operates an extensive range at Wallops Island, Virginia, which supports aeronautics research as well as sounding rocket and small weather balloon launches. In 1986, a capability was established at WFF to provide tracking and data acquisition support to certain Earth orbiting satellites to supplement the capabilities of the Spaceflight Tracking and Datn Network (STDN). WFF also manages the operation of off-site ranges located at *the* White Sands Missile Range, New Mexico: Poker Flats Research Range, Alaska; and the National

Scientific Balloon Facility, at Palestine, Texas. Mobile campaigns for balloon and sounding rocket launches are conducted at various sites throughout the world.

The ranges at Moffett Field, Crows Landing and the Dryden Flight Research Facility (DFRF), are under the management of ARC and are configured to support aeronautics research. The DFRF has the additional capability to support shuttle landings.

The AB&SR system implementation program is directed primarily at the systematic replacement of obsolete systems and the upgrade of these facilities to assure reliable support to NASA's research programs.

CHANGES **FROM FY 1988 REVISED** BUDGET

The decrease of $.2 million in the FY 1988 revised budget estimate results from various miscellaneous equipment deferrals.

BASIS **OF FY 1989** ESTIMATE

The aeronautical research efforts and scientific experiments using sounding rockets and balloons are programs of a continuing nature which generally require a relatively constant level of support. Support for these programs requires fixed and mobile instrumentation systems which include radar, telemetry, optical, communications, command, data handling and processing systems. To maintain these facilities, replacement parts must be acquired, test and calibration equipment routinely replaced, and equipment refurbished or modified to assure reliable support.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Aeronautics, balloons, and sounding rocket support operations.....	16,500	16,300	16,500	17,800

OBJECTIVES AND STATUS

The operations element of the AB&SR Program includes the operations and maintenance of ground-based instrumentation systems, both fixed and mobile, under the management of the Ames Research Center (ARC) and the Goddard Space Flight Center (GSFC). These facilities support NASA aeronautics, sub-orbital, and a limited number of Earth orbit research programs. Funding provides for services and consumable supplies required to operate and maintain the radar, telemetry, data acquisition, data processing, data display, communications and special purpose optical equipment essential to the conduct of these research programs.

The aeronautical test ranges at the Dryden Flight Research Facility (DFRF) and the Moffett Field Flight Complex (MFFC), under the auspices of the Ames Research Center, maintain an active schedule of aeronautics research support. During FY 1987, more than 1450 missions were conducted at DFRF and MFFC. Programs supported by the ranges encompassed a wide variety of activities including revolutionary aircraft configurations, advanced technologies, high performance aircraft, highly integrated control systems and powered lift technologies.

The GSFC activities support aeronautics programs as well as sounding rocket, balloon and Earth orbiting satellite programs at the Wallops Flight Facility (WFF). During 1987, approximately 220 aeronautics missions were supported at the WFF covering such programs as heavy payload mid-air retrieval systems development, XV-15 Aircraft Noise Program, runway friction testing, microwave landing system operations testing, storm hazards research, and the general aviation light aircraft thruster research program.

The sounding rocket program at the WFF conducted approximately 120 launches in FY 1987, which included 29 of the larger rockets with major scientific payloads. The remainder were the smaller meteorological and special purpose rockets supporting a vzriety of research programs. The balloon program had 200 launches during FY 1987, including 41 large balloons with major scientific payloads. Earth orbiting satellites supported included International Ultraviolet Explorer, Interplanetary Monitoring Platform-8, and Nimbus-7.

CHANGES FROM FY 1988 REVISED BUDGET

The increase of $.2 million in the FY 1988 revised budget estimate is required to support the supernova sounding rocket campaigns in Australia.

BASIS FOR FY 1989 ESTIMATE

The funding estimate for FY 1989 is based on a relatively constant level of mission support activity. Operations, maintenance, logistical support and technical services for the ground-based fixed and mobile instrumentation systems will be continued in support of the ongoing sounding rocket, balloon, Earth orbiting satellite and aeronautical research programs.

BASIS OF FY 1989 FUNDING REQUIREMENT

COMMUNICATIONS AND DATA SYSTEMS

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Communications systems implementation....	6,800	6,300	6,300	12,100
Communications operations.....	95,515	95,700	109,500	116,300
Mission facilities.....	12,200	7,300	11,500	8,800
Mission operations.....	23,300	27,000	25,000	32,000
Data processing systems implementation...	24,385	21,500	21,500	25,800
Data processing operations.....	41.700	46.700	42.700	53.300
Total.....	203,900	204.500	216,500	248,300

OBJECTIVES AND STATUS

Funds requested for the Communications and Data Systems program provide for the implementation and operation of facilities and systems which are required for data transmission, mission control and data processing support.

Communication circuits and services provide for the transmission of data among the remote tracking and data acquisition facilities, launch areas, and the mission control centers. Real-time information is crucial to determine the condition of the spacecraft and payloads for the generation of spacecraft and payload control commands. Data received from the various spacecraft must be processed into a usable form for spacecraft monitoring in the control centers and before the transfer of data to the experimenters. Missions supported include Shuttle, Spacelab, NASA scientific and application projects, and international cooperative efforts.

Major activities underway include: implementing necessary changes to the Hubble Space Telescope mission control and data capture system, and mission control and data processing capabilities required to support upcoming missions such as Gamma Ray Observatory (GRO), Spacelabs, Upper Atmosphere Research Satellite **(UARS)**, Global Geospace Science (GGS) and Advanced X-ray Astronomy Facility (AXAF). In addition, studies are continuing to evaluate Space Station support requirements.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Communications systems implementation.....	6,800	6,300	6,300	12,100

OBJECTIVES AND STATUS

The objective of the Communications Systems Implementation program is to provide the necessary capability in NASA's Global Communications Network (NASCOM) to meet new program support requirements, to increase the efficiency of the network, and to keep NASCOM at a high level of reliability for the transmission of data. NASCOM interconnects the tracking and data acquisition facilities which support all flight projects; it also links such facilities as launch areas, test sites, and mission control centers.

The major effort being initiated in NASCOM is the planning, engineering, and equipment acquisition required to tie together the existing TDRSS ground terminal at White Sands, New Mexico, with the Second TDRSS Ground Terminal. This requires an integrated communications capability for the control and transfer of data between the two facilities. The secondary effort under way is the equipment acquisition to upgrade the Deep Space Network's ground communications data handling capability at Madrid, Spain; Tidbinbilla, Australia; and the Jet Propulsion Laboratory.

BASIS OF FY 1989 ESTIMATE

The FY 1989 funding requirements will provide the sustaining equipment and modifications to support the NASCOM network and provide for the engineering and equipment acquisition to support the Second TDRSS Ground Terminal at White Sands. Efforts will continue at the Goddard Space Flight Center (GSFC) on the implementation of the new voice intercom system for all the Payload Operations Control Centers. Funding will also provide for the ground communications data handling capability required in the Deep Space Network to support the increased data rates of the Magellan, Galileo, and Ulysses satellites.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Communications operations.....	95,515	95,700	109,500	116,300

OBJECTIVES AND STATUS

NASA's global Communications Network (NASCOM) interconnects, by means of leased voice, data, and wideband circuits, the tracking and data acquisition facilities which support all flight projects. Also, NASCOM links such facilities as launch areas, test sites, and mission control centers. Goddard Space Flight Center (GSFC) operates the NASCOM and serves as its major switching control point. In the interest of economy, reliability, and full utilization of trunk circuitry, subswitching centers have been established at JPL and Madrid. The NASA flight projects require the transfer of data between the mission control centers and the sites because of the need for real time control of spacecraft and on-board experiments. In addition, there are requirements to provide experiment data expeditiously to users for analysis.

NASA's Program Support Communications Network (PSCN) interconnects the NASA Centers, Headquarters, and major contractor locations through leased voice, data and wide-band circuits for the transfer of programmatic and scientific information. Marshall Space Flight Center (MSFC) operates the PSCN and serves as its major switching control point.

CHANGES FROM FY **1988** REVISED BUDGET

The net increase of $13.8 million in the FY 1988 revised budget estimate reflects increased requirements in the Program Support Communications Network to meet user demands; the PSCN increase has been partially offset by further NASCOM savings associated with the STS standdown.

BASIS OF FY **1989** ESTIMATE

The FY 1989 funding requirements for the Communications Operations program will provide the circuits and service required to operate and maintain the NASA Global Communications Network. International communications satellites and cables will continue to provide digital wideband services to all the overseas tracking stations. Domestic satellite systems and terrestrial networks will continue to service the continental United States stations. With the reactivation of the Shuttle network and the trend toward fiber optic systems, there will be a dramatic increase in the use of digital technology in NASCOM with a corresponding decrease in the use of analog technology. Funding increases will be required to simultaneously support the Shuttle and the deep space projects with wideband data links to the Deep Space Network stations in Spain and Australia.

Funds are included for Program Support Communications Network (PSCN) which provide for the circuits and facilities for programmatic operations such as data transmission and computer-to-computer data sharing for NASA Centers and Headquarters. In FY 1989, funds are required to operate and maintain the PSCN hardware and wideband satellite and terrestrial circuits at all NASA locations and selected contractor sites. The network will support all NASA programs and projects such as the Shuttle, Hubble Space Telescope. and Space

Station. Beginning in FY 1989, the PSCN backbone circuits, which support all programs, will be funded by the Office of Space Operations and the individual program offices will fund additive unique tail circuit requirements.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Mission facilities.....	12,200	7,300	11,500	8,800

OBJECTIVES AND STATUS

The Mission Facilities Implementation Program provides the capabilities needed for the command and control of NASA's unmanned scientific and applications satellite programs. Command and control of the spacecraft and on-board experiments are carried out via the Payload Operations Control Centers (POCC's) and related mission support systems.

The POCC's are responsible for the receipt, processing, and display of spacecraft engineering data and the transmission of commands. Four POCC's currently monitor and control numerous spacecraft. In addition, a new dedicated control center is under development to control the Hubble Space Telescope scheduled for launch in mid-CY 1989. Related mission support systems include a Johnson Space Center/Goddard Space Flight Center Shuttle POCC Interface Facility (SPIF) and a Mission Planning/Command Management System to schedule spacecraft support and generate command sequences for transmission to the spacecraft by the POCC's.

CHANGES FROM FY 1988 REVISED BUDGET

The increase of $4.2 million in the FY 1988 revised budget estimate is required to complete implementation of the Hubble Space Telescope support requirements.

BASIS OF 1989 ESTIMATE

The FY 1989 funding requirements will provide for Hubble Space Telescope prelaunch systems testing and software development. This software will control the accurate pointing of the telescope and determine the on-orbit power consumption and thermal gradients of the spacecraft subsystems and scientific instruments.

In addition, FY 1989 funds are included for modifications to the existing Multi-satellite Operations Control Center (MSOCC) for control of the Gamma Ray Observatory (GRO), Cosmic Background Explorer (COBE), Upper Atmosphere Research Satellite (UARS), Extreme Ultra-Violet Explorar (EWE), and various Shuttle attached payloads. In FY 1989, control center modifications will be underway which permit spacecraft payload operations from user facilities. This new concept, which is planned for use with Space Station, will provide operational efficiencies for experimenters.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Mission operations.....	23,300	27,000	25,000	32,000

OBJECTIVES AND STATUS

The Mission Operations program in FY 1989 will provide for the operation of the five Payload Operations Control Centers (POCC's) and the related software and support services necessary for the monitoring and control of eight in-orbit spacecraft and pre-launch preparations for five spacecraft.

The POCC's, which are the control facilities for spacecraft/payload operations, have the capability for receiving, processing, and displaying spacecraft engineering and telemetry data and for sending commands to the spacecraft. Commands transmitted to the spacecraft include both emergency commands resulting from decisions made by the spacecraft analysts and preplanned command sequences generated in advance to carry out the mission objectives. Each POCC is operated 24 hours per day, 7 days per week in mission support. For Shuttle launches with attached payloads, having GSFC responsibility, there is a specialized GSFC Shuttle Payload Interface Facility (SPIF) which processes and provides for the display of Shuttle-unique data that is necessary for payload control.

CHANGES FROM FY 1988 REVISED BUDGET

The decrease of $2 million in the FY 1988 revised budget estimate reflects rephasing of mission support requirements.

BASIS OF FY 1989 ESTIMATE

The FY 1989 budget request includes funds to operate the POCC's and supporting facilities for control of on-orbit missions and to develop control center software to support upcoming missions. In FY 1989, the new Hubble Space Telescope POCC will be in the final stages of spacecraft and ground systems testing in preparation for a late FY 1989 launch, followed by a period of on-orbit checkout of the new telescope

observatory. A major activity that will be conducted in this facility is the operational checkout and calibration of the total ground system, the spacecraft and its scientific instruments. Also in FY 1989, software development activities will continue for the GRO, UARS, EUVE, and AXAF missions. POCC software for mission control to the COBE will also be completed to support a mid-FY 1989 launch.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Data processing systems implementation...	24,385	21,500	21,500	25,800

OBJECTIVES AND STATUS

The Data Processing Systems Implementation program provides for the procurement of equipment and related services for the large data processing and computation systems at the Goddard Space Flight Center (GSFC). These systems support both the operational and payload requirements of flight missions. To meet operational requirements, these systems determine spacecraft attitude and orbit and generate on-board commands to the spacecraft subsystems. In support of spacecraft payloads, the systems process the data from science and applications experiments for subsequent transfer to the experimenters for analysis.

Major computation capabilities include the Flight Dynamics Facility which performs the real-time attitude, orbit computation and flight maneuver control functions and the Mission Operations and Data Systems Information Network (MODSIN). In addition, there are four major systems for processing payload data: 1) the Telemetry On-Line Processing System (TELOPS) which routinely supports a number of Earth-orbiting spacecraft; 2) the Image Processing Facility (IPF) which generates products for Nimbus-7; 3) the Spacelab Data Processing Facility (SLDPF) which has provided support to the Spacelab missions and the Shuttle Imaging Radar-B experiment; and 4) the Hubble Space Telescope Data Capture Facility (HSTDCF) which will capture, process, and forward to the Science Institute Facility the packetized telemetry data from the Hubble Space Telescope spacecraft.

Significant activities in this program continue at GSFC to keep the large systems viable and responsive to project support requirements. Implementation continues on new systems to process data from the Gamma Ray Observatory (GRO) and the Upper Atmosphere Research Satellite (UARS) missions.

Also included is the improvement in the test bed facility to be used for prototyping, testing, and evaluating maturing technologies resulting from the Advanced Systems Program. Promising technologies for application to future support will be investigated in the areas of remote payload operation and control, expert systems, high speed data processing, high level languages, and very large scale integration (VLSI).

BASIS OF FY 1989 ESTIMATE

The FY 1989 budget request will provide continued funding for improvements in the existing computation systems at GSFC which provide real-time support to NASA spacecraft. Funding is also included for initial development of the MODSIN Host system and initial cost-benefit study to determine the life-cycle cost effectiveness of integrating and improving the orbit and attitude large applications software programs. In addition, the request provides for the improvement and upgrade of the Flight Dynamics Facility (FDF) and for systems studies in autonomous navigation.

The FY 1989 budget request includes funds to continue the upgrade of the existing TELOPS system in order to develop a generic time division multiplexed (TDM) system for processing data. The Upper Atmosphere Research Satellite (UARS), will be the first user. The handling of UARS data will serve as a baseline for providing such support to other users allowing for trade-offs between development costs and support risks for future missions. Funds are also requested for upgrading the data processing capabilities at GSFC to facilitate the exchange of data within the data processing complex and with other mission support facilities.

There is a continuing requirement to procure and maintain an adequate supply of unique spare parts to replace failure-prone and high-maintenance electronic modules, to provide test equipment, and to undertake minor modifications and hardware fabrication associated with new equipment installation and reconfiguration. Funds are included in the request for continuing the evaluation of Space Station support requirements and the capabilities needed to meet the requirements. In FY 1989, a systems definition study will be initiated for the Customer Data and Operations Systems (CDOS) which will provide preliminary design and specifications.

	1987 Actual	1988 Revised Budget	1988 Current Estimate	1989 Budget Estimate
		(Thousands of Dollars)		
Data processing operations.....	*41,700*	*46,700*	*42,700*	*53,300*

OBJECTIVES AND STATUS

Information received in the form of tracking and telemetry data from the various spacecraft must be processed into a usable form before transfer to the experimenters. This transformation and computation process is performed as part of the data processing function and applies to a wide variety of programs, ranging from the small Explorer satellites to complex imaging-type satellites such as Nimbus.

In addition to the actual processing of data, upcoming projects require extensive pre-launch orbit analysis including spacecraft position and attitude predictions analyses are also required to develop operational sequences, procedures and optimization of systems resources and look angles for maximum science data return during the actual operation of these complex spacecraft.

Telemetry data is the primary product of spacecraft, and it is through reduction and analysis of this data by the experimenters that the planned objectives are achieved. Data is processed to separate the information obtained from various scientific experiments aboard the spacecraft, consolidate information for each experimenter, determine spacecraft attitude, and correlate these measurements with spacecraft position data. Four facilities, the Image Processing Facility (IPF), the Telemetry On-Line Processing System (TELOPS) facility, the Spacelab Data Processing Facility (SLDPF), and the Hubble Space Telescope Data Capture Facility (HSTDCF) have been established at the Goddard Space Flight Center to pre-process different types of raw experimental data. Sustained operations of these facilities is needed to support the on-going spacecraft in-orbit.

The IPF, initially established to handle image data from the Landsat-1 satellite, has supported Landsat-2 and Landsat-3 and presently is processing data from the Nimbus-7 mission. The Nimbus-7 mission support will end in late FY 1988. However, retroactive Nimbus-7 data processing is anticipated to last through FY 1989. The TELOPS handles satellite non-image data which is received in a digital form from the tracking stations via NASCOM. It is capable of electronically storing large volumes of telemetry data, thus eliminating most of the tape and tape handling operations. Facility management, maintenance and operations, and software development support for the image and non-image data processing facilities are also provided. The operation of the SLDPF is included along with software development and maintenance required for attitude determination, flight maneuvers, mission simulations, and Mission Operations and Data Systems Information Network (MODSIN).

CHANGES FROM FY 1988 REVISED BUDGET

The decrease of $4 million in the FY 1988 revised budget estimate is associated with the termination of Nimbus mission support and rephasing of procurements planned for future Spacelab mission support.

BASIS OF FY 1989 ESTIMATE

The FY 1989 budget request provides for operation of the various computation and data processing facilities including the SLDPF which requires maintenance of unique hardware and software for Spacelab and Dedicated Discipline Laboratory (DDL) missions.

Application software development, prototyping, and system testing activities are continuing. Additional activity in support of such upcoming space science and applications missions as Cosmic Background Explorer, Gamma Ray Observatory, Shuttle Attached Payloads, Upper Atmosphere Research Satellite, and Extreme Ultraviolet Explorer is also planned. For on-orbit spacecraft, software development and maintenance is required on a continuing basis in order to perform flight control maneuver operations and for the data processing activities.

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