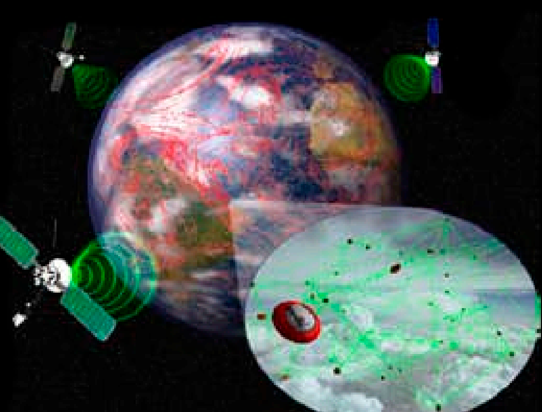
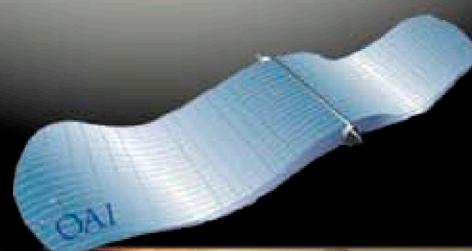
NIAC

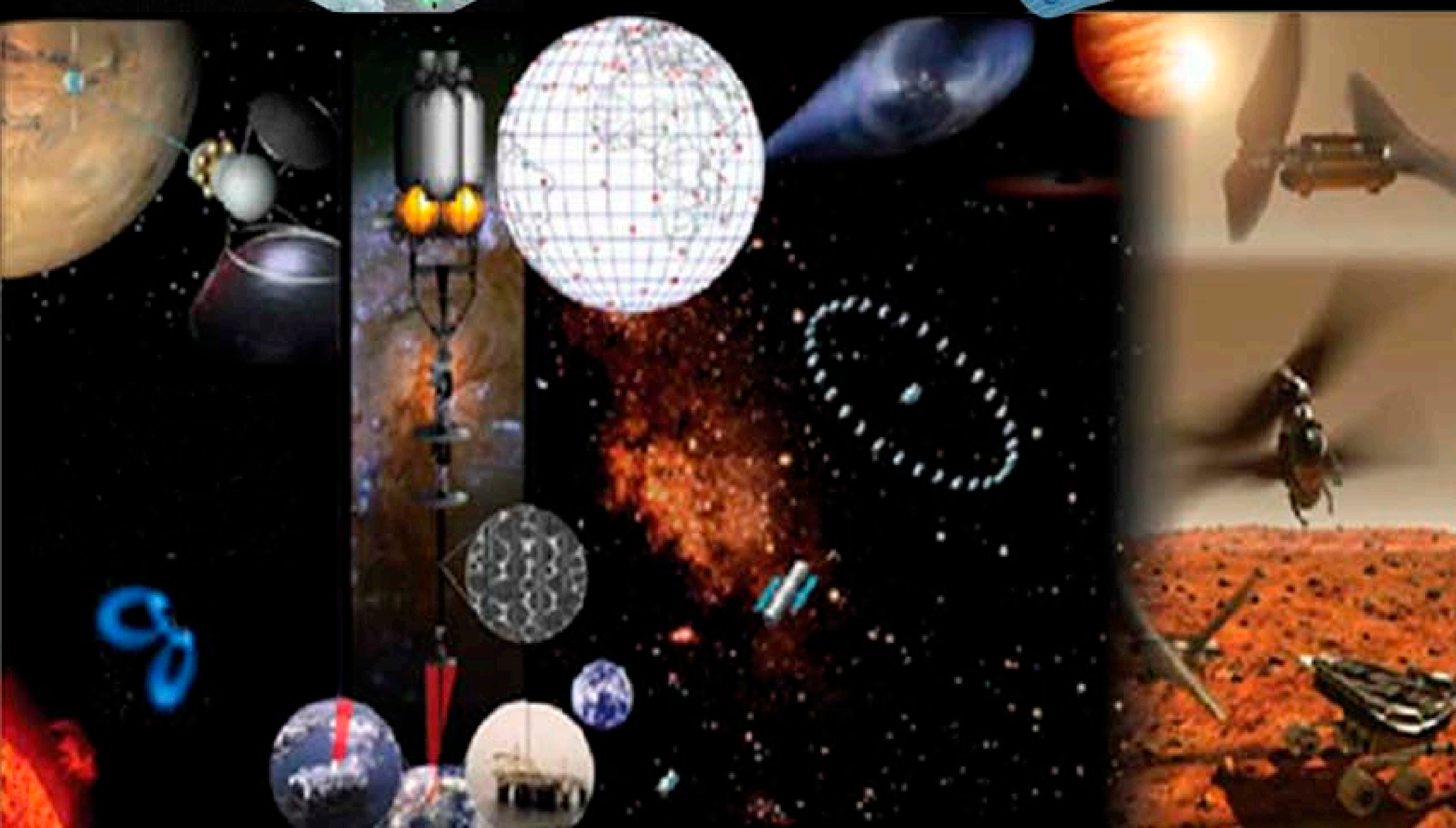
NASA Institute for Advanced Concepts

5th ANNUAL REPORT

July 2003







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NASA Institute for Advanced Concepts

5th ANNUAL REPORT

EXECUTIVE SUMMARY

The NASA Institute for Advanced Concepts (NIAC) has completed its fifth year of operation, and has successfully expanded the technical breadth of funded advanced concepts and begun the process of infusing promising concepts into NASA. The role of the Universities Space Research Association (USRA) in operating the NIAC, relative to the roles and missions of NASA, is to provide additional options for consideration by NASA with potentially revolutionary improvement in aerospace performance and resulting dramatic extension of mission and programmatic goals. During the fifth year of operation, the USRA team built on the acclaimed success of its operation of the prestigious NIAC as an independent and trustworthy Institute that is a model for:

- Inspiring and sustaining interest by the general public and technical communities in revolutionary, paradigm-changing aerospace concepts,
- Exciting a passion in the nation's youth for the process of scientific discovery through visionary leadership to stretch the possibilities of their imagination, and
- Nurturing revolutionary advanced concepts toward an ultimate goal of infusing them into NASA's long range plans across the Enterprises.

Throughout the first sixty months of NIAC operation, USRA has consistently received an "excellent" rating from NASA in all categories of contract performance. NIAC has consistently met financial goals for funds allocated to advanced concepts development and for maintaining an efficient, cost-effective operational structure. During this fifth contract year, NIAC awarded five Phase II contracts totaling $1.1 million (without options), and sixteen Phase I grants totaling $1.2 million. Since the beginning of the contract, NIAC has received a total of six hundred-sixty proposals, and has awarded eighty Phase I grants and twenty-one Phase II contracts for a total value of $14.6 million. These awards to universities, small businesses, small disadvantaged businesses and large businesses were for the development of revolutionary advanced concepts that may have a significant impact on NASA's future aeronautics and space missions.

Many of the activities of NIAC are conceived and orchestrated to provide encouragement to a broad technical community of potential principal investigators. Methods of encouragement and inspiration include the NIAC annual meetings, NIAC Fellows meetings, workshops focused on emerging technical areas, active participation by NIAC staff in national technical conferences, NIAC representation on technical committees and boards, and NIAC presentation of seminars at universities, K-12 schools and other organizations. These activities not only afford opportunities for NIAC to distribute notices of upcoming Calls for Proposals and to provide awareness of NIAC-funded advanced concepts, but also serve to catalyze new aerospace concepts built on new generations of emerging technologies.

NIAC has continued to reinforce a very productive atmosphere for open communication and feedback from the science and engineering community at large and from NASA researchers and managers at NASA Headquarters and the Centers. In addition, the NIAC Science Council provides focused oversight and dedicated involvement that is especially supportive of the NIAC operation and future activities.

On June 13, 2003 NASA announced that USRA will be awarded a new contract beginning on July 11, 2003 to continue leading the operation of NIAC. The next five years of NIAC leadership will build on the acclaimed success of the first five years.

ACCOMPLISHMENTS

Summary

During the fifth year of operation, NIAC has continued the processes that it successfully established to inspire, solicit, review, select, fund, nurture, and infuse into NASA revolutionary advanced concepts for aeronautics and space. The performance periods for all completed and currently planned awards are summarized in Table 1. The following sections describe the Calls that were awarded or initiated during the past year.

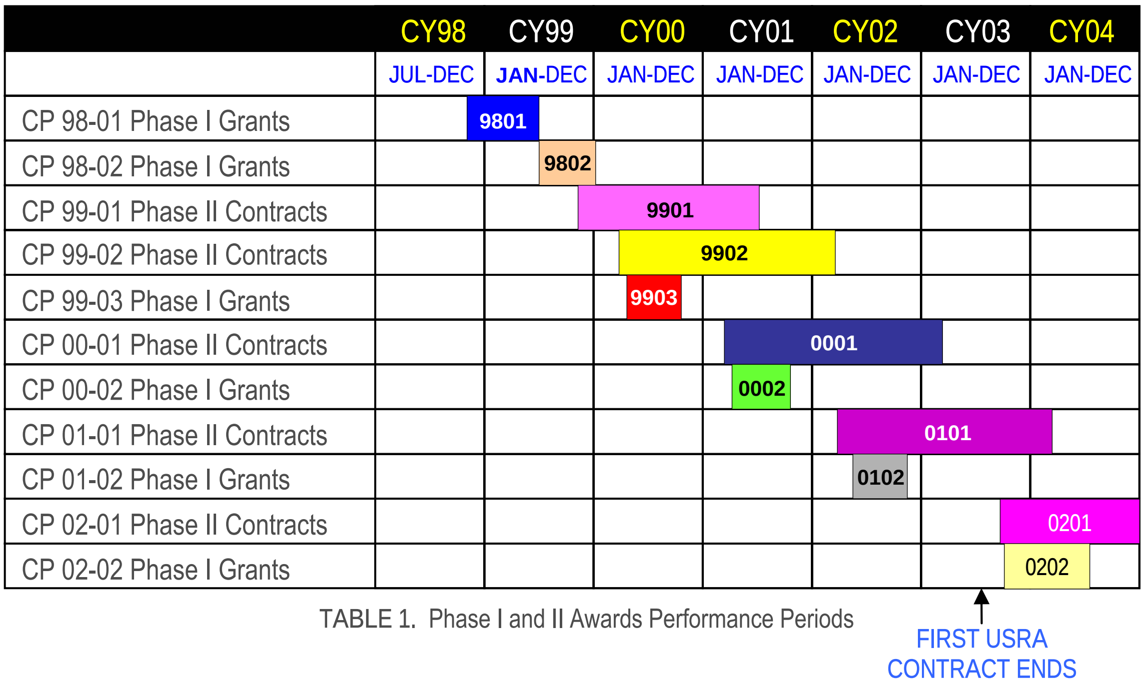


TABLE 1. Phase I and II Awards Performance Periods

Call for Proposals CP 01-01 (Phase II)

NIAC CP 01-01 Phase II Call for Proposals was released on July 13, 2001 to each of the Phase I grantees who had not previously been awarded a Phase II contract. The respective business categories distribution of the eighteen proposals received are summarized in Table 2.

Business Category	Proposals Received	Awarded
Universities	9	2
Historic Black Colleges/Universities & Minority Institutions	0	0
Small Disadvantaged Businesses	1	0
Small Businesses	6	2
National Labs	0	0
Large Businesses	2	1
Total Proposals Received for CP 01-01	18	5

TABLE 2. Summary of CP 01-01 Responding Organizations

Peer review of all the proposals received began January 7, 2002. There were five proposals selected for awards, and the contracts were made in March 2002. The proposals that were selected for awards under Call for Proposals CP 01-01 are summarized in Table 3 and abstracts are included in Appendix C. Detailed descriptions of these concepts are available on the NIAC Web site.

Principal Investigator & Organization	CP 01-01 Concept Proposal Title
PENELOPE BOSTON Complex Systems Research, Inc.	System Feasibility Demonstrations of Caves & Subsurface Constructs for Mars Habitation and Scientific Exploration
EDWARD HODGSON Hamilton Sundstrand Space Systems International	A Chameleon Suit to Liberate Human Exploration of Space Environments
ROSS HOFFMAN Atmospheric & Environmental Research	Controlling the Global Weather
TERRY KAMMASH University of Michigan	Ultrafast Laser-Driven Plasma for Space Propulsion
TERRI LOMAX Oregon State University	Developing a Plant Genetic Assessment and Control System for Space Environments

TABLE 3. CP 01-01 Phase II Award Winners

Call for Proposals CP 01-02 (Phase I)

There were a total of one hundred-fourteen Phase I proposals received by the February 11, 2002 due date under NIAC CP 01-02 Call for Proposals which was released on October 1, 2001. Table 4 summarizes the business category distribution of these proposals.

Business Category	Proposals Received	Awarded
Universities	34	9
Historic Black Colleges/Universities & Minority Institutions	1	1
Small Disadvantaged Businesses	9	1
Small Businesses	59	4
National Labs	0	0
Large Businesses	11	1
Total Proposals Received for CP 01-02	114	16

TABLE 4. Summary of CP 01-02 Responding Organizations

Peer review began shortly after receipt of the proposals. Subsequently, there were sixteen grants made in May 2002. The proposals selected for awards are summarized in Table 5, and abstracts are available in Appendix D. Detailed descriptions are available on the NIAC Web site.

Principal Investigator & Organization	CP 01-02 Concept Proposal Title
JOSEPH CARROLL Tether Applications	Space Transport Development Using Orbital Debris
A.C. CHARANIA SpaceWorks Engineering	Networks on the Edge of Forever: Meteor Burst (MB) Communication Networks on Mars
ANTHONY COLOZZA Ohio Aerospace Institute	Solid State Aircraft
STEVEN HOWE Hbar Technologies	Antimatter Driven Sail for Deep Space Missions

Table 5 continues on the following page …

NARAYANAN KOMERATH Georgia Tech Research Institute	Tailored Force Fields for Space-Based Construction
HOD LIPSON Cornell University	Autonomous Self-Extending Machines for Accelerating Space Exploration
JOHN MANOBIANCO ENSCO	Global Environmental MEMS Sensors (GEMS): A Revolutionary Observing System for the 21st Century
ANTHONY MARCHESE Rowan University	The Black Light Rocket (BLR) Engine
CONSTANTINOS MAVROIDIS Rutgers University	Protein Based Nano-Machines for Space Applications
ELIZABETH McCORMACK Bryn Mawr College	Investigation of the Feasibility of Laser Trapped Mirrors in Space
DAVID MILLER Massachusetts Institute of Technology	Electromagnetic Formation Flight (EMFF)
SEIGO OHI Howard University	The Hematopoietic Stem Cell Therapy for Exploration of Space
ALEXEY PANKINE Global Aerospace Corporation	Planetary Science from Directed Aerial Robot Explorers
NILANJAN SARKAR Vanderbilt University	A Novel Interface System for Seamlessly Integrating Human-Robot Cooperative Activities in Space
PARVIZ SOROUSHIAN Technova Corporation	Inherently Adaptive Structural Systems
DAVID WETTERGREEN Carnegie Mellon University	Planetary Circumnavigation

TABLE 5. CP 01-02 Phase I Award Winners

Call for Proposals CP 02-01 (Phase II)

Release of Phase II CP 02-01 on July 1, 2002 resulted in nineteen proposals received by the December 2, 2002 deadline. The business category distribution of these proposals is summarized in Table 6.

Business Category	Proposals Received	Awarded
Universities	10	3
Historic Black Colleges/Universities & Minority Institutions	1	0
Small Disadvantaged Businesses	1	1
Small Businesses	6	2
National Labs	0	0
Large Businesses	1	0
Total Proposals Received for CP 02-01	19	6

TABLE 6. Summary of CP 02-01 Responding Organizations

NIAC began peer review immediately upon receipt of the proposals. The evaluation and prioritization process was completed on June 25, 2003 with the meeting of a review panel. The review panel, consisting of the NIAC leadership and five technical consultants, reviewed all peer reviewer evaluations for each proposal and prioritized the proposals for awards. The prioritized list will be presented at the concurrence briefing at NASA Headquarters on July 13, 2003.

Call for Proposals CP 02-02 (Phase I)

This Phase I solicitation was released on September 26, 2002 with a proposal due date of February 17, 2003. Amendment 1 to CP 02-02 was issued on November 22, 2002 for the purpose of suspending the proposal due date. This action was taken due to delays in the procurement process of awarding the contract for the operation of NIAC. Amendment 2 was issued on December 3, 2002 to clarify some of the wording contained in Amendment 1. On June 13, 2003 NASA awarded the second five-year contract to USRA to operate NIAC, and NIAC reinstated this Call for Proposals with the due date of July 28, 2003 for receipt of proposals.

Phase II Site Visits

As part of normal contract management activity, NIAC conducts site visits with all of the Phase II contractors near the end of the first year to review the technical and management performance of their Phase II contract before exercising the contract option on the remainder of the Phase II activity. In addition to the NIAC Director, other people who may attend these site visits include Sharon M. Garrison (NIAC COTR), NIAC technical consultants, and representatives from NASA Headquarters and the NASA Centers. The agenda for the site visits includes a review of the status and plans for development of the advanced concepts and discussions exploring the possibility of follow-on funding after the Phase II contract. Site visits have been conducted with the following Phase II contractors. NIAC and ANSER staff, NIAC consultants, and NASA representatives are noted in Table 7.

ROSS HOFFMAN
Atmospheric & Environmental Research

This site visit was held at USRA Headquarters in Seabrook, Maryland, December 19, 2002 with the principal investigator, Ross Hoffman. Attendees were: John Evans, Keith Raney and Milt Halem (NIAC consultants); Sharon Garrison, Marian Albjerg, J.C. Duh, Stephen Cohn, Parminder Ghuman (GSFC); Ron Turner (ANSER); Pat Russell (USRA-NIAC); and Bob Cassanova (NIAC Director).

EDWARD HODGSON
Hamilton Sundstrand Space Systems International

This site visit was held May 14, 2003 at Hamilton Sundstrand Space Systems International, with the principal investigator, Ed Hodgson. Attendees were: Bill Emrich (NASA MSFC); Ron Turner (ANSER): Pat Russell (USRA-NIAC); and Bob Cassanova (NIAC Director).

PENELOPE BOSTON
Complex Systems Research

This site visit was held January 8-10, 2003 at Oregon State University-Cascade Campus with Penny Boston and her team. Attendees were: Cary Mitchell and Lynda Goff (NIAC consultants); T.J. White, Kirk Findlay, William Winner (Oregon State University); Gus Frederick (CSR); Ron Turner (ANSER); Pat Russell (USRA-NIAC); and Bob Cassanova (NIAC Director).

Photo of Group Tour of the Lava Cave during Site Visit

TERRY KAMMASH
University of Michigan

This site visit was held at the University of Michigan on May 20, 2003 with the principal investigator, Terry Kammash, and his team, K. Flippo, D. Umstadter and S. Jahshan. Attendees were: Ron Turner (ANSER); Pat Russell (USRA-NIAC); Bill Emrich (NASA MSFC); and Bob Cassanova (NIAC Director).

TERRI LOMAX
Oregon State University

This site visit was held January 8-10, 2003 at Oregon State University-Cascade Campus in conjunction with Penny Boston's site visit. Attendees were: Cary Mitchell and Lynda Goff (NIAC consultants); T.J. White, Kirk Findlay, William Winner (Oregon State University); Gus Frederick (CSR); Ron Turner (ANSER); Pat Russell (USRA-NIAC); and Bob Cassanova (NIAC Director).

TABLE 7. Phase II Site Visits

Infusion of Advanced Concepts into NASA

The primary purpose of NIAC is to provide leadership to *inspire, solicit, review, select, fund, nurture and infuse* advanced concepts that may have significant impact on future NASA missions and programs. After a concept has been developed and nurtured through the NIAC process, it is NASA's intent that the most promising concepts will be transitioned into its program for additional study and follow-on funding. NIAC has taken a proactive approach to this infusion process. In addition to the routine activities to maintain public awareness and visibility for all its funded advanced concepts, NIAC orchestrates the following activities:

- Conducts status and visibility briefings with NASA researchers and managers;
- Provides names of key NASA contacts to NIAC Phase I and Phase II Fellows;
- From the beginning of the Phase II Call for Proposals, NIAC connects Fellows with NASA to provide synergy and optimal program consideration for future follow-on funding by NASA;
- Invites NASA leaders to Phase II site visits to participate in status and planning discussions;
- Encourages NIAC Fellows to publish their work in technical society meetings and technical journals;
- Supports NIAC Fellows to gain NASA testing/evaluation when NASA facilities are key to advanced concept verification.

By the end of this contract year, a number of concepts have successfully begun the process of transitioning into NASA and some have obtained funding from other sources. Table 8 reports the status of those concepts that have begun the transition process. Detailed descriptions of these advanced concepts are available on the NIAC Web site.

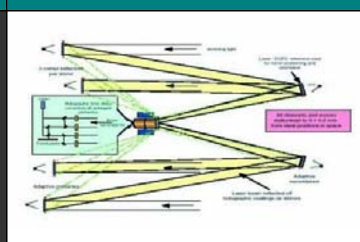
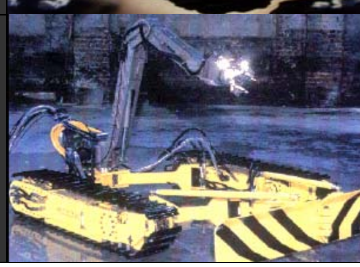
Concept Awards	Concept Graphics	Concept Status
IVAN BEKEY Bekey Designs An Extremely Large Yet Ultra-light Space Telescope and Array		Similar concept study by this principal investigator was funded by the NRO after completion of the Phase I grant.
ROBERT GOLD The Johns Hopkins University A Comprehensive Earth Protection System Array		System analysis of concept has been completed at NASA Langley Research Center under the RASC Program. RASC contacted the principal investigator to explore collaboration.
ALEX IGNATIEV University of Texas - Houston New Architecture for Space Solar Power Systems: Fabrication of Silicon Solar Cells using In Situ Resources		Awarded a Code R Cross-Enterprise contract for its related technology.

Table 8 continues on the following page …

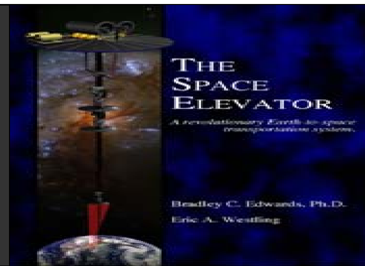
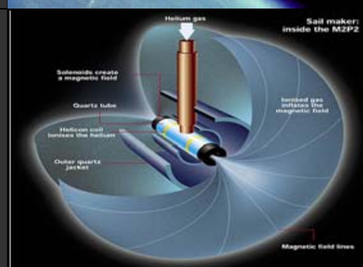
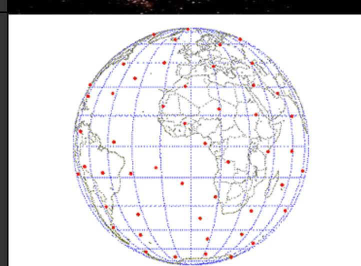
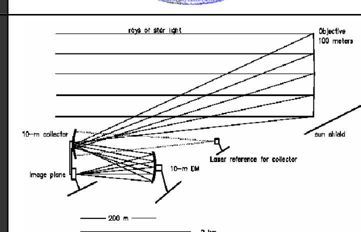
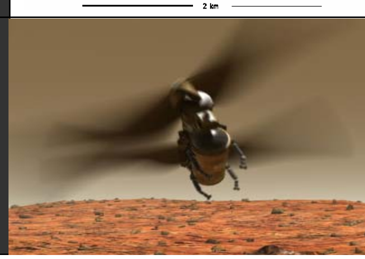
BRAD EDWARDS Eureka Scientific The Space Elevator		Included in the NASA NeXT Plan. Numerous invited presentations have been made at NRO, NSA, JFCOM, FCC, FAA, NASA, National Defense University, NASA, congressional groups and technical associations and societies.
ROBERT HOYT Tethers Unlimited, Inc. Moon and Mars Orbiting Spinning Tether Transport		NASA's In-Space Propulsion Program awarded contracts valued at $2.1M for further development of tether systems.
ROBERT WINGLEE University of Washington The Mini-Magnetospheric Plasma Propulsion System, M^2P^2		Received funding from MSFC for experiments and system analysis support. Awarded additional funding from OSS. Ranked as high-priority concept for both in-space propulsion and radiation shielding. Included in the NASA NeXT plan.
WEBSTER CASH University of Colorado X-ray Interferometry		Included in the NASA Space Sciences Strategic Plan. Additional funding from GSFC.
KERRY NOCK Global Aerospace Corporation Global Constellation of Stratospheric Scientific Platforms		Included in the NASA Earth Sciences Strategic Plan.
NEVILLE WOOLF University of Arizona Steward Observatory Very Large Optics for the Study of Extrasolar Terrestrial Planets		Life Finder included in NASA Space Sciences long range plan.
ANTHONY COLOZZA Ohio Aerospace Institute Entomopter for Mars		*Entomopter* animation was used by Scott Hubbard, NASA Ames Research Center Director, in his inaugural address to ARC employees on September 27, 2002.

TABLE 8. Status of Infusion of Concepts into NASA

Survey of Technologies to Enable NIAC Concepts

NASA has a continuing challenge to invest in technology development to support future missions. One aspect of this challenge is to identify, from the full range of emerging technologies, those that have the highest potential payoff. This investment strategy considers those technologies that may lead to the most significant increase in performance of existing approaches to accomplish missions or may have the greatest potential to enable future missions.

NIAC funds studies of potential revolutionary systems and architectures that may have an impact on NASA missions ten to forty years in the future. The authors of these studies, Fellows of the Institute, are visionary thinkers looking beyond today's technologies to identify future options. In so doing, they embrace the most technically challenging opportunities and push past the state-of-the-art. However, in conducting their Phase II studies, they are required to identify pathways to enable the innovative concepts. The resulting collective insight from a survey of Phase II Fellows provides NASA with a unique view of enabling technologies that goes beyond what can be gained by addressing incremental enhancements of today's evolving aerospace technologies.

Dr. Cassanova started the NIAC Enabling Technology Survey by sending the following request by email on April 14, 2003 to each of NIAC's twenty-one Phase II Fellows. (The message went to those currently under contract and to those who had completed their Phase II studies).

> "NIAC is in the process of performing an identification and analysis of technologies that would enable the further development of the NIAC Phase II concepts. Ultimately, this survey of enabling technologies may help to lay the groundwork for additional funding for your NIAC concept. Would you please assist this process by responding to the survey below?
>
> Please provide your response no later than Friday, April 25, 2003.
>
> What are the three most critical technologies to enable the further development of your NIAC concept? Please give a brief explanation, two or three sentences, describing the critical relationship of each technology to your concept.
>
> What are the other technologies that are important for the further development of your concept? Please briefly describe their relationship to your concept.

The response from the Fellows was outstanding. Seventy-five percent of the Fellows provided comments. Rather than reply with a simple "wish list," they responded by identifying critical technologies and described why further development of these technologies was important.

Because of the range of topics covered by the NIAC investigations, the responses included very specific technologies (i.e. "infrared electrochromic polymers," submitted by Ed Hodgson), more general technology categories (i.e. "advanced crystal growth technology," submitted by Terry Kammash), and broad areas of strategic development (i.e. "assembly and operation in space," submitted by Kerry Nock).

The details submitted by the Fellows provide the optimal input to NASA. Accordingly, the responses as received are provided in Appendix E of this report. To direct readers to relevant sections of the appendix, a series of short tables were prepared to:

- Summarize the responses (Appendix E, Table 13)
- Organize the submitted technologies by broader categorization (Appendix E, Table 14)
- Provide cross-references between the studies and the general response areas (Appendix E, Tables 15 and 16)

Special Recognition for NIAC Concept

The NIAC sponsored "Entomopter" advanced concept received international recognition. Robert Michelson, a professor and principal research engineer at Georgia Tech, received the prestigious **Pirelli Prize** for his work on the Entomopter.

The link to the announcement is:
http://www.pirelliaward.com/web/index/html.
A quote from the **Pirelli Prize** announcement:

"After evaluating more than 1,000 entries, the International Jury has assigned the various awards for this edition subdivided in two main categories "educational" and "environment." The 25,000 Euros worth Top Pirelli Prize was won by Professor Robert Michelson, Georgia Institute of Technology, USA. His work was awarded as the best product coming from any school, college, university or research center and simulates a mission to Mars, actually planned by NASA for the period 2013-2017, performed by Michelson's candidate – the ***Entomopter*** *– a revolutionary flying-crawling machine fueled by a new chemical energy named reciprocating chemical muscle."*

Professor Robert Michelson with the Entomopter

NIAC is funding the Phase II contract with the Ohio Aerospace Institute (OAI) for development of the Entomopter, and Rob Michelson at the Georgia Tech Research Institute (GTRI) leads in the development through an OAI subcontract.

NASA Medals Awarded to NIAC Personnel

In late May 2003 it was announced that Robert Cassanova will receive the NASA Public Service Medal and Sharon Garrison will receive the NASA Exceptional Achievement Medal. Their awards will be presented on August 27, 2003 at NASA Goddard Space Flight Center.

Coordination and Collaboration with NASA and Other Agencies

Sharon M. Garrison, the NASA Coordinator for NIAC, is in the Aerospace Technology Office (ATO) of the Flight Program & Projects Directorate at NASA Goddard Space Flight Center (GSFC). She is the primary point-of-contact between NIAC and NASA. Ms. Garrison actively communicates throughout NASA to a review team comprised of representatives from the Enterprises, Centers, and the Office of the Chief Technologist. Table 9 is a listing of these representatives. Throughout the process of managing NIAC, these representatives have been kept informed by Ms. Garrison of the status of the Institute and have been appropriately involved in decisions and feedback. NIAC provides monthly contract status reports and an annual report to the NASA Coordinator who forwards the reports to the support team and others within NASA.

NASA COTR	NASA Office of the Chief Technologist	NASA Enterprises	NASA Centers
Sharon M. Garrison (GSFC)	Murray Hirschbein (R)	John Mankins (M) Phil Milstead (R) Glenn Mucklow (S) Alex Pline (U) Lou Schuster (Y)	Larry Lasher (ARC) Steve Whitmore (DFRC) Daniel Glover (GRC) Lisa Callahan (GSFC) Neville Marzwell (JPL) Kenneth Cox (JSC) Dave Bartine (KSC) Dennis Bushnell (LaRC) John Cole (MSFC) Bill St. Cyr (SSC)

TABLE 9. NASA-NIAC Support Team

Throughout the five years of this NIAC contract, the NIAC Director briefed the associate administrators and other senior technical staff at NASA Headquarters and the directors of NASA Centers. The purpose of these briefings is to facilitate the eventual transition of NIAC advanced concepts into mainstream NASA funding, to inform them about the plans for NIAC, and to seek their active support and feedback. Yearly, each of the NASA Enterprises was requested to provide visionary, grand challenges for use in future NIAC Calls for Proposals. In addition, NASA technical staff presented overviews of related NASA advanced concept activities to the NIAC Director. Visits with NASA managers and technical leaders as well as visits with other agencies by NIAC staff and NIAC Fellows during the fifth year are listed in Table 10.

Organization	Date	Purpose of Visit
AAS 40th Goddard Memorial Symposium – Partnering with NASA: The Wave of the Future Marriott Hotel Greenbelt, Maryland	20-21 March 2002	Pat Russell (USRA-NIAC) and Sharon Garrison (NASA GSFC/NIAC COTR) attended the symposium. Garrison met the University of Maryland President, Dr. Mote, which resulted in NIAC Director Bob Cassanova communicating with him via telephone and email. Cassanova sent Dr. Mote information about NIAC.
NASA Associate Administrators NASA HQ Washington, DC	2-4 April 2002	Bob Cassanova attended meetings with NASA Associate Administrators and their senior staff as well as the staff of the Chief Scientist and gave status briefings on NIAC activities and encouraged discussions on future challenges for each Enterprise that might influence the technical emphasis of future NIAC Phase I Calls for Proposals. Pat Russell, Ron Turner and Sharon Garrison attended also.
National Research Council (NRC) Panel Washington, DC	5 August 2002	Bob Cassanova, Pat Russell and Ron Turner participated in a teleconference with members of the panel to discuss the entire peer review process. The panel was given general information about the qualifications of the reviewers. Answers were given to questions about the correlation of selections within the NASA Enterprises and corresponding research community and how NIAC works to encourage additional proposals from under-represented scientific communities. Karen Harwell requested NIAC to respond by September 2002 with certain statistics, which were sent to her by the requested time.
Defense Advanced Research Projects Agency (DARPA) Washington, DC area	22 September 2002	NIAC Fellow Brad Edwards gave presentations on the space elevator to NASA HQ, NRO, National Defense University, the FCC and the FAA. These meetings are critical for follow-on funding and insuring legal issues are addressed. Ron Turner (ANSER) attended representing NIAC.

Table 10 continues on the following page ...

National Reconnaissance Office (NRO) Chantilly, Virginia	25 September 2002	NIAC Fellow Kerry Nock (Global Aerospace) gave an invited seminar about the global stratospheric balloon constellation study to about 57 people including Ron Turner, who represented NIAC management. Nock was invited to brief the National Security Agency and the Defense Intelligence Agency. Representatives from the Lawrence Livermore National Lab expressed strong interest in pursuing collaborative work on the balloon constellation.
AIAA World Space Congress (WSC) Houston, Texas	10-19 October 2002	USRA and ANSER set up a booth, which was occupied by various staff, with an emphasis on NIAC and distributed literature about NIAC and USRA. Pat Russell, Ron Turner, Matt Prebble, and Robert Cassanova attended several of the technical sessions.
DARPA Rosslyn, Virginia	9 December 2002	Ron Turner met with Karen Woods (DARPA) to explore technical collaboration with NIAC. Ron continued discussions into January 2003 to establish better lines of communication and to explore the relevance of NIAC concepts to DARPA goals.
USRA Directors USRA HQ-Seabrook, MD	18-19 December 2002	Bob Cassanova attended and reported on the status of NIAC.
Revolutionary Aerospace Systems Concepts (RASC) Program NASA Langley Research Center Hampton, Virginia	14-16 January 2003	Bob Cassanova participated at the invitation of the RASC program management in the Systems and Mission Analysis Peer Review of the Aerospace Systems Concepts and Analysis Competency at NASA Langley, which included a number of high-quality briefings by technical staff. He was one of four external reviewers. Feedback was prepared and briefed to Langley Research Center upper management on their findings.
Biological and Physical Research Advisory Committee (BPRAC) NASA HQ Washington, DC	13-14 February 2003	Pat Russell (USRA/NIAC) attended the meeting of the BPRAC to stay informed about the latest OBPR plans.
National Security Agency (NSA) Fort Mead, Virginia	20 February 2003	Kerry Nock gave a Science & Engineering Society Seminar at NSA on the subject of Global Constellations of Stratospheric Satellites for Earth Science, Meteorology and Disaster Management, based on his NIAC-sponsored concept.
Space Applications Experimentation Cell - US Joint Forces Command (USJFCOM) NIAC HQ – Atlanta, Georgia	5 March 2003	Cassanova, Russell and Turner met with representatives from the US Joint Forces Command, Joint Experimentation Directorate, at NIAC HQ. Their mission was to explore various realms for space concepts and issues that could be used in joint experimentation to support future space capabilities for war fighters. The purpose of the meeting was to explore mutual interests in advanced space concepts with a particular interest in the Space Elevator. NIAC was given an overview of their plans, and Cassanova and Turner gave overviews of the NIAC operation and concepts that had been identified as special interests of the USJFCOM group.
American Society for Gravitational and Space Biology (ASGSB) Spring Board Meeting Washington, DC	14-15 March 2003	As the Executive Director of ASGSB, Pat Russell met with the governing board. NASA representatives attended and discussed current efforts before the Board members visited Congressional representatives and staff.

Table 10 continues on the following page …

14th Annual Advanced Space Propulsion Workshop University of Alabama Huntsville, Alabama	15-17 April 2003	Ron Turner (ANSER) presented an overview of NIAC concepts related to space propulsion.
14th Annual Space Radiation Health Investigators Program Workshop Houston, Texas	27-30 April 2003	Ron Turner's participation in this program was funded by a grant from NASA. His attendance will benefit NIAC through increased visibility for future NIAC funding opportunities for this community.
NASA Fundamental Space Biology Roadmap Workshop NASA Ames Research Center	29 April 2003	Pat Russell (USRA/NIAC) attended by invitation. NIAC Phase II Fellow Terri Lomax, who is now Director of the Fundamental Space Biology Division in NASA HQ, was a speaker at the workshop.
Large Optical Systems in Space Workshop Boulder, Colorado	1-2 May 2003	Bob Cassanova attended the workshop by invitation and gave a luncheon talk about NIAC. This workshop was sponsored by the NASA Office of Space Science.
Revolutionary Aerospace Systems Concepts – Academic Linkage Forum 2003 Cocoa Beach, Florida	18-21 May 2003	Pat Russell gave a lecture about NIAC.

TABLE 10. Visits with NASA and Other Agencies

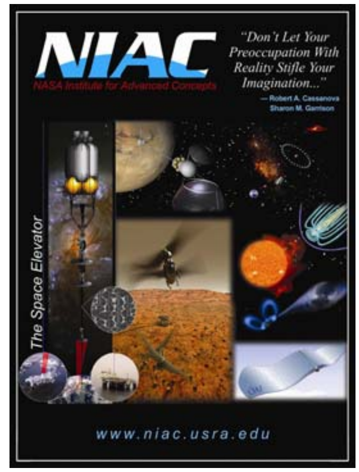
In addition to the periodic coordination visits to NASA Headquarters and the Centers, the NIAC Director has been invited to participate in a number of planning and oversight groups organized by NASA. Currently, the NIAC Director is a member of the Space Science Technology Management and Operations Working Group (SSTMOWG) that meets approximately every three months.

Inspiration and Outreach

The process of inspiring the submission of revolutionary advanced concept proposals to NIAC begins with the continuous building of a foundation of creative and innovative thinking within a broad spectrum of professional communities. It is essential that the process of inspiring and nurturing the development of revolutionary, paradigm-shifting, advanced concepts includes a very active and continuous stimulation of a broad cross-section of innovators who reside in aerospace and non-aerospace communities and include all age groups from kindergarten to the most experienced innovators. The NIAC maintains a high degree of connectivity with a diverse cross-section of innovative researchers in established and emerging technical disciplines.

NIAC maintains an open line of communication with leaders in the global technical community through the NIAC Web site and participation in national and international technical society meetings through the presentation of technical papers and use of NIAC display booths (e.g., American Association for the Advancement of Science, World Space Congress). The NIAC leadership also provides advocacy by orchestrating vigorous dialogue about revolutionary concepts through their active participation in appropriate technical societies and in technical committees affiliated with these societies. In addition to interfaces with technical societies, NIAC actively pursues exposure with aerospace industry associations through presentations to these organizations, many of which have been invited presentations. One recent example is the invited presentation about NIAC by Associate Director Patricia Russell to the Aerospace States Association.

The leadership of NIAC, including the Director, Associate Director and Senior Science Advisor, promote revolutionary, advanced concepts through participation, primarily by invitation, on steering and oversight committees organized by NASA and other civilian agencies, Department of Defense, National Academy of Sciences, and National Research Council committees. This key activity continues to provide open examination and expansion of the NIAC process for advocacy, analysis and definition of advanced concepts. NIAC regularly interfaces with other U.S. research agencies to (1) stay informed about technology breakthroughs developed by these agencies; (2) encourage feedback to NIAC Fellows from a diverse constituency of research organizations; (3) explore the potential for supplemental funding for NIAC advanced concepts; and (4) establish links with the community of researchers funded by these agencies. NIAC has established collaborative interfaces with the following agencies: Office of Naval Research, Air Force Office of Scientific Research, Army Research Office-Physics Program, U.S. Joint Forces Command, National Reconnaissance Office, National Institute of Standards and Technology, the National Security Agency, the Defense Advanced Research Projects Agency, and the Air Force Research Lab.



The (above) NIAC poster has become a useful tool for soliciting and increasing NIAC's visibility. It is distributed by the NIAC staff and its representatives at numerous meetings, workshops, seminars and conferences.

The NIAC annual meeting, the annual NIAC Phase I Fellows meeting and focused NIAC workshops provide opportunities for open analysis and advocacy of currently funded advanced concepts as well as an unbiased and open-minded examination of revolutionary concepts and enabling technologies.

Targeted NIAC workshop presentations and discussions encourage proposals addressing under-represented research areas. Web casts of these events can provide unlimited exposure to new groups. Meeting presentations and funded studies' reports posted on the NIAC Web site provide detailed examples of pertinent areas of interest to NIAC, inspiring new proposal submissions.

In addition to the ongoing publicity through the NIAC Web site, NIAC activities have been the subject of articles in publications serving the general public and the technical community. Appendix A contains a listing of the NIAC activities during the fifth contract year.

Recruitment of Nationally- and Internationally-Acclaimed Peer Reviewers

The NIAC leadership has developed an efficient and proven method for identifying and selecting the most qualified and appropriate external review panel members to evaluate proposals submitted to the Institute. Over the last five years, NIAC has continuously recruited experts across a broad cross-section of technical expertise and a total of one hundred seventy eight individuals have been used, thus far, for peer review. In order to ensure a continuous refreshment of the available expertise representing newly emerging technologies within the scientific community, the NIAC leadership continually recruits additional reviewers for each new peer review cycle. NIAC peer reviewers recruited by USRA include senior research executives in private industry, senior research faculty in universities, specialized researchers in both industry and universities, and aerospace consultants.

For identifying prospective peer reviewers, several resources are used in combination. Because Phase I proposals are necessarily less technically specific and will be judged more for the validity of the concept itself, evaluation of these proposals requires experts regarded as "big picture" people (i.e., individuals whose careers have exposed them to a variety of technical disciplines and an understanding of complex systems employing many different technologies). An example of this type of individual might be a vice president of a major aerospace corporation.

Phase II proposals, however, which offer far more technical detail, will typically require a more specific group of evaluators.

One significant resource that the Institute has employed successfully and will continue to exploit is the personal knowledge of the NIAC Director, Associate Director, and Senior Science Advisor of many qualified experts in a wide variety of fields related to NIAC. Some of these experts have a prior association with NIAC, some served previously as NIAC reviewers, and some participated in one of the Grand Challenges workshops. Others may have been suggested by NIAC Science Council members. An additional resource of qualified peer reviewers can be found in the authors of publications cited in the proposals to be reviewed. These researchers often represent the forefront of knowledge in a specific, emerging technology directly relevant to the proposed study. Figure 1 is a breakdown of NIAC peer reviewers recruited over the life of the Institute.

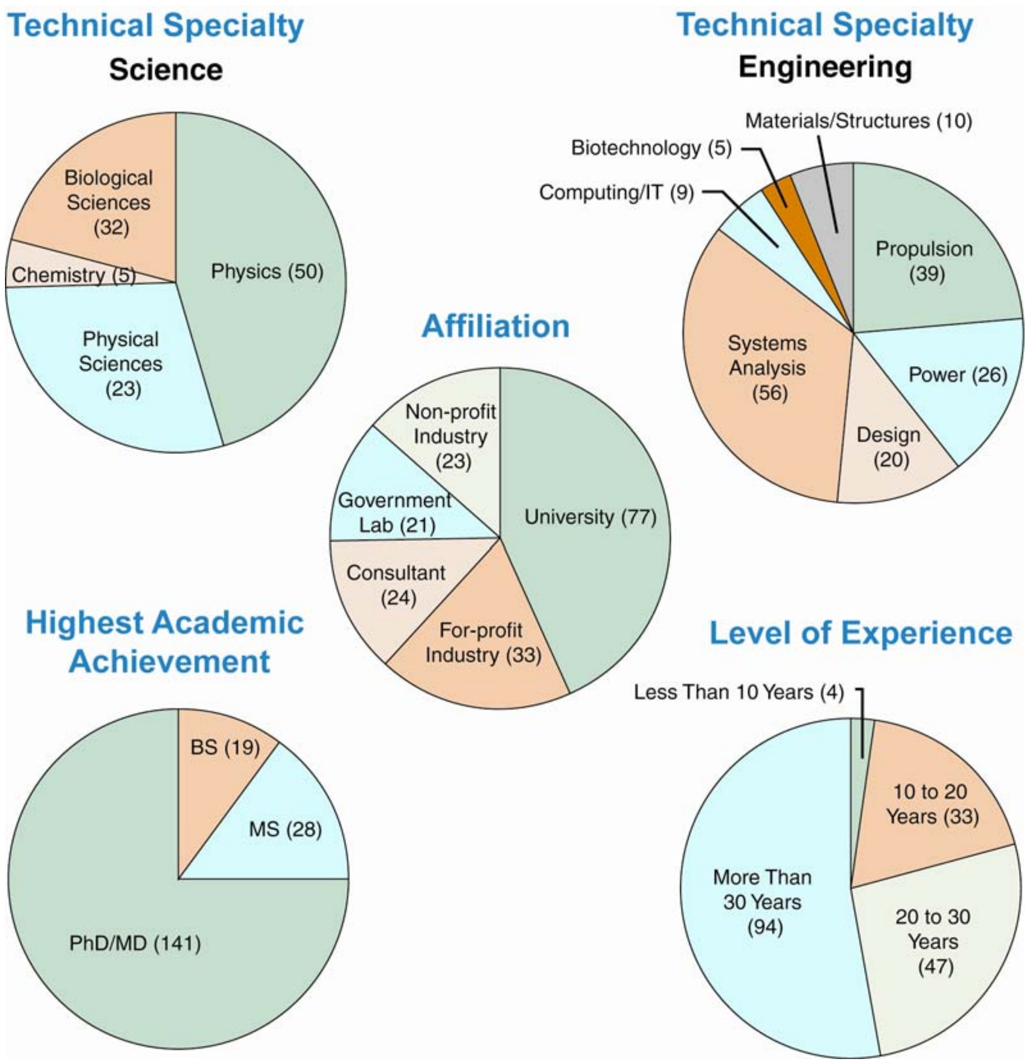


FIGURE 1. NIAC Peer Reviewer Demographics

NIAC Fourth Annual Meeting

Visions of the Future was the theme of the NIAC Fourth Annual Meeting and Workshop. The Lunar and Planetary Institute (LPI) in Houston, Texas, hosted the event on June 11-12, 2002. Each of the Phase II NIAC Fellows funded under Calls for Proposals CP 00-01 and CP 01-01 presented a 45-minute status report on their contract.

Each of the following three keynote speakers gave one-hour presentations:

DR. DONNA L. SHIRLEY
University of Oklahoma
The Myths of Mars:
Why We're Not There Yet and How to Get There

A Mars Exploration Program employing honesty, openness, patience and hard-nosed management can get us (at least a steady stream of robots – and hopefully – eventually, people) to Mars on a regular basis. Standing firm by the old myths has been proven not to work.

Exploring Mars, by Chesley Bonestell

DR. JACK STUSTER
Anacapa Sciences, Incorporated
The Relevance of Previous Expeditions to Future Space Exploration

DR. HARLEY THRONSON
NASA Office of Space Sciences
The Future of Space Science: NeXT's Vision

NEXT'S GRAND VISION

Exploration of life in the Universe enabled by technology, first with robotic trailblazers – and eventually humans – going anywhere, anytime.

Dr. Robert A. Cassanova's *Introduction*, all of the presentations and the Agenda are available on the NIAC Web site. Among the sixty-three people in attendance were the CP 01-02 Phase I NIAC Fellows, who displayed posters depicting their funded concepts. A special thanks to NASA Langley Research Center (LaRC) for their assistance in Web casting the two-day event.

NIAC Fellows Meeting and Workshop

This Phase I Fellows meeting and workshop was held at NIAC Headquarters in Atlanta, Georgia on October 23-24, 2002. All of the presentations, the attendance list and the agenda are accessible via the NIAC Web site. From the NIAC HOMEPAGE, go to LIBRARY, MEETINGS, then to OCTOBER 2002 FELLOWS MEETING to access the presentations and attendance list. There were fifty-five people in attendance, most of whom are included in the photograph (below).

NIAC Fellows Meeting and Workshop – October 2002

Special insight was provided through the presentations made by the following two keynote speakers:

PROFESSOR ROBERT MICHELSON
Georgia Tech Research Institute (GTRI)
21st Century Aerial Robotics

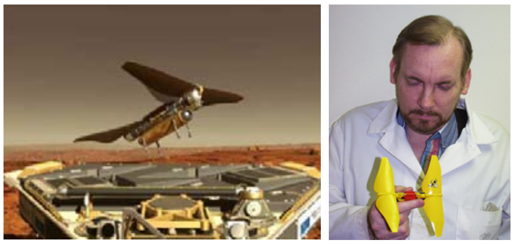


Photo and graphic courtesy of Georgia Tech Research Institute

DR. SETH SHOSTAK
Search for Extraterrestrial Intelligence Institute (SETI)
The Search for Cosmic Company

Photo and graphics courtesy of SETI Institute

NIAC Science Council Meetings

Council meetings are normally scheduled to follow the NIAC Annual Meeting and the Phase I Fellows Workshop. This schedule makes the most productive use of the Council members' time by allowing them to participate in the meetings and see the very latest progress reports from the Fellows. Attendees include the Council members, NIAC leadership administrative staff, a USRA management representative and the NASA COTR. Occasionally, special guests are invited to attend to address specific technical topics.

The NIAC Science Council met on June 13, 2002 following the Fourth NIAC Annual Meeting at the Lunar and Planetary Institute and on October 25, 2002 following the Phase I Fellows Meeting at NIAC Headquarters. A typical agenda for the meeting includes a summary of the NIAC financial status, a summary of all activities since the last meeting, discussion of any management or technical issues, a schedule for future activities and discussion about future directions. Informal and vigorous discussion is encouraged. A written summary of the discussions, recommendations and action items are prepared by the USRA management representative and transmitted to the Council members, USRA management and the NASA-NIAC technical and management teams.

Inputs to NASA Technology Inventory Database

NIAC provides input to the NASA Technology Inventory Database immediately following the announcement of all awards for Calls for Proposals for Phase I and Phase II concepts. The public version of this database, which is maintained by NASA Goddard Space Flight Center (GSFC), is available at http://technology.gsfc.nasa.gov/technology/.

Financial Performance

NIAC measures its financial performance by how well it minimizes its operational expenses in order to devote maximum funds to viable advanced concepts. During the first five years of NIAC operation, 76.6% of the total NIAC budget has been devoted to advanced concepts research and development. Our five-year average demonstrates our ability to meet this goal. We take great pride in this achievement.

On February 10, 2003, NASA approved the contract extension for USRA to operate NIAC through July 10, 2003 or until the contract was awarded for the continuation of full operation of NIAC. This was necessary due to delays in procurement of the follow-on contract for operation and management of NIAC. During the contract extension, NIAC continued with the Phase II (CP 02-01) peer review, Phase II site visits, numerous outreach activities and coordination with NASA. The Phase II (CP 01-01) contracts were also extended during this time period. On July 11, 2003, USRA was awarded the follow-on contract for operation and management of NIAC for a period of three years with an option for a two-year extension.

DESCRIPTION OF THE NIAC

Mission

The NASA Institute for Advanced Concepts (NIAC) was formed for the explicit purpose of functioning as an independent source of revolutionary aeronautical and space concepts that could dramatically impact how NASA develops and conducts its missions. The Institute provides a highly visible, recognized and high-level entry point for outside thinkers and researchers. The ultimate goal of NIAC is to infuse the most promising NIAC-funded advanced concepts into future NASA plans and programs. The Institute continues to function as a *virtual institute* and utilizes Internet resources whenever productive and efficient for communication with grant recipients, NASA, and the science and engineering communities. Figure 2 depicts the NIAC Mission.

The NIAC Focus
Revolutionary concepts for systems and architectures that can have a major impact on future missions of the NASA Enterprises, inspire the general public, and excite the nation's youth.

The NIAC Method
Provide a pathway for innovators with the ability for non-linear creativity to explore revolutionary solutions to the grand challenges of future aerospace endeavors.

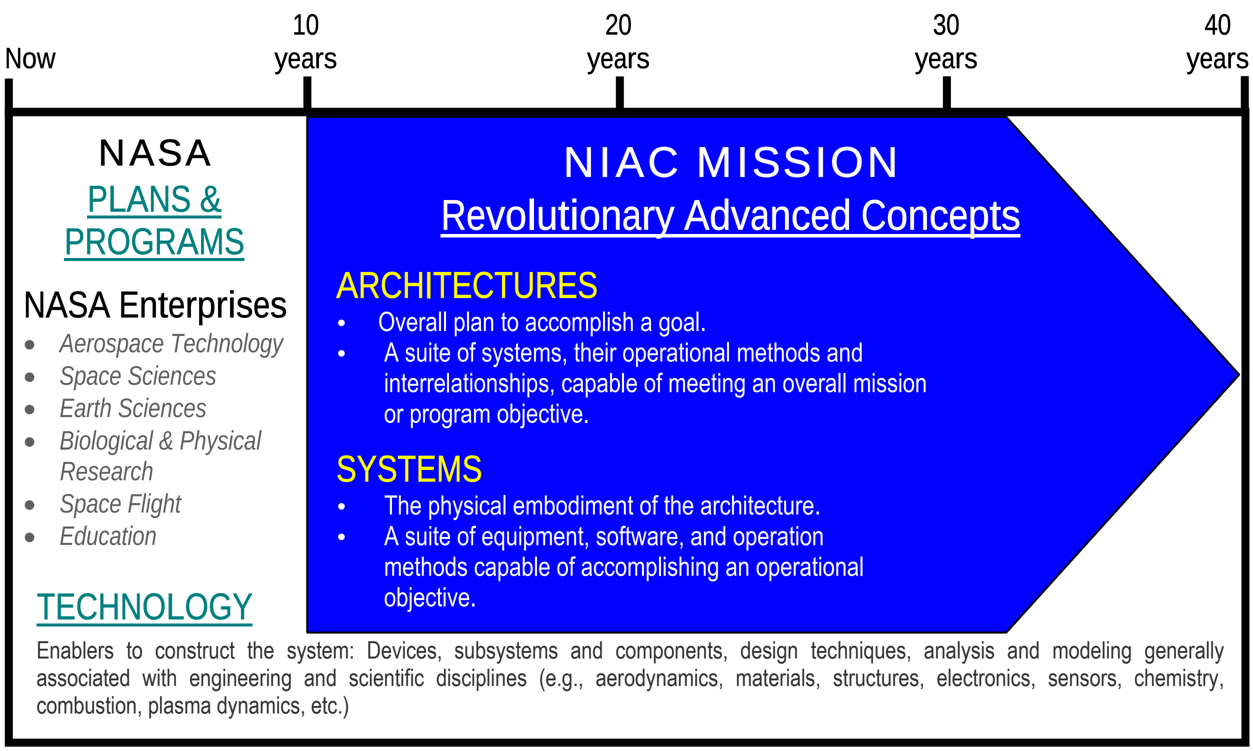


FIGURE 2. NIAC Mission

Organization

The NIAC staff is currently located at the NIAC Headquarters office in Atlanta, Georgia and consists of its director, business manager, and administrative assistant. ANSER provides full-time, on-site computer network and software application support at NIAC Headquarters.

Recipients of NIAC grant or contract awards are designated as "NIAC Fellows."

As an Institute of the Universities Space Research Association (USRA), NIAC reports to the President of USRA. USRA uses many methods in its management of NIAC to ensure NASA is provided with quality service at a reasonable price. Approximately 70% of the funds provided by NASA for the operation of NIAC are used for funding advanced concepts. USRA refers to the remaining 30% of the NIAC budget as NIAC operations costs. Three general management processes and/or methods are employed to provide a comprehensive and cost-effective, advanced concepts development program to NASA. First, USRA uses a proven solicitation and peer review process to solicit, evaluate, and select proposed advanced concepts. Once new concepts are selected for funding, USRA employs the second phase of its acquisition management approach, which is to award a grant or contract to the selected organizations. To accomplish this, USRA uses its government-approved purchasing system. USRA personnel working this aspect of the acquisition process are guided by the USRA Procurement Manual, which is modeled from the Federal Acquisition Regulations. After the appropriate contractual instrument has been awarded, USRA monitors overall performance against the respective proposed budget and concept development milestones through bi-monthly reports from the principal investigators covering technical, schedule, and budget status.

ANSER, through a subcontract from USRA-NIAC, brings unique knowledge and expertise to the NIAC program by providing technical and programmatic support to the operation of the Institute. ANSER's participation in the operation of NIAC enables the Institute to have access to significant resources developed over decades of support to the government through the Department of Defense (DoD). ANSER provides a means to stay aware of innovative DoD and Homeland Security (HS) activities relevant to NASA and NIAC. ANSER has a long association with U.S. military aerospace activities, DoD research facilities, and the Defense Advanced Research Projects Agency (DARPA). ANSER's Institute of Homeland Security, established in April 2001, maintains a close working relationship with agencies and organizations involved in homeland security. This facilitates a means to introduce NIAC Fellows and concepts to the relevant DoD and HS communities. At ANSER's initiative, several NIAC Fellows have presented their research in invited talks in classified settings (e.g., through an NRO speaker's forum). These well-attended presentations get additional exposure after the taped talk and the electronic slides are posted on a DoD Web site. ANSER supports the operation of the Institute as an electronic virtual entity. The NIAC organization is illustrated in Figure 3.

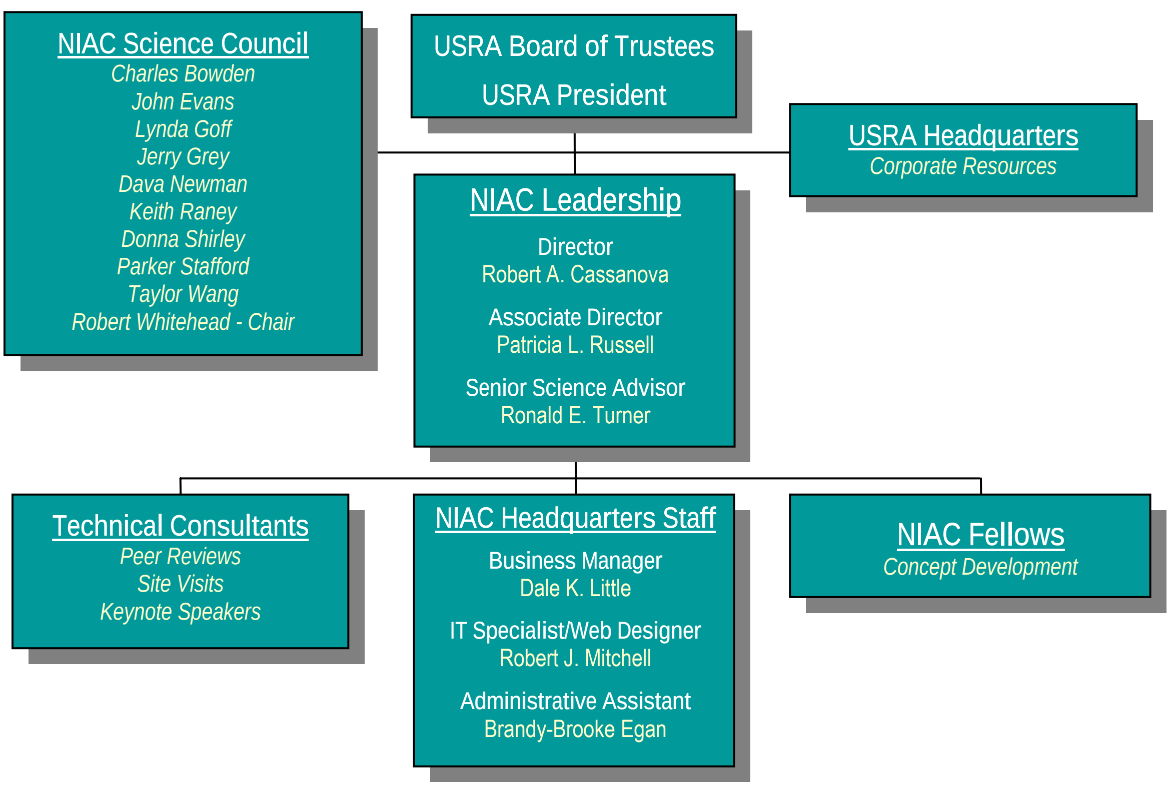


FIGURE 3. NAC Organization

As a corporate expense, the NIAC Science Council (formerly called the NIAC Science, Exploration and Technology Council) was formed to oversee the operation of NIAC on behalf of the relevant scientific and engineering communities. The Council is composed of a diverse group of thinkers, eminent in their respective fields, and representing a broad cross-section of technologies related to the NASA Charter. The Council has a rotating membership with each member serving a three-year term. The USRA Board of Trustees appoints all Council members. The current membership of the NIAC Science Council is listed in Table 11.

Member	Affiliation
Dr. Charles Bowden	US Army Aviation & Missile Command
Dr. Robert A. Cassanova	NASA Institute for Advanced Concepts (NIAC) [ex officio]
Dr. John V. Evans	Aerospace Consultant
Dr. Lynda J. Goff	University of California-Santa Cruz
Dr. Jerry Grey	Aerospace Consultant
Dr. Dava J. Newman	Massachusetts Institute of Technology
Dr. R. Keith Raney	Johns Hopkins University
Dr. Donna L. Shirley	University of Oklahoma
Mr. Parker S. Stafford	Aerospace Consultant
Dr. Taylor Wang	Vanderbilt University
Dr. Robert E. Whitehead	Aerospace Consultant

TABLE 11. Current Membership of the NIAC Science Council

Facilities

NIAC Headquarters, currently located in midtown Atlanta, occupies 2,000 square feet of professional office space with access to two on-site conference rooms as well as a 75-seat auditorium. The staff is linked via a Windows NT-based Local Area Network (LAN) consisting of five Pentium II PCs, one Macintosh G3 and two UNIX servers. Internet access is provided via a fiber-optic link through the Georgia Tech network. Other equipment includes one Dell Inspiron 7000, one IBM Thinkpad T-21, one NEC MT 1030 LCD projector, one flatbed scanner, one HP Color LaserJet 5 printer, one HP LaserJet 4000TN printer, one HP LaserJet 3100 facsimile machine and a Sharp AR405 copier.

The servers use RedHat Linux for their operating systems, Apache for the Web server, Sendmail for the email server, Sybase SQL server for the database, and OpenSSL for Web and email security. The workstations use Windows 2000E for their operating systems, Microsoft Office 2000 Professional for office applications, Netscape Communicator for email access, and Adobe Acrobat for distributed documents.

Virtual Institute

NIAC envisions progressive use of the Internet as a key element in its operation. The Internet is the primary vehicle to link the NIAC office with grantees, NASA points-of-contact, and other members of the science and engineering communities. The Internet is also the primary communication link for publicizing NIAC, announcing the availability of Calls for Proposals, receiving proposals, and reporting on technical status. All proposals must be submitted to NIAC in electronic format. All reports from the grantees to NIAC and from NIAC to NASA are submitted electronically. The peer review of proposals is also conducted electronically whenever the peer reviewer has the necessary Internet connectivity and application software.

ANSER created and maintains the NIAC Web site at http://www.niac.usra.edu, which serves as the focal point of NIAC to the outside world. The Web site can be accessed to retrieve and submit NIAC information and proposals. The NIAC Web site is linked from the NASA Research Opportunities Web site at http://search.nasa.gov/nasasearch/search/search.jsp?nasaInclude=niac&Simple+Search.x=27&Simple+Search.y=1, the Office of Earth Science Research Opportunities at http://www.earth.nasa.gov/nra/current/index.html, the GSFC Flight Programs and Projects Directorate at http://fpd.gsfc.nasa.gov/408/index.html and the Small Business Innovative Research program at http://sbir.nasa.gov. Numerous other links to the NIAC Web site are now established from NASA Centers and science and engineering Web sites. Since February 4, 2000, the NIAC Web site has logged over 124,000 connections. Figure 4 depicts the site map of the NIAC Web site.

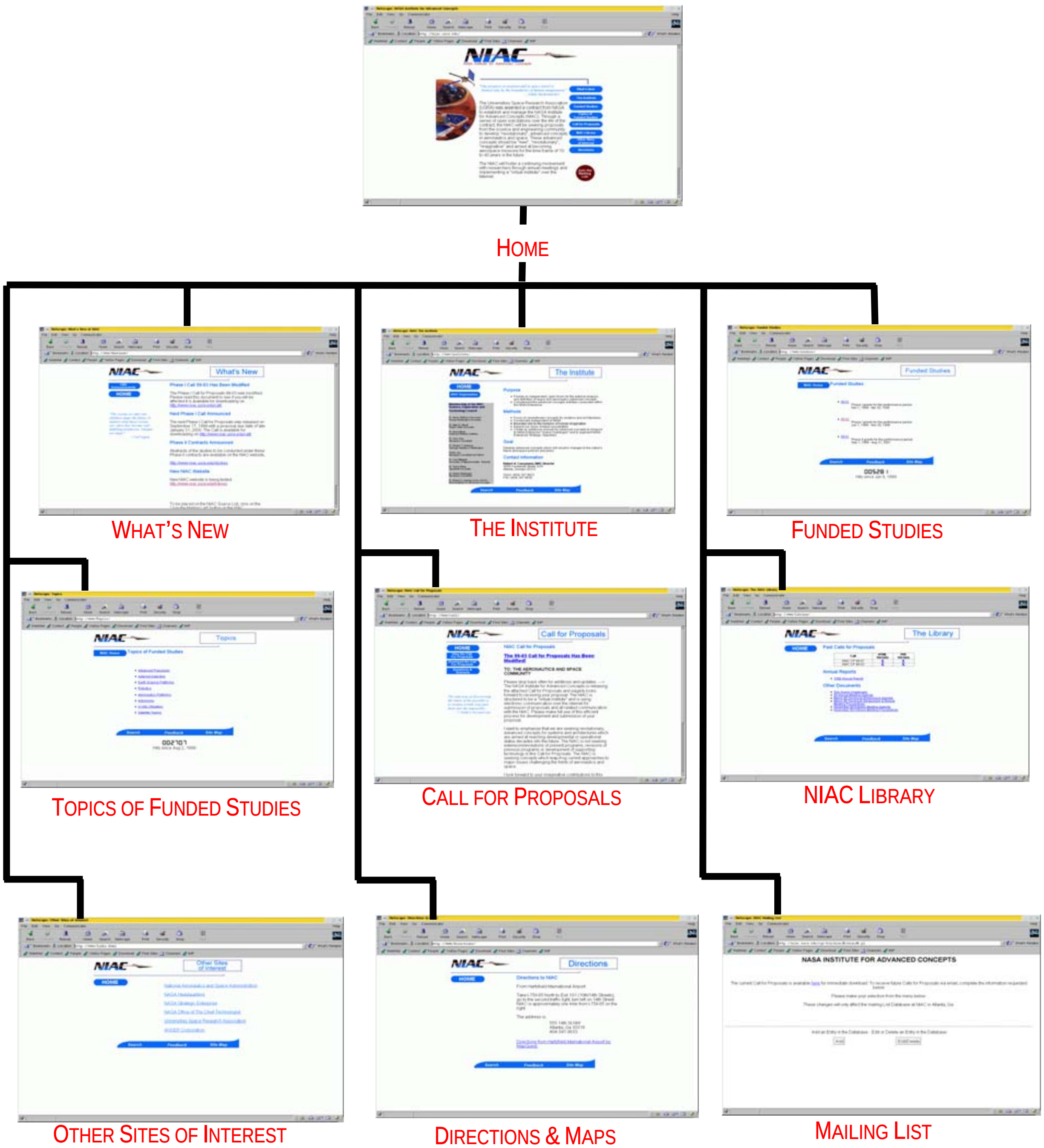


FIGURE 4. Map of the NIAC Web Site - http://www.niac.usra.edu.

NIAC HOME PAGE

WHAT'S NEW	News pertaining to NIAC is found through this link. There is also a link to the latest *Commerce Business Daily* release pertaining to NIAC.
THE INSTITUTE	This link provides information about NIAC that includes a list of the NIAC Science Council members, its purpose, method, goal, and contact information. There is also a link to an Organizational Chart of NIAC.
FUNDED STUDIES	Information about each principal investigator and project that NIAC has funded is in this section. There are links to various documents including abstracts of proposals, presentations and final reports. This category can be sorted by Call, PI name, and topic.
CALL FOR PROPOSALS	This is a link to the current Call for Proposals. There is a link to the Questions & Answers section provided as well.
NIAC LIBRARY	This contains an archive of previous Calls for Proposals, NIAC annual reports and other miscellaneous documents. There are links to view the proceedings of Fellows Meetings and various Workshops as well.
LINKS	Links to other sites are provided via this section.
MAILING LIST	NIAC provides a Mailing List where users can access the latest Call for Proposals via email. Users are allowed the capability to add, edit and/or delete their own entry in this section.
FEEDBACK	This provides users the opportunity to ask questions about NIAC. Questions & Answers pertaining to the current Call for Proposals may be viewed in this section.

The NIAC Web page has undergone a marked change since last year's annual report. The implementation of JAVA server pages has allowed the dynamic production of certain Web pages. This is most evident in the Funded Studies section and the Mailing List section.

ADVANCED CONCEPT SELECTION PROCESS

The NIAC process of inspiring and moving toward an ultimate goal of infusing revolutionary advanced concepts into NASA's long range plans across the Enterprises is depicted in Figure 5.

FIGURE 5. NIAC's Operating Paradigm

Publicity

There are various methods used to publicize the NIAC Phase I Calls for Proposals. Some of the ways that NIAC solicits Calls to the community are as follows:

- Notices sent to a NIAC email distribution list generated from responses by individuals who signed up on the NIAC Web site to receive the Call;
- Announcements on professional society Web sites or newsletters (American Institute for Aeronautics and Astronautics, American Astronautical Society and the American Astronomical Society);
- Announcements on the USRA and NIAC Web sites;
- NASA Goddard Space Flight Center (GSFC) news release;
- Web links from NASA Enterprises Web pages;
- Web link from the NASA Coordinator's Web page;
- Announcements to a distribution list for Historic Black Colleges & Universities (HBCU), Minority Institutions (MI) and Small Disadvantaged Businesses (SDB) provided by NASA;
- Distribution of announcements to an Earth Sciences list provided by NASA GSFC;
- Announcements in the *Commerce Business Daily*;
- Announcements distributed at technical society meetings.

FIGURE 6. Publications Featuring Articles about NIAC and Its Fellows

Since Phase II awards are based on a down-select from Phase I winners, all Phase II Calls for Proposals are emailed directly to past Phase I winners who have not previously received a Phase II contract.

In addition to the solicitation vehicles itemized above, NIAC has been featured in numerous articles published in newspapers, magazines, and on the World Wide Web. Several television networks and radio stations around the world have broadcast coverage on NIAC Fellows and their NIAC-funded advanced concepts as well.

NIAC Director Dr. Robert Cassanova has participated in several live radio interviews also. Since its inception, NIAC has been mentioned in about 300 publications. The collage of logos/icons in Figure 6 illustrates only a few publications in which articles featuring NIAC and its funded concepts have appeared. All of the publications and broadcasts during the final contract year are listed in Appendix B.

Solicitation

The actual solicitation for advanced concepts is assembled and published by the NIAC staff. The technical scope of the solicitation emphasizes the desire for *revolutionary* advanced concepts that address all elements of the NASA mission. This is particularly true for the Phase I solicitation. The scope of work is written to inspire proposals in all NASA mission areas and contains brief descriptions of NASA Enterprise areas of emphasis.

In general, proposed advanced concepts should be:

- Revolutionary, new and not duplicative of concepts previously studied by NASA,
- An architecture or system,
- Described in an aeronautics and/or space mission context,
- Adequately substantiated with a description of the scientific principles that form the basis for the concept,
- Largely independent of existing technology or a unique combination of systems and technologies.

These revolutionary concepts may be characterized by one or more of the following attributes:

- The genius is in the generalities, and not the details,
- The new idea creates a pathway that addresses a roadblock,
- It inspires others to produce useful science and further elaboration of the fundamental idea,
- It contributes to a shift in the world view,
- It triggers a transformation of intuition.

Over the last 100 years of scientific and engineering development, there have been many notable concepts, technical accomplishments and scientific breakthroughs that have had a revolutionary impact on transportation within the Earth's atmosphere, the exploration of our solar system and beyond, and on our understanding of the cosmos. Creative and often intuitive approaches may lead to revolutionary paradigm changes and interpretative applications or concepts.

The Phase I Call for Proposals that was released September 26, 2002 expressed a special interest in receiving proposals for innovative and visionary concepts from disciplines that are normally focused on non-aerospace endeavors and may have the potential for innovative application in the aerospace sector. These concepts may be emerging at the interface of traditional disciplines where innovation often spring forth in non-aerospace fields.

Based on an analysis of Phase I proposals submitted in response to previous Calls, CP 02-02 also included an explanation of the basic requirements for concepts submitted to NIAC as expressed in the following statement. The evaluation criteria for Phase I and Phase II concepts are structured to convey what is being sought and are summarized in Figure 7.

Phase I – 6 months $50 - $75K	Phase II – Up to 24 months Up to $500K
• Is the concept revolutionary rather than evolutionary? To what extent does the proposed activity suggest and explore creative and original concepts? • Is the concept for an architecture or system, and have the benefits been qualified in the context of a future NASA mission? • Is the concept substantiated with a description of applicable scientific and technical disciplines necessary for development?	• Does the proposal continue the development of a revolutionary architecture or system in the context of a future NASA mission? Is the proposed work likely to provide a sound basis for NASA to consider the concept for a future mission or program? • Is the concept substantiated with a description of applicable scientific and technical disciplines necessary for development? • Have enabling technologies been identified, and has a pathway for development of a technology roadmap been adequately described? • Has the pathway for development of a cost of the concept been adequately described, and are costing assumptions realistic? Have potential performance and cost benefits been quantified?

FIGURE 7. NIAC Proposal Evaluation Criteria

The NIAC Calls for Proposals are distributed in electronic form only. Under a typical schedule for NIAC operation, NIAC solicits for *one* Phase I and *one* Phase II, both of which are prepared and released each calendar year. These releases generally occur in the latter half of the calendar year.

Proposals

In order to be considered for award, all proposals are required to be submitted to NIAC electronically as a .pdf file. Technical proposals in response to Phase I Call for Proposals are limited to 12 pages; whereas, Phase II technical proposals are limited to 25 pages. There is no page limit for cost proposals.

Phase II proposals are only accepted from proposal authors who have previously received a Phase I award and have not previously received a Phase II follow-on contract. The deadline for submission is the same for the Phase II proposal and associated Phase I final report. Phase I Fellows may submit a Phase II proposal at any time after completion of their Phase I grant, but it must be received by NIAC by the designated deadline in order to be considered in a particular review cycle.

Peer Review

Peer reviewers are selected from the technically appropriate reviewers in the NIAC database. Additional reviewers are recruited as needed to adequately represent the technical emphasis of each proposal. Each reviewer is required to sign a non-disclosure and a no-conflict-of-interest agreement prior to their involvement. A small monetary compensation is offered to each reviewer. The technical proposals and all required forms are transmitted to the reviewer via the Internet, by diskette or by paper copy, depending on the electronic capabilities of the reviewer.

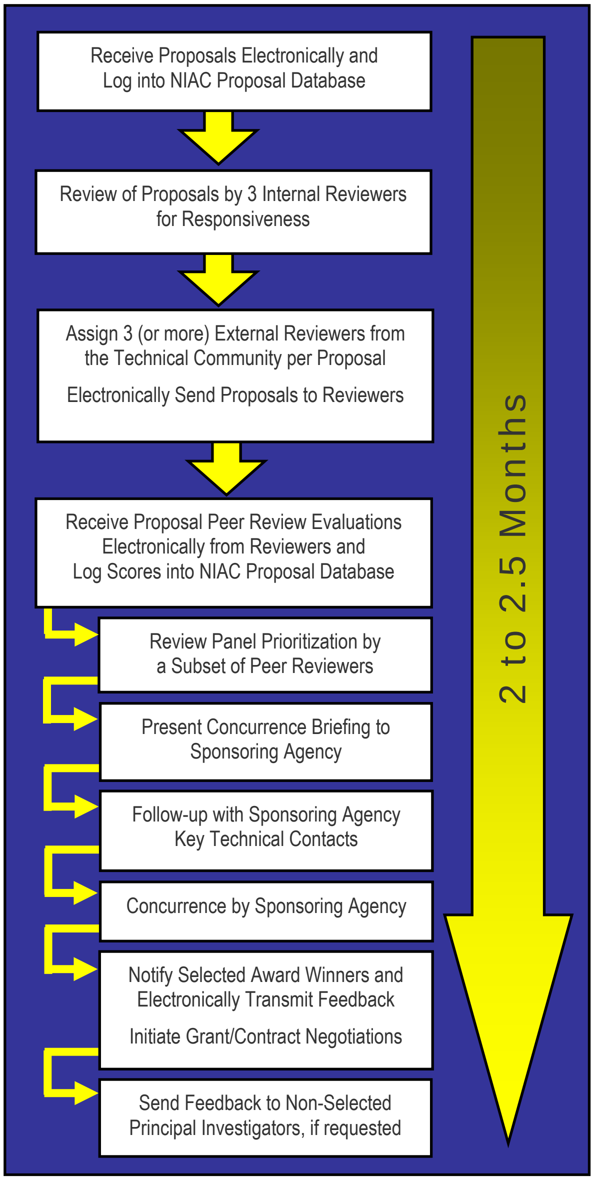


FIGURE 8. NIAC Peer Review Process

Reviewers are given approximately thirty days to review the technical proposals and return their completed evaluation forms. Figure 8 illustrates the peer review process. Each proposal receives at least three independent peer reviews. Each reviewer evaluates a proposal according to the criterion stated in the Call for Proposals.

Templates/forms are created to help guide the reviewer through the process of assigning a numerical ranking and providing written comments. Only NIAC and USRA staff analyze cost proposals.

The ANSER Corporation provides valuable assistance to the peer review process through a search of its archives, knowledge databases and additional resources. These information databases are used to provide additional background on prior and ongoing advanced concept research efforts sponsored by NASA and non-NASA sources. To help assure that a proposed concept is not duplicating previously studied concepts, NIAC accesses the NASA Technology Inventory Database and searches for related NASA-funded projects. Results of the peer reviews are compiled by NIAC, rank-ordered by a review panel, and prepared for presentation to NASA at a concurrence briefing.

NASA Concurrence

The NIAC Director is required to present the apparent research selections to the NASA Chief Technologist and the representatives of NASA Strategic Enterprises before the announcement of awards. Technical concurrence by NASA, required before any subgrants or subcontracts are announced or awarded, is obtained to assure consistency with NASA's Charter and to assure that the concept is not duplicating concepts previously or currently being developed by NASA.

Awards

Based on the results of the NIAC peer review, technical concurrence from NASA's Office of the Chief Technologist and the availability of funding, the award decision is made by the NIAC Director. All proposal authors are notified electronically of the acceptance or rejection of their proposals. If requested, feedback based on the peer review evaluator's comments is provided to the non-selected proposal authors.

The USRA contracts office then begins processing contractual instruments to each of the winning organizations. The NIAC staff inputs all pertinent technical information regarding the winning proposals into the NASA Technology Inventory Database as well as on the NIAC Web site. The "product" of each award is a final report. All final reports are posted on the NIAC Web site for public viewing.

Key Milestones

During the sixth year of the NASA contract, NIAC will build on the operational framework established in the first five years to broaden the constituency of innovators responding to NIAC initiatives and to expand the participation of scientists and engineers from outside the normal aerospace disciplines. NIAC will continue to improve the Phase I and Phase II selection strategy to inspire and competitively select revolutionary advanced concepts with the greatest potential for significant impact. To reinforce an atmosphere of revolutionary and innovative, but technically-credible thinking, the technical themes chosen for annual meetings and workshops will give special emphasis to scientific discoveries and emerging technologies that could be the basis for innovative, interdisciplinary architectures and systems aimed at the major challenges of aeronautics and space.

The activities planned for the sixth year will build on NIAC's leadership position to inspire, select, fund and nurture revolutionary advanced concepts and to orchestrate the transition of successful concepts into consideration by NASA for long-range development. Table 12 summarizes the major activities to be conducted in the next five years as well as activities that began in prior years.

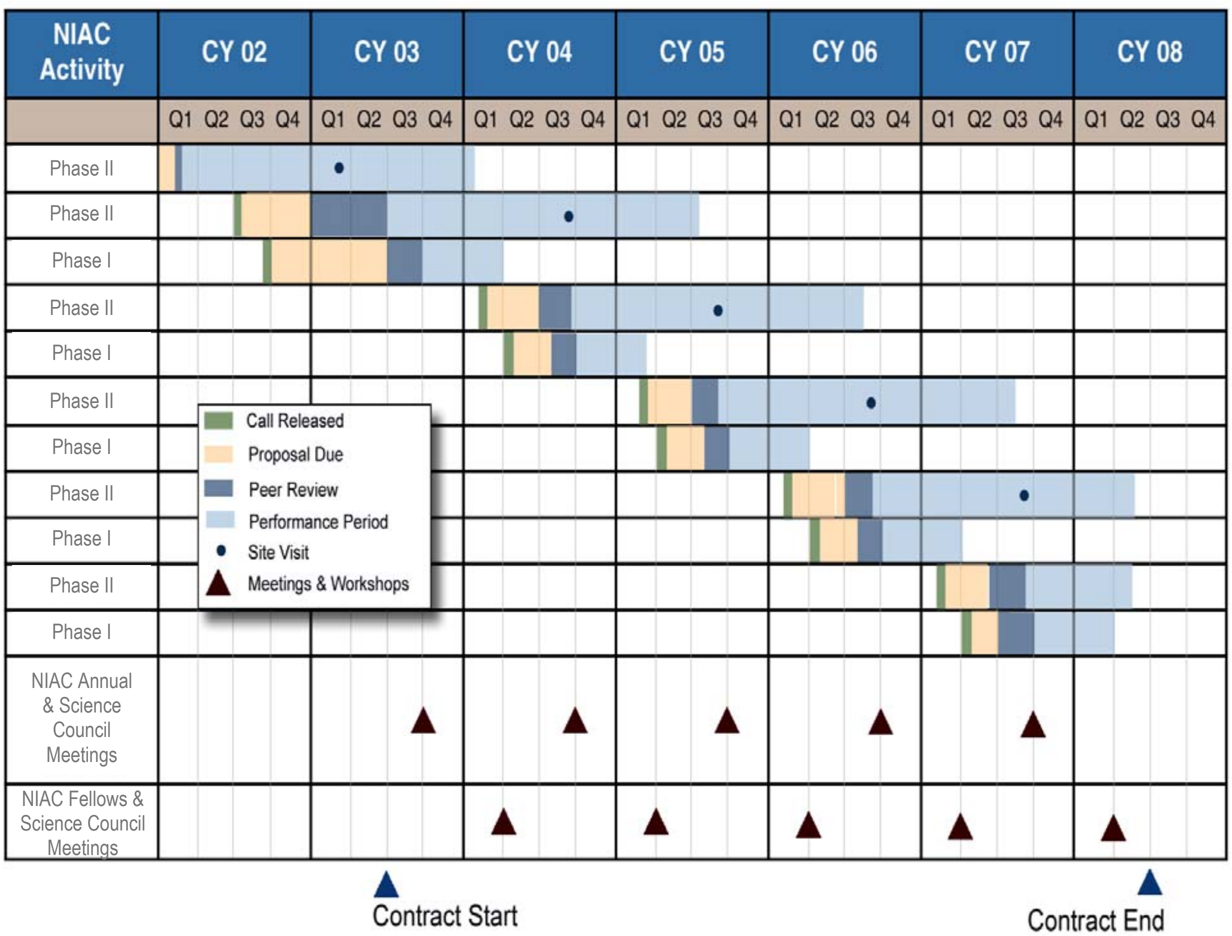


TABLE 12. Key Milestones

Concept Solicitation, Selection and Award for the Sixth Year

The peer review, selection, and concurrence by NASA and award based on proposals received in response to Phase II Call CP 02-01 and Phase I Call CP 02-02 will be completed in the third quarter of the sixth contract year. Grant and contract start dates are anticipated in September 2003.

The next Phase II Call for Proposals CP 03-01 will be sent to all eligible Phase I fellows by the third month of their Phase I grant. The next Phase I Call for Proposals, CP 03-02 will be released in the Fall Quarter 2003. The peer review and award will occur in 2004.

Management of Awards

NIAC will continue to require all grant and contract recipients to submit bi-monthly and final reports. All Phase II contractors will be required to host a site visit and to submit an interim report before the end of the first half of their contract. Participants in the site visits will include the NIAC Director, invited experts in the technical field of the concept, and NASA representatives who may be able to facilitate the eventual transition to its long-range NASA funding. All Phase II Fellows are required to give a status briefing at the NIAC annual meeting. All Phase I Fellows are required to present a poster at the annual meeting and give a status briefing at the Phase I Fellows workshop held near the end of their Phase I grant.

Coordination with NASA and Other Federal Agencies

All NASA Associate Administrators or their designees, selected HQ theme managers, Center Directors, as well as selected technical staff at the Centers are briefed annually on NIAC status and plans. Other federal agencies, such as the National Reconnaissance Office, Air Force Office of Scientific Research, Office of Naval Research, and the Army Research Office, will be regularly visited to explore opportunities of collaboration with NIAC and with NIAC Fellows.

Oversight by USRA Management

The NIAC Science Council will meet to receive an overview of the status and plans of NIAC on the day following each of the scheduled annual meetings and Fellows meetings. The Council will issue a report to USRA management and NASA on the operation of NIAC and will offer suggestions for future activities.

Reaching out to the Nation’s Youth

NIAC offers a perfect opportunity to engage the imagination of our young people, upon whom the nation’s future depends. By offering visions of the future available through NASA priorities, youth are inspired to pursue educational goals in science, engineering, and mathematics that will enable them to pursue careers dedicated to remarkable achievements. NIAC continues to give presentations about NIAC and provide appropriate, age-related handouts to teachers describing the goals of the program and current project descriptions.

USRA has a new major innovation for involving students in NIAC. The NIAC Student Fellows program will competitively award research projects for university students, and will be funded by USRA’s donation of 25% of the contract fee. Undergraduate students, consisting of individual students or multi-disciplinary groups of students, overseen by a faculty advisor, will be given the opportunity to develop proposals addressing NIAC topics, adhering to our unique requirements for projects 10-40 years into the future. Based on ultra-university competition, up to five

Expand our nation's vision of future possibilities by inspiring a passion for creative and innovative solutions to the challenges of aeronautics and space.

university teams and their mentors will be supported to attend the NIAC Annual Meeting and present posters describing their concepts. Student teams responsible for the two most innovative concepts, as judged by the NIAC Science Council, will be invited to present results at the NIAC Fellows Meeting. USRA's contribution will enable student recipients to attend and participate in NIAC meetings, thus broadening their exposure to ideas and assistance from the NIAC Fellows.

NIAC has established relationships with existing programs (e.g., the NASA Academy and the Spaceflight and Life Sciences Training Program at Kennedy Space Center). Through an intensely competitive process, these programs select the best and brightest university students interested in pursuing space careers. NIAC will expand its interaction with these types of programs to reveal opportunities available to motivated participants. We will develop university-level student workshops that encourage new perspectives to addressing known and yet-to-be-discovered aerospace related topics.

NIAC will continue to seek cooperative arrangements with established programs for a spectrum of students (e.g., the Johns Hopkins University's Center for Talented Youth, where 2nd through 8th graders qualify for special academic programs, and become part of a worldwide community of advanced learners; the NASA Student Launch Initiative where teams of high school students build and launch model rockets; and Space Day, when thousands of students participate in space-related activities). NIAC's participation with these and other similar programs can greatly expand our ability to reach young people interested in space. A student "button" will be added to the NIAC home page to facilitate links among relevant NASA student programs, especially leveraging the activities of the new NASA Code N (Office of Education).

USRA will capitalize on its extant in-house student internship programs operated by the Lunar and Planetary Institute and the Research Institute for Advanced Computer Science. USRA will provide NIAC information to summer student interns accepted into USRA-coordinated programs at the NASA Johnson Space Center and NASA Ames Research Center. Activities will be coordinated with USRA's Revolutionary Aerospace Systems Concepts – Academic Linkage (RASCAL) at the NASA Langley Research Center to create synergy and avoid duplication. USRA's network of ninety member universities provides a valuable resource for accessing our nation's youth. USRA's University Relations Directors, including NIAC's Associate Director, disseminate NIAC information to faculty and students during periodic site visits to all USRA member institutions.

Inspiration and Outreach Contacts

Earth-Sun Connection Roadmap Meeting Greenbelt, Maryland	4-5 March 2002	Ron Turner (ANSER) attended the meeting.
NASA Explorer Program Workshop Washington, DC	12 March 2002	This community workshop was sponsored by the Explorer Program of the NASA Office of Space Science. Ron Turner attended.
Envisioning Future Spaceport Needs Scenario Planning Workshop Titusville, Florida	19-20 March 2002	Bob Cassanova presented a summary of NIAC activities that may have an impact on future spaceports.
AAS 40th Goddard Memorial Symposium Greenbelt , Maryland	20-21 March 2002	Pat Russell and Sharon Garrison attended the "Partnering with NASA: The Wave of the Future" symposium, which resulted in information about NIAC given to the University of Maryland President, Dr. Mote.
Annual Meeting of the USRA Council of Institutions & Symposium USRA HQ – Washington, DC	5 April 2002	Bob Cassanova attended and distributed a special edition of the USRA Newsletter featuring an article about the NIAC Phase II Space Elevator concept.
1st International Agenzia Spaziolel Italiana (ASI) Workshop on Futuristic Space Technologies Trieste, Italy	6-7 May 2002	Bob Cassanova gave an invited presentation and participated in panel discussions in the session on "2025 and Beyond." NIAC Fellows Brad Edwards and Ralph McNutt, and Gentry Lee (former NIAC Science Council member) were speakers at this session.
Meeting of the Commission on the Future of the U.S. Aerospace Industry NASA HQ – Washington, DC	14 May 2002	Pat Russell attended this public meeting in the auditorium of the Herbert C. Hoover Building.
Mars Scout Pre-Proposal Conference U.S. Dept. of Commerce HQ	20 May 2002	Ron Turner (ANSER) attended the meeting representing NIAC.
In-Space Construction and Maintenance of Complex Science Facilities Workshop University of Maryland Inn & Conference Center	21-23 May 2002	Ron Turner attended this workshop co-hosted by NASA Goddard Space Flight Center and NASA Langley Research Center.
Women in Aerospace Meeting Washington, DC	23 May 2002	Pat Russell attended the meeting held in the Rayburn House Office Building, and spoke with keynote speaker Rita Colwell. She spoke with numerous people, including keynote speaker Rita Colwell, Aviation Week reporters Marc Selinger and Leonard David. NIAC Science Council member Jerry Grey was one of the speakers.

Kindercare Lawrenceville, Georgia	31 May 2002	Bob Cassanova gave an electronic presentation with material from LPI to a group of 20 children. Handouts were provided by the Space Grant College at Georgia Tech.
NIAC 4th Annual Meeting Lunar & Planetary Institute Houston, Texas	11-12 June 2002	Refer to the section, NIAC Fourth Annual Meeting, for details pertaining to the meeting.
Revolutionary Aerospace Systems Concept (RASC) Earth Science Meeting Greenbelt, Maryland	19 June 2002	NIAC Fellow Kerry Nock led a study sponsored by the RASC program to explore the further uses of balloon constellations for Earth Sciences missions to a group of about 25 people in Earth Sciences.
NASA Academy Seminar University of Maryland College Park, Maryland	6 August 2002	Bob Cassanova gave an invited presentation at a dinner meeting to 15 undergraduate and graduate students enrolled in a GSFC-sponsored NASA Academy program.
Space Elevator Workshop Seattle, Washington	12-13 August 2002	Bob Cassanova and Pat Russell attended.
Commission on the Future of the U.S. Aerospace Industry Meeting Washington, DC	22 August 2002	The meeting included presentations addressing aviation, pilots, controllers, research infrastructure, space and planetary plans. Pat Russell attended and spoke with Commissioner Dr. Neil deGrasse Tyson, Director the Hyden Planetarium in NYC, about future collaboration with NIAC.
Aerospace States Association (ASA) Meeting Washington, DC	6 September 2002	Pat Russell gave an overview on the activities of USRA and NIAC at this meeting which was attended by representatives from the governor's offices of 25 states.
Graduate Student Seminar Duke University	24 September 2002	Bob Cassanova presented an invited seminar to about 35 Master of Engineering Management students.
AIAA World Space Congress Houston, Texas 	10-19 October 2002	USRA and ANSER set up a booth with an emphasis on NIAC and distributed literature about NIAC and USRA. Pat Russell and several USRA representatives occupied the booth throughout the WSC. Bob Cassanova (NIAC), Ron Turner and Matt Prebble (ANSER) attended several technical sessions.
NASA University Engineering Research Summit Meeting NASA Johnson Space Center Houston, Texas	11 October 2002	Bob Cassanova gave an invited overview of USRA and NIAC at this seminar which included engineering deans and other faculty from a number of major research universities, resulting in invitations to give seminars at universities across the U.S.

AIAA Technical Committee on Space Colonization & Microgravity and Space Processes Houston, Texas	16-17 October 2002	Bob Cassanova attended the Space Colonization in conjunction with the World Space Congress meeting in Houston. He gave a briefing and led discussion on "How to Colonize in Space," that is a topic proposed to be a white paper from the Technical Committee.
NIAC Fellows Meeting and Workshop NIAC HQ – Atlanta, Georgia	23-24 October 2002	See the section on NIAC Fellows Meeting and Workshop for details pertaining to the meeting and workshop.
NIAC Science Council Meeting NIAC HQ – Atlanta, Georgia	25 October 2002	See the section on NIAC Science Council for details pertaining to this meeting.
University of Arizona Graduate Seminar Tucson, Arizona	31 October 2002	Bob Cassanova gave an invited seminar to 80 graduate students and faculty. He also held individual meetings with 8 faculty members and toured their research labs.
2002 Annual Meeting of the American Society for Gravitational and Space Biology (ASGSB) Cocoa Beach, Florida	6-9 November 2002	Bob Cassanova and Pat Russell arranged for a technical session on Advanced Concepts, which was chaired by Bob Cassanova. Several NIAC Fellows were speakers.
Future Intelligent Earth-Observing Satellites Symposium (FIEOS) Denver, Colorado	10-15 November 2002	Bob Cassanova gave an invited keynote presentation during the FIEOS Symposium. NIAC Fellow Zhou presented a technical paper based on his concept.
Lockheed-Martin *Waterton Facilities* (near) Denver, Colorado	12 November 2002	Bob Cassanova gave a seminar on NIAC advanced concepts, toured the labs and manufacturing facilities, and participated in technical discussions with the research staff.
Nebo Elementary School Paulding County, Georgia	15 November 2002	Bob Cassanova gave a seminar on "space" to 120 second grade students.
Arlington Chapter of the AIAA Arlington, Virginia	20 November 2002	Ron Turner gave an invited presentation on NIAC.
George Washington University Georgetown, DC	20 November 2002	Dr. Hussein Hussein (USRA) and Pat Russell met with the executive dean, several department chairs and other faculty members. Literature about NIAC was distributed and discussions were held with faculty about the NIAC Charter.
University Park Elementary School University Park, Maryland	20 December 2002	Bob Cassanova presented an inspirational seminar to 300 first, second and third grade students. Various handouts were given to the students as well as letters to the parents from Bob Cassanova and Sharon Garrison.

Space & Advanced Communications Research Institute Meeting George Washington University	15 January 2003	Pat Russell attended this Advisory Board meeting and discussed NIAC goals and processes.
Auburn University Auburn, Alabama	22-23 January 2003	Pat Russell and Jacques L'Heureux (university liaison for USRA HQ) visited and held discussions with faculty to increase NIAC visibility. Pat Russell explored the possibilities of providing NIAC-generated information about education and outreach activities.
SciTrek Atlanta, Georgia	30 January 2003	Astronaut Sally Ride made an appearance at the kick-off celebration of the new Challenger Center at SciTrek, which Bob Cassanova attended. Several days later SciTrek Director Lewis Massey and Bob Cassanova met to discuss the possibility of seminars and education programs for K-12 students.
Space Technology & Applications International Forum (STAIF) – 2003 Albuquerque, New Mexico	2-5 February 2003	Bob Cassanova chaired a session on Advanced Concepts for Colonization and presented a paper co-authored with Ron Turner and Pat Russell. Bob Cassanova was on the selection committee for the "best paper on space colonization," while Ron Turner attended the forum. The agenda included papers by several NIAC Fellows.
AIAA Space Colonization Technical Committee Albuquerque, New Mexico	February 2003	While attending the STAIF meeting, Bob Cassanova and Ron Turner also attended this meeting of the AIAA.
Office of the Biological & Physical Research Advisory Committee (OBPR) NASA Headquarters	13-14 February 2003	In order to stay informed of the latest OBPR plans, Pat Russell attended this meeting.
Simpson Middle School E. Cobb County, Georgia	24 February 2003	Bob Cassanova gave an invited seminar on the subject of "Visions of Aeronautics and Space" to 300 eighth-grade students and distributed NIAC posters to all the students and science teachers.
Cub Scout Pack Meeting Atlanta, Georgia	10 March 2003	Bob Cassanova gave an invited presentation on advanced concepts for space at this pack meeting consisting of 40 cub scouts and 15 parents which was sponsored by the Holy Innocence Episcopal Church.
National Space Grant Foundation Awards Arlington, Virginia	19 March 2003	Pat Russell attended the dinner meeting. Senator Lloyd Bentsen received an award. Gene Kranz was a speaker.

Space Elevator Briefing Washington, DC	21 March 2003	Pat Russell attended a Congressional briefing at the Rayburn House Office Building given by NIAC Fellow Brad Edwards, representing HighLift Systems on the Space Elevator concept. This event was sponsored by the House Aerospace Caucus, the National Space Society and the Space Transportation Association. Rep. Mollohan (D-WV) as well as about 13 House personal staff and 4 Senate staff attended.
Seminar for Atlanta Business Leaders Atlanta, Georgia	23 March 2003	Bob Cassanova gave a seminar to a group of 16 Atlanta business leaders. This multi-national group included accomplished leaders in business, scientific instruments, optics and medicine.
American Astronautical Society Symposium Greenbelt, Maryland	25-26 March 2003	Pat Russell attended the AAS 41st Goddard Memorial Symposium hosted at the Greenbelt Marriott.
National Space Education Workshop George Washington University	27 March 2003	Pat Russell and Ron Turner made contact with numerous speakers and attendees while attending this workshop and talked about NIAC. Sponsors included: NASA, USRA, GWU, Ohio University, the International Space University, the Arthur C. Clarke Institute, Embry Riddle University, the Society of Satellite Professionals, the Space Foundation, AIAA, AAS, ESU, Intelsat, Arianespace, General Dynamics, Loral, SIA and others.
Hang Glider Competition Kitty Hawk, North Carolina 	5 April 2003	Bob Cassanova participated as a panel judge for a hang glider competition. The gliders were constructed of paper.
The Jefferson Literary and Debating Society University of Virginia Charlottesville, Virginia	18 April 2003	Bob Cassanova gave an invited talk in Jefferson Hall at the University of Virginia. The talk was attended by Pat Russell and about 100 students and faculty.
Creekland Middle School Suwanee, Georgia	23 April 2003	Bob Cassanova gave an invited talk to students and teachers for the school's Career Day. The NIAC poster was handed out to everyone.
University of Oklahoma Oklahoma City, Oklahoma	29-30 April 2003	Bob Cassanova gave an invited seminar at the university.
Large Optics Workshop Boulder, Colorado	1-2 May 2003	Bob Cassanova gave an invited luncheon talk at this workshop, which was sponsored by NASA Headquarters Code S.

Preston Arkwright Elementary School Atlanta, Georgia	9 May 2003	Bob Cassanova was invited and participated in the school's Career Day activities. He gave a series of talks throughout the day to students (grades 3 - 5).
Georgia Society of Professional Engineers Meeting Atlanta, Georgia	12 May 2003	Bob Cassanova gave an invited talk at this meeting, which was attended by 37 people.
Revolutionary Aerospace Systems Concepts – Academic Linkage Forum 2003 Cocoa Beach, Florida	18-21 May 2003	An invited lecture was given by Pat Russell at this meeting. There were 10 teams of university students competing for recognition of their advanced space concept designs.
IEEE/AESS Meeting Ballston, Virginia	28 May 2003	Ron Turner was invited and gave an overview of NIAC at this meeting.
Product Development Managers Association (PDMA) Meeting Atlanta, GA	2 June 2003	Bob Cassanova gave an invited talk at this meeting, which was attended by 41 people.

NIAC Publicity

Discoveries and Breakthroughs Inside Science (DBIS) Program 2002 27 February 2002	NIAC Director Bob Cassanova and Robert Michelson of GTRI were interviewed for this TV program about the NIAC-funded Entomopter concept.
American Meteorological Society (AMS) News Release 21 February 2002	An article on Ross Hoffman's research studies was published entitled, "Can We Influence Global Weather – Some Scientists Say Theoretically Yes, Practically, Not Yet," which mentions the NIAC Web site.
www.popsci.com March 2002	"Robot Bugs Planned for Mars Invasion!" was the title of an article published about NIAC Fellows Anthony Colozza and Rob Michelson and their Entomopter concept study.
USRA Researcher Spring 2002	"The Space Elevator – Space Flight Without Rockets" was the title of the article published in this edition.
USRA Newsletter 5 April 2002	This Special Edition newsletter, distributed at the USRA Annual Meeting, contained an article about the Space Elevator concept.
Science News Online 25 May 2002	This article featured Anthony Colozza's Entomopter and quotes NIAC Director Bob Cassanova.
The Seattle Times June 2002	Eran Karmon interviewed Bob Cassanova for a newspaper article being written about the Space Elevator.
www.govexe.com 1 June 2002	An article written by Beth Dickey about NIAC entitled, "It Doesn't Take a Rocket Scientist" was published online.
BBC World Service Radio July 2002	Janet Williams interviewed Bob Cassanova in preparation of a program on the subject of Brad Edwards' Space Elevator concept.
Art Bell Production Tea July 2002	Kerry Nock was interviewed about his space tourism project.
www.beyond2000.com 8 July 2002	An article published about the concept entitled, "Stratospheric Balloon Constellation," which is under development by the Global Aerospace team contract with NIAC.
www.seattletimes.com 8 July 2002	"Brad Edwards dreams of an elevator stretching 62,000 miles into space" was the title of the article published that also mentions NIAC.
NEW SCIENTIST Volume 175, Issue 2353 27 July 2002	A six-page magazine article about Ross Hoffman's "Controlling the Global Weather" concept entitled "Raising a Storm," was written by Justin Mullins.
www.nationalpost.com August 2002	An article posted online about the Space Elevator after the Space Elevator Conference in August 2002.

The Canadian National Post August 2002	This newspaper cover story was published on the Space Elevator, Brad Edwards' concept study.
British Broadcasting Channel 1 August 2002	Broadcast about Hoffman's concept entitled, "Controlling the Global Weather."
www.news.bbc.co.uk 12 August 2002	Space Elevator article published.
www.space.com 19 August 2002	An article written by Leonard David entitled, "Going Up? Private Group Begins Work on Space Elevator," featuring Brad Edwards' concept and NIAC.
Liberty Radio - London, England 20 August 2002	Bob Cassanova was interviewed live via telephone by Alton Andrews on the subject of the Space Elevator project funded by NIAC.
Interstellar Transmission Radio Show 23 August 2002	A radio broadcast aired about Ross Hoffman's "Controlling the Global Weather" concept.
Biology and Physical Research Committee 30 August 2002	Lisa Guerra and Gary Martin (NASA HQ) gave a briefing to the Committee on the NeXT activities, including a specific mention of the M^2P^2 system and the Space Elevator concepts.
www.abcnews.com 24 September 2002	An article written by Amanda Onion entitled, "Taking on Mother Nature: Is Science Ready to Change the Weather?" was published about Hoffman's concept.
FOCUS Fall 2002	A magazine article about NIAC was published in this Italian magazine.
Cal Tech News Fall Issue 2002, Number 3	An article on Pankine of Global Aerospace and the balloon concepts that have been sponsored by NIAC.
Tech Topics Fall 2002	This Georgia Tech Alumni publication contained an article written about Rob Michelson and the Georgia Tech Research Institute's School of Aerospace Engineering and the Entomopter project currently funded by NIAC.
MAXIM October 2002	MAXIM IS WATCHING: "More proof we're taking over the universe: NASA named its new mega-money project after us" was the title of this magazine article, which mentions Webster Cash's NIAC-funded concept.
www.newscientist.com 10 October 2002	An article written by Bennett Davies is entitled, "Radio waves could construct buildings in space," about Narayanan Komerath's Phase I concept.
www.sensormag.com October 2002	An online story regarding GEMS is featured about John Manobianco's GEMS concept.
NASA Tech Brief October 2002	John Manobianco's phase I project, GEMS, is referenced.
www.space.com 30 October 2002	An article written by Robert Myers entitled, "Antimatter Power: Reaching for Deep Space" featured Steven Howe's NIAC-funded concept.

Caltech News Volume 36, Number 3 – 2002	"Up, Up and Away" was the title of an article written by Michael Rogers, which mentions Dr. Pankine of Global Aerospace Corporation.
The Dallas Morning News 18 November 2002	"Trying to tame the weather," was an article written by Lian Unrau (special contributor) about Hoffman's research on his NIAC concept.
www.space.com 20 November 2002	Article written by Leonard David entitled, "Space Elevator Upstarts Settle Down to Business."
WCLK Radio – Clark Atlanta University 22 November 2002	The BBC interviewed Bob Cassanova about NIAC.
www.space.com 5 November 2002	An article included a quote from NIAC Phase I investigator Jordin Kare was written by David Leonard entitled, "Beamed Propulsion: Out of the Lab into Space."
www.space.com 6 November 2002	An article written by Robert Myers about Hodgson's project entitled, "The Chameleon Spacesuit: Light-weight Life-saver."
DISCOVER 7 November 2002	Writer William Weed contacted Bob Cassanova concerning an article being written for this magazine on interstellar travel in which some of the NIAC-sponsored concepts will be included.
NATURE 7 November 2002	A magazine article describing the NIAC Fellows Meeting that was held at NIAC HQ October 23-24, written by Tony Reichhardt entitled, "Out of this world."
www.space.com 13 November 2002	"Robotic Balloon Probe Could Pierce Venus' Deadly Clouds," was the title of an article published describing the NIAC Phase I DARE concept being developed by the Global Aerospace Corporation, written by Robert Myers.
DER SPIEGEL 18 November 2002	Tobias Huerter interviewed Bob Cassanova for an article in this German magazine publication to include the NIAC-funded Space Elevator project, and is also accessible online at www.spiegel.de/spiegel/0,1518,223139,00.html.
The Dallas Morning News 18 November 2002	Ross Hoffman's concept on changing the global weather was featured in this article by Lian Unrau entitled, "Trying to tame the weather."
www.washingtonpost.com 18 November 2002	An article entitled, "A Trip as Far Away as Space-Time Will Allow," was published on page A12, written by Staff Writer, Guy Gugliotta, about interstellar travel and NIAC Phase II Fellow Ralph McNutt.
United Press International 27 November 2002	Bob Cassanova was contacted by Phil Berardelli of United Press during preparation of an article about the Tailored Force Fields concept being developed by Narayanan Komerath, to be published at a future date.
www.villagevoice.com 6 December 2002	Erik Baard wrote an article featuring NIAC and Marchese's BlackLight Rocket project entitled "Hydrino Theorist Gets Nod From NASA-Funded Investigation Eureka?" This same journalist wrote about the project in www.wired.com.
The Daily Register 6 December 2002	Nilanjan Sarkar and Craig Smith's robot project was featured in an article that mentioned NIAC entitled, "Designing a robot that can sense human emotion."

www.nanotech-now.com 15 December 2002	Published interview with Constantinos Marvroidis about his "Protein based nano-machines for space applications" project [see Rutgers Bio-Nano Robotics Web site also].
www.vanderbilt.edu 16 December 2002	An article published entitled, "Designing A Robot That Can Sense Human Emotion."
www.sciencedaily.com 16 December 2002	An article on Sarkar's concept entitled, "Designing A Robot That Can Sense Human Emotion," which mentioned NIAC.
www.eurekalert.org 16 December 2002	Sarkar's concept featured in the article entitled, "Designing A Robot That Can Sense Human Emotion."
www.healthscout.com 17 December 2002	Article about Sarkar's robot project entitled, "Robot Says: I Shrink I am, I Shrink I Am" – Scientists trying to create robots that sense human emotions.
www.washtimes.com 17 December 2002	"Research seeks emotion-seeking robot," an article written by Scott R. Burnell about Sarkar's robot concept.
www.beyond2000.com 17 December 2002	Another article featuring Sarkar and his robot concept entitled, "Metal as Anything."
www.news.bbc.co.uk 19 December 2002	"Robot helper knows how you feel" is the title of another article written about Sarkar's concept.
www.cyberpunks.org 20 December 2002	"Robot helper knows how you feel" was published on this Web site, featuring Sarkar's robot project.
BBC Radio 18 December 2002	On November 16, 2002, Bob Cassanova participated in a 45-minute interview for preparation of the "Ahead of Their Time" documentary about visionary and maverick scientists, which was broadcast in Britain on 18 December 2002. The documentary will be picked up by the BBC Worldwide Network later on.
The Atlanta Journal-Constitution 26 December 2002	A cover-story article, "A launchpad for dreams – NASA offshoot in Atlanta takes sci-fi seriously," featured interviews with NIAC Fellow Robert Winglee and NASA's Murray Hirschbein.
www.nashvillecitypaper.com 27 December 2002	An article entitled, "Robotic evaluation? Robot could sense human psychological state," written by Colleen Creamer featured Sarkar's robot concept.
The Charlotte Observer 27 December 2002	Newspaper publication written by Mike Toner (Cox Newspapers) entitled, "NASA puts money into dreams," featured NIAC HQ.
Aerospace America December 2002	Brief descriptions of several NIAC-sponsored concepts (Kammash, Winglee, Rice, Edwards, Komerath) were included in this magazine article entitled, "2002 Air/Space: The Year in Review."
FOCUS	Another article published in this Italian magazine on Edwards' Space Elevator, written by Andrea Parlangeli.
MSNBC December 2002	The Space Elevator was featured in an article.
www.space.com December 2002	Featured another article on the Space Elevator.

www.loe.org 2002	National Public Radio article published in Living on Earth broadcast aired by Jennifer Chu's Note on Emerging Science, entitled "Emerging Sciences Note/Sensitive Robots," mentions Vanderbilt's research study on Sarkar's robot concept.
Georgia Tech Alumni Winter Issue	This magazine issue featured a story about the NASA Institute for Advanced Concepts (NIAC).
A Vision of Future Space Transportation – A Visual Guide to Future Spacecraft Concepts Apogee Books, 2003	The M^2P^2 Plasma Sail, a NIAC Phase II concept, was described in this book written by Tim McElyea. It mentions the work of Robert Winglee at the University of Washington. It also acknowledges NASA's funding, but does not specifically mention NIAC.
www.xtio.com January 2003	A foreign publication featured an article on Alexey Pankine's DARE project.
www.supercable.es January 2003	A foreign publication about Alexey Pankine's DARE concept.
AD ASTRA January 2003	The Space Elevator was featured as the cover story in this magazine.
www.wired.com 1 January 2003	An article written by Louise Knapp featured Nilanjan Sarkar's NIAC-funded robot project entitled, "Feeling Blue? This Robot Knows It."
The Christian Science Monitor 2 January 2003	"Tinkering with clouds – Researchers say evolving technologies could allow manipulation of major weather patterns – but should humans tamper?" was the title of an article written by Peter N. Spotts, on Ross Hoffman's funded concept.
www.technologyreview.com 3 January 2003	Article, "Touchy-Feely Robot Senses Emotion," taken from www.abcnews.com featured Sarkar's robot concept funded by NIAC.
www.abcnews.com 3 January 2003	Another published article about Sarkar's robot project entitled, "Automatons Acting on Attitudes," was written by Paul Eng.
www.vanderbilthustler.com 10 January 2003	This publication featured a short write-up on Sarkar's robot concept in an article entitled, "Two Vanderbilt professors team up to revolutionize robot capabilities."
www.admiroutes.asso.fr 18 January 2003	A French article written about Sarkar's NIAC-funded concept on robots entitled, "Le robot martien Beagle2 et les autres."
ROBOTWARS	This United Kingdom publication featured an article about Dr. Alexey A. Pankine's DARE concept being developed by Global Aerospace Corporation.
TNT WEEKLY February 2003	NIAC Fellow Constantinos (Dinos) Mavroidis' Final Report was cited in the article, "Nanomachine work starts in earnest."
www.cmp-cientifica.com February 2003	Phase I Fellow Dinos Mavroidis was interviewed by the online portal, "Nanotechnology Now."
ATLANTA February 2003 Volume 42, Number 11	This 10-page magazine article, "Space Elevators, Chameleon and Robotic Coke Cans," was written after author Steve Walburn attended the NIAC Fellows Meeting in October 2002 and interviewed a number of NIAC Fellows and NASA employees for the article.

www.wired.com 4 February 2003	Steve Kettmann's "To the Moon in a Space Elevator" article was published featuring Brad Edwards' Space Elevator concept.
The West Australian 13 February 2003	An article was included by Dawn Gibson on the Space Elevator.
www.nature.com 24 February 2003	NIAC Fellow Carlo Montemagno was mentioned in this article about the UCLA Institute for Cell Mimetic Space Exploration, which is funded mainly by a 10-year $30M grant from NASA.
WIRED March 2003	NIAC Fellow Brad Edwards' NIAC-funded Space Elevator concept was a featured story in this magazine.
www.nanotech-now.com March 2003	An interview published on the online portal Nanotechnology Now featured an interview with NIAC Fellow Constantinos Mavroidis.
www.asgsb.indstate.edu March 2003	The American Society for Gravitational and Space Biology (ASGSB) Newsletter included a short report on the ASGB\SB meeting where a number of NIAC Fellows presented papers. Candid photos are included in the publication.
US Joint Forces Command (USJFCOM) Newsletter March 2003 - Issue 3	Space Application Experimentation Cell (SAEC).
www.abcnews.com March 2003	Another article published about Sarkar's concept.
TNT WEEKLY March 2003	Mavroidis' NIAC report was cited in an article entitled, "Nanomachine work starts in earnest."
IEEE Transactions on Computers Volume 52, No. 4 April 2003	"What designers of bus and network architectures should know about hypercubes," by L.E. LaForge, K.F. Korver and M.S. Fadali.
www.wired.com April 2003 Issue	Kevin Kelleher wrote an article entitled, "Starlight Express" featuring Brad Edwards' Space Elevator.
www.kabayanonline.com May 2003	A Dutch article about Nilanjan Sarkar's concept study on robots entitled, "Robot, nakaiintinki ng emosyon."
www.space.com 9 May 2003	After he attended the Large Optics in Space Workshop, Leonard David wrote this article entitled "Eye on the Future: NASA Explores Innovative Space Telescope Technologies." Bob Cassanova, Harley Thronson, John Mather, Rud Moe and Michael Kaplan are quoted in the article.
FORBES 12 May 2003	An article in the Entrepreneur's section of this magazine appeared about Elon Musk and about NIAC and some of its funded concepts (Space Elevator, ALPH, Astrotels, Programmable Plants) entitled, "Way Out There."
Raleigh News 16 May 2003	Published an article based on Associated Press writer Mark Niesse's article about NIAC.
Access North Georgia 17 May 2003	Published an article based on Associated Press writer Mark Niesse's article about NIAC.
Times Daily 17 May 2003	Published an article based on Associated Press writer Mark Niesse's article about NIAC.

Sarasota Herald-Tribune 17 May 2003	Published an article based on Associated Press writer Mark Niesse's article about NIAC.
Tuscaloosa News 17 May 2003	Published an article based on Associated Press writer Mark Niesse's article about NIAC.
Montgomery Independent 17 May 2003	Published an article based on Associated Press writer Mark Niesse's article about NIAC.
Charleston Post Courier 18 May 2003	Published an article based on Associated Press writer Mark Niesse's article about NIAC.
Everett Herald 25 May 2003	Published an article based on Associated Press writer Mark Niesse's article about NIAC.
Knoxville News Sentinel 25 May 2003	Published an article based on Associated Press writer Mark Niesse's article about NIAC.
Chicago Daily Herald 26 May 2003	Published an article based on Associated Press writer Mark Niesse's article about NIAC.
The Orange County Register 26 May 2003	Bob Cassanova was quoted in an article about Brad Edwards' Space Elevator concept entitled, "NASA considers elevator to space." Associated Press staff writers Mark Niesse, Ron Harris and Amick Jesdanun contributed to the article.
Seattle Post Intelligencer 26 May 2003	Published an article based on Associated Press writer Mark Niesse's article about NIAC.
Seattle Daily Journal of Commerce 27 May 2003	Published an article based on Associated Press writer Mark Niesse's article about NIAC.
The Orange County Register 29 May 2003	Published an article based on Associated Press writer Mark Niesse's article about NIAC.
www.nature.com 29 May 2003	An article written by Tony Reichhardt entitled, "NASA aims high with orbital transport system hi-tech ropes may replace rocket boosters," about an advanced concept using tethers for space transportation. The article includes a description of the tether system developed by NIAC Phase II Fellow Robert Hoyt of Tethers Unlimited.
www.nature.com 29 May 2003	This magazine published an article about NIAC Phase II Fellow Robert Hoyt, who recently received a contract from NASA to continue his development of the rotating momentum exchange tether that was originally funded by NIAC.
San Antonio Express 31 May 2003	Published an article based on Associated Press writer Mark Niesse's article about NIAC.

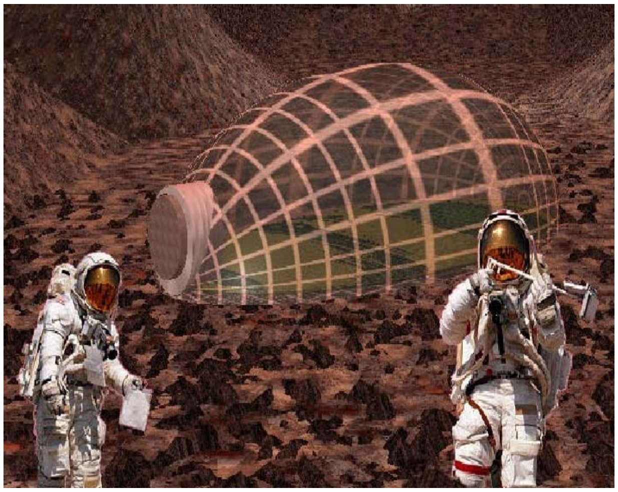
The Washington Post 7 June 2003	An article about NIAC written by Mark Niesse appeared in the Sunday early edition (7th), complete with a photograph of NIAC Director Bob Cassanova and the NIAC coffee mug. USRA and ANSER were mentioned and Murray Hirschbein was quoted. The following day (8th), the paper published an article about the Space Elevator entitled, "Sky Is Not the Limit for These Researchers: NASA Unit is Willing to Take Far-Out Concepts and Turn Them into Reality."
www.space.com 18 June 2003	An article entitled "Tether Technology: A New Spin on Space Propulsion," written by Leonard David was published. In the article, NIAC-funded Robert Hoyt is interviewed and his work discussed. No mention was made, however, that he was originally funded through NIAC Phase I and II awards. Additionally, Code S In-Space Propulsion (ISP) Program is discussed.

Call for Proposals CP 01-01 Phase II Award Abstracts

PENELOPE BOSTON, Complex Systems Research, Inc.

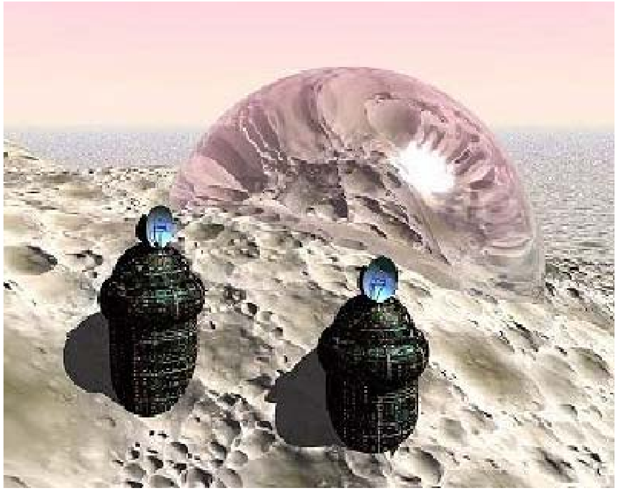
System Feasibility Demonstrations of Caves and Subsurface Constructs for Mars Habitation and Scientific Exploration

Natural subsurface cavities and subsurface constructs present the most mission effective habitat alternative for future human missions in the high-radiation environment of Mars. Additionally, lava tubes, other caves, cavities and canyon overhangs are sites of intense scientific interest. They offer easier subsurface access for direct exploration and drilling and may provide extractable minerals, gases and ices. Expanding our NIAC Phase I feasibility assessment of a subsurface Mars mission architecture for the scientific exploration and human habitation of caves and subsurface facilities, we propose a two-part viability demonstration of selected technologies combined into a functioning system. This system can be integrated into both robotic precursors and human missions.



Transparent bubble over the cave habitat below provides light. The ISRU units are busily supplying necessary volatiles to the habitat. Such direct input of photons into a habitat or plant growth facility will depend upon the successful development of radiation-shielding transparent materials.

Part I (months 1-11) involves construction of an in-cave test habitat with associated life-support and auxiliary systems for use with rodents and plants. This will culminate in an extended duration "Mouse Mission to Inner Space" in an Earth lava tube representative of those visible in recent MOC images of Mars. This will provide proof-of-concept for organism responses to system components and synergistic behavior. Additionally, it will lay the foundation for viability testing of non-human Earth organisms in situ on Mars – an indispensable precursor to human missions not currently recognized nor planned for within NASA.

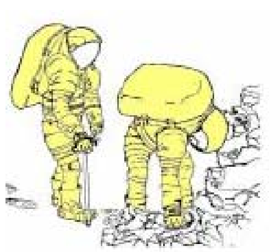


Photos courtesy of R.D. Frederick

Part II (months 12-23) expands on design, engineering, and scientific lessons learned during Part I to construct a human-scale inflatable in-cave habitat with associated life-support and auxiliary systems. This will culminate in an extended duration "Speleonaut Mission to Inner Space" with a human crew (2) living and performing scientific work in a pristine biologically-sensitive Earth cave representative of possible Martian subsurface life detection sites. This proposal describes a revolutionary system comprising a merger of unique technologies that will enable future NASA missions by solving human survival and exploration problems in the hostile Martian environment.

EDWARD HODGSON, Hamilton Sundstrand Space Systems International, Inc.
A Chameleon Suit to Liberate Human Exploration of Space Environments

The direct operations of humans in space environments must become commonplace if the goals of the HEDS (Human Exploration and Development of Space) Enterprise are to be achieved. This transition from rare and expensive Extra Vehicular Activity (EVA) to normal and expected "going outside" can be enabled by a system concept in which the walls of the protective clothing work with the space environment to provide required life-support functions. This will liberate future space workers and explorers from reliance on cumbersome mechanisms and consumable resources currently used for life-support. It will be achieved by providing the ability to tune the heat transmission characteristics of the outer garment and by incorporating other life-support functions in the suit wall.



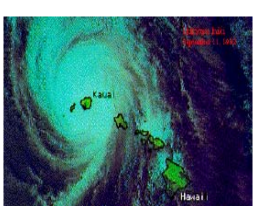
Maximum radiated heat load from combined PLSS and pressurized suit area.

EVA is the essential element for real human space exploration.

This will allow heat flow from the body to be modulated to match varying metabolic activity levels in any environment, and use of the body's surface area to optimize EVA life-support processes. As a result, the system can be made lighter, more robust and less reliant on consumable resources. This study is proposed to evaluate the broader implications of the "Chameleon Suit" system concept studied under our Phase I program. Our Phase I study showed the benefits and feasibility of applying emerging technologies to enable heat rejection from the suit surface. Under Phase II, we will study the logical extension of this concept to revolutionize all aspects of EVA life-support. By applying emerging technology for microelectronics, active polymers and biomimetic chemical processes, we will seek to substantially eliminate the bulky life-support backpack that dominates current EVA systems and truly liberate human explorers for future NASA missions.

ROSS HOFFMAN, Atmospheric and Environmental Research, Inc.
Controlling the Global Weather

The key factor enabling control of the weather is that the atmosphere is sensitive to small perturbations. That is, it is the very instability of the atmosphere's dynamics that makes global weather control a possibility. Certainly, realistic numerical weather prediction models are very sensitive to initial conditions. Extreme sensitivity to initial conditions suggests that small perturbations to the atmosphere may effectively control the evolution of the atmosphere, if the atmosphere is observed and modeled sufficiently well. The architecture of a system to control the global atmosphere and the components of such a system are described. A feedback control system similar to many used in the industrial setting is envisioned. Although the weather controller is extremely complex, the realization of the required technology is plausible in the time range of several decades.

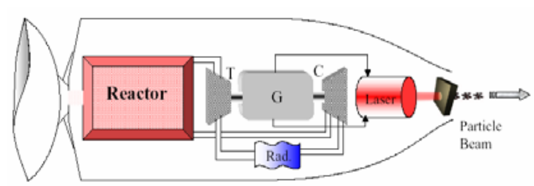


Arthur C. Clark on *weather control*

"It had not been easy to persuade the surviving superpowers to relinquish their orbital fortresses and to hand them over to the Global Weather Authority, in what was – if the metaphor could be stretched that far – the last and most dramatic example of beating swords into plowshares. Now the lasers that had once threatened mankind directed their beams into carefully selected portions of the atmosphere, or onto heat-absorbing target areas in remote regions of the Earth. The energy they contained was trifling compared with that of the smallest storm; but so is the energy of the falling stone that triggers an avalanche, or the single neutron that starts a chain reaction."

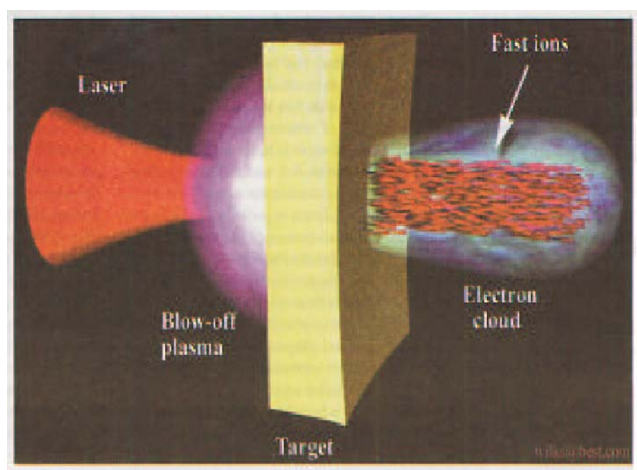
A critical concern is the feasibility of the required perturbations. The Phase I research demonstrated a proof-of-concept approach for calculating the perturbations required to move a hurricane. Altering the track of a hurricane is a clear goal of global weather control. The Phase II research will refine this approach, making the results more realistic, and translate the required perturbations into requirements for a fleet of solar reflectors in orbits close to the plane of the terminator, as the physical controller. These requirements, in turn, will be used to estimate the area, and hence the mass, which must be stationed in orbit. In addition to being directly relevant to the call for revolutionary concepts which expand our vision of the future, many of the technologies involved in our proposed system are areas of interest to NASA that will be developed for other reasons. These include atmospheric science, remote sensing, aviation systems, fleets of low-cost satellites, solar power satellites, advanced computational systems, mega-systems engineering, and more.

TERRY KAMMASH, University of Michigan
Ultrafast Laser-Driven Plasma for Space Propulsion



Laser-Accelerated Plasma Propulsion Systems (LAPPS)

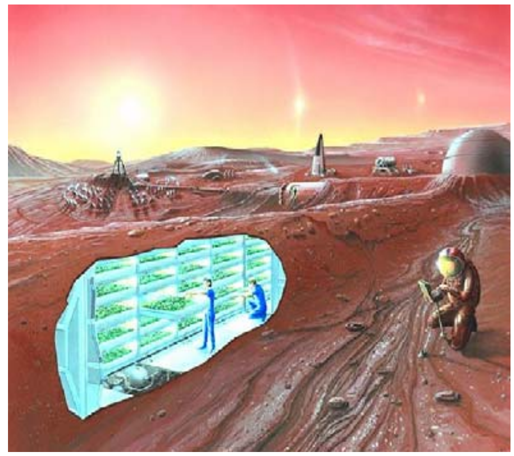
Analytical and experimental investigations based on the findings of the Phase I study are proposed to accelerate the development of "LAPPS," the (ultra-fast) Laser Accelerated Plasma Propulsion System that could meet NASA's needs for space exploration in the next few decades. Preliminary examination of the underlying physics reveals that intense lasers are capable of accelerating charged particles to relativistic energies when focused on small focal spots in very thin targets. Experiments at the University of Michigan and other world-wide laboratories have demonstrated dramatically the production of nearly collimated beams of protons at mean energies of several MeV when lasers of intensities of $\geq 10^{18}$ W/cm^2, at about one micron wavelengths, are made to impinge on focal spots of several microns in radius in solid targets with few microns thickness. When viewed from the propulsion standpoint, these present-day experiments are capable of producing specific impulses that exceed million seconds albeit are very modest thrusts. If employed as propulsion devices, they can achieve interstellar fly-by robotic missions in a human's lifetime, but they fail to do manned interplanetary missions in acceptable times due to the smallness of thrust that results in a sizable imbalance with the specific impulse as required for optimum travel time. This Phase II proposal is aimed at enhancing the thrust that can be generated by LAPPS without seriously degrading the specified impulse. This can be accomplished in several ways:1) by increasing the number of particles in the beam, (2) by increasing the rep rate, and 3) by increasing the velocity of the ejected charged particles. The first approach will be tested by increasing the size of the focal spot while maintaining the same intensity; the second will be addressed by achieving kilohertz rep rates on the target side to match that on the laser side which has already been achieved; and the last by increasing the power of the laser. The current laser at the University of Michigan delivers 10 TW, but is expected to be upgraded to 100 TW and a petawatt in the time frame of this proposal so that these issues can be addressed. Jet targets, rather than solid ones, will also be investigated in order to establish their feasibility for large rep rates that match those of the laser.



TERRI LOMAX, Oregon State University

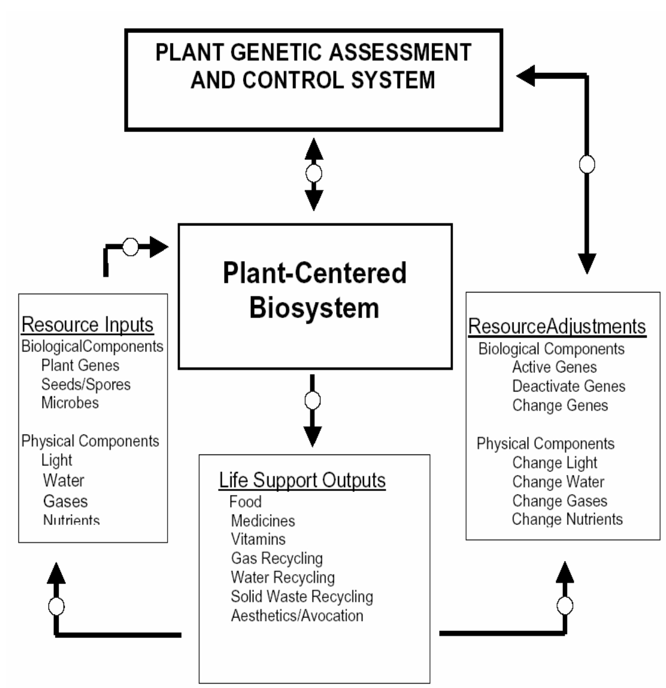
Developing a Plant Genetic Assessment and Control System for Space Environments

Plants will play an essential role in providing life-support for any long-term space exploration or habitation. This proposal describes an adaptable system that measures the response of plants to any unique space condition and then optimizes plant performance under those conditions. The proposed architecture is based on a unique combination of systems including the rapid advances in the field of plant genomics, micro array technology for measuring gene expression, bioinformatics, and physiological monitoring. The resulting flexible module for monitoring and optimizing plant responses will play an integral, cross-cutting role in achieving the goals of several NASA Strategic Enterprises including Human Exploration and Development of Space, Biological and Physical Research, and Space Science.



Role of Plant Genetic Assessment and Control

In Phase II, we will assess the capacity for applying the results from future plant functional genomics projects to those plant species most likely to be used in space environments. Eventually, it will be possible to use this architecture to optimize the performance of any plant in any space environment. In addition to allowing the effective control of environmental parameters for enhanced plant productivity and other life support functions, the module will also allow the selection or engineering of plants optimized to thrive in specific space environments. Future additions to the architecture will include the technical advances necessary for remote collection and evaluation of data. In Phase II, we will study the major feasibility issues associated with cost, performance, development time, and key technology issues for developing a Plant Genetic Assessment and Control System to provide a sound basis for NASA to consider implementation of the concept for future missions. The proposed concept will advance NASA's mission of human exploration, use, and development of space in the near- and mid-term on the International Space Station and in the far-term for longer duration missions and eventual space habitation.

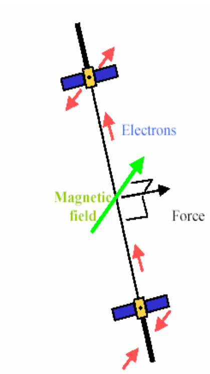


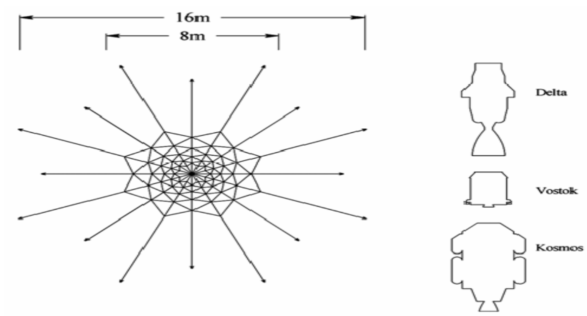
Role of Plant Genetic Assessment and Control System in a Plant Centered Life Support System. Circles show control joints.

Call for Proposals CP 01-02 Phase I Award Abstracts

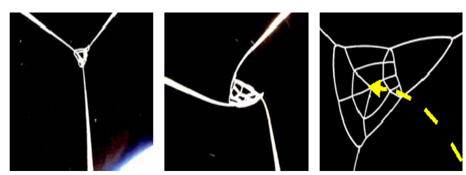
JOSEPH CARROLL
Tether Applications, Inc.
Space Transport Developing using Orbital Debris

Orbital debris is a minor annoyance for many space programs, and a major issue for others like the ISS. We propose to investigate a development scenario and architecture that convert orbital debris into both an opportunity and also a resource. The basic concept is to use a small fleet of agile electro-dynamic maneuvering vehicles to rendezvous with and capture debris objects. The vehicles can de-boost smaller objects into short-lived orbits or controlled re-entry trajectories. They would boost more massive objects into low-risk storage orbits intended to allow easy recovery later. In this scenario, debris provides an opportunity to demonstrate and operationally use tethered capture capabilities, without risking more expensive space assets. This process allows extensive use and refinement of targeting sensors and rendezvous and capture strategies that are relevant to more ambitious tether transport facilities such as HASTOL and MXER. It also provides a key resource for such facilities, in that an ability to adjust the orbits of most of the >1,000 tons of orbital debris now in low Earth orbit allows this debris mass to be accumulated and used as the main ballast mass for a few ambitious tether transport facilities. Large orbital debris objects tend to cluster in a few particularly useful inclinations like Sun-synchronous orbit, so debris-ballasted tether facilities can serve transport needs to useful inclinations. Our Phase I effort will focus on characterizing the debris population, exploring capture concepts suite to that population, quantifying guidance issues, and estimating the throughput of a straw man system.





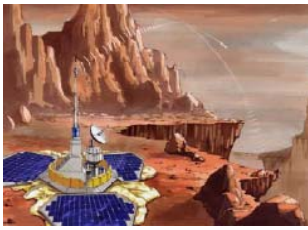
~100-gram thrown-web, to scale with spent stages



Net spin-up viewed from support, with desired payload trajectory shown in frame 3.

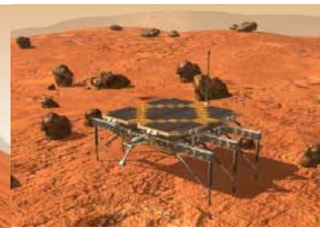
A. C. CHARANIA
SpaceWorks Engineering, Inc.
Networks on the Edge of Forever: Meteor Burst Communication Networks on Mars

The envisioned future may include continuous operating outposts and networks on other worlds supporting human and robotic exploration. Given this possibility, a feasibility analysis is proposed for a communications architecture based upon reflection of ion trails from meteors in planetary atmospheres. Such Meteor Burst (MB) communication systems consist of semi-continuous, low bandwidth networks possessing both long distance capability (hundred of kilometers) and lower susceptibility to atmospheric perturbations. Meteor Communications Corporation (MCC) and its personnel (developers and patent holders of commercial terrestrial MB systems) are associated as technical partners for this examination. A proposed architecture on the Martian surface is presented. In order to facilitate global communication, various high-power nodes are scattered throughout the planet. These act as nerve centers that can

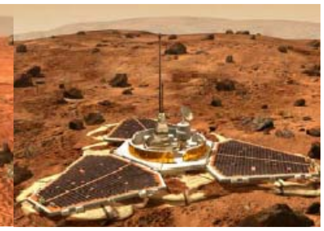


A conceptual illustration of the Meteor Burst Telecommunication Lander Platform on Mars.

A conceptual rendering of the Meteor Burst Telecommunication Human Platform on Mars.



A conceptual rendering of the Meteor Burst Telecommunication Insect Robot Platform on Mars.



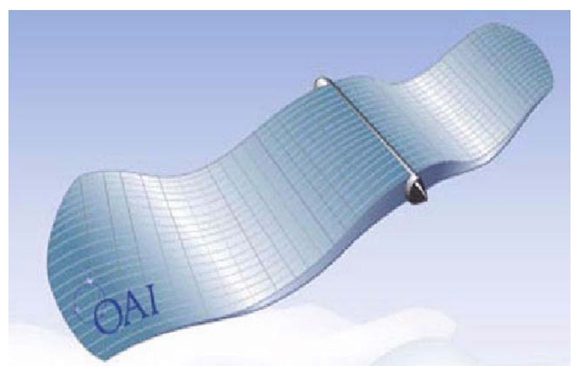
A conceptual rendering of the Meteor Burst Lander Platform on Mars.

communicate either directly with Earth or relay information to orbiting satellites. Remote terminals can be placed on various systems: autonomous robots, weather stations, human transport craft, and crewed bases. The work plan proceeds with analyses of state-of-the-art technical capabilities, development of archetype systems on Mars, examination of the use in space of such architectures in the rest of solar system besides Mars, and technology road-mapping activities.

ANTHONY COLOZZA
Ohio Aerospace Institute

Solid State Aircraft

A revolutionary system type of unmanned aircraft may now be feasible due to recent advances in polymers, photovoltaics and batteries. This aircraft is a “solid state” aircraft, with no conventional moving parts. Airfoil, propulsion, energy storage and control are combined in an integrated structure for the first time.



The most innovative aspect of this concept is the use of an ionic polymeric-metal composite (IPMC) as the source of control and propulsion. This material has the unique capability of deforming in an electric field like an artificial muscle, and returning to its original shape when the field is removed. Combining the IPMC with emerging thin-film batteries and thin-film photovoltaics provides both energy source and storage in the same structure.

Combining the unique characteristics of the materials enables flapping motion of the wing to be utilized as the main propulsion. With a flight profile similar to a hawk or eagle, the Solid State Aircraft will be able to soar for long periods of time and utilize flapping to regain lost altitude.

Recent discoveries and developments in these materials have indicated that this concept, on a preliminary level, may provide a robust advanced aeronautical architecture suitable for both terrestrial and planetary missions.

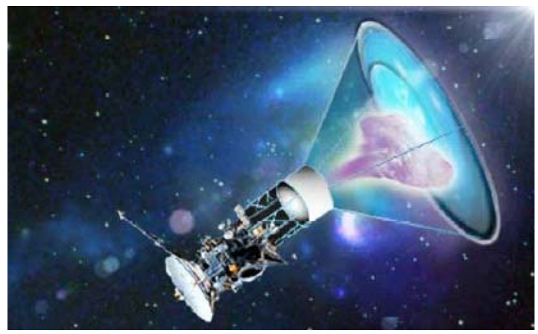
Combining and building on the research for these materials and on flapping wing aerodynamics, we have organized a collaborative team to investigate the integration and application of these technologies for a revolutionary aeronautical system.

STEVEN HOWE

Hbar Technologies, LLC

Antimatter Driven Sail for Deep Space Missions

Space is vast. Over the next few decades, humanity will strive to send probes farther and farther into space to establish long baselines for interferometry, to visit the Kuiper Belt, to identify the heliopause, or to map the Oort cloud. In order to solve many of the mysteries of the universe or to explore the solar system and beyond, one single technology must be developed – high performance propulsion. In essence, future missions to deep space will require specific impulses greater than 20,000 seconds in order to accomplish the mission within the career lifetime of an individual. Only two technologies available to mankind offer such performance – fusion and antimatter. Fusion has proven unattainable despite forty years of research and billions of dollars. Antimatter, alternatively, reacts 100% of the time in a well described manner. Development of a suitable propulsion system, however, based on antimatter has yet to be shown.

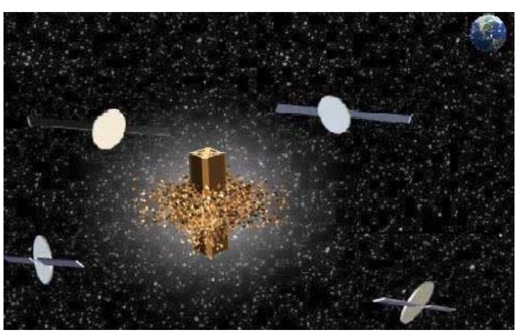


We propose to develop such a system. We will design a very straightforward system that will produce a variable specific-impulse with a maximum of near one million seconds. The concept is one that can be throttled, that can be steered, and that can be demonstrated within the next two years. We will identify the components of the system architecture that will be needed to perform a mission to the Kuiper Belt. In Phase I, we will also design a series of three experiments that will validate the concept and can be completed in Phase II using the Low Energy Antiproton Production facility.

NARAYANAN KOMERATH

School of Aerospace Engineering, Georgia Institute of Technology

Tailored Force Fields for Space-Based Construction



Conceptual drawing of a large radiation shield being formed using radio waves from pulverized asteroidal material. Earth is shown much larger than it would be seen from the Near-Earth Object region at the Earth-Sun L5.

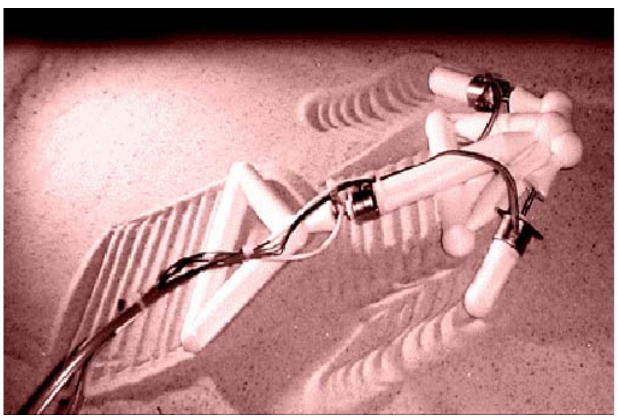
Potential fields can be used to assemble and construct solid structures over a wide range of size scales. This proposal is to start planning for using such force fields to build large, massive structures in space using extraterrestrial materials. The development of a comprehensive space-based economy is being recognized as the best way to achieve NASA's HEDS goals. A fundamental obstacle to building human settlements in space is the construction of the massive outer radiation shield. Human labor in space is prohibitively dangerous and costly for this mission. A unique set of experiments by our team has shown that by tailoring potential fields, large numbers of objects can be moved into desired positions and desired shapes can be constructed in reduced-gravity environments. This idea holds promise for several types of force fields suitable for automated construction at levels ranging from micrometer-scale discs and fibers to kilometer-scale habitats. Results from microgravity flight experiments at the 10^{-1} m level prove the basic theory. A concept for the 10^3 m scale using radio waves holds promise at the 50-year horizon. Calculations show that in the 15-30 year time frame, a 2km diameter radiation shield can be built at the Earth-Moon L2 Lagrangian point using lunar materials. The project architecture is aligned with proposals for various other elements of a space-based economy, bringing project cost well within reason. The project will focus on the issue of building the infrastructure of a space-based economy using electromagnetic and acoustic fields. In Phase I, the sample problem of the 1km-radius cylinder will be taken through detailed system and architecture feasibility analysis. The idea of pulverizing carbonaceous asteroids and reconstituting a spaceship structure from pulverized material at the Earth-Sun L5 point will be taken through architecture definition. Phase II will refine the mission plans further.

HOD LIPSON

Cornell University

Autonomous Self-Extending Machines for Accelerating Space Exploration

The rate at which we explore planets is tightly linked with the rate at which we are able to successfully complete robot deployment cycles. Judging from past experiences of Mars and lunar explorations, the design-fabricate-test-deploy cycle takes an order of a few years to complete at least. The approach advocated here shifts the focus from designing and launching the ultimately capable and robust robot, to launching a fabrication system that can fabricate and recycle task-specific robots in the field, as well as extend its own capabilities. In this vision, a self-contained fabrication facility is launched with initial material and component stock. Tested blueprints are transmitted subsequently for fabrication on site, as appropriate to exploration state and findings. Materials and components recycled from the original spacecraft, unused robots and in-situ resources of energy and material are used to construct newer machines as required. The focus of this proposal is on the architecture of a 100% automatic, self-contained and versatile fabrication process, capable of autonomously producing an entire working machine with no human intervention. This proposal is well grounded in physics of new multi-functional materials and free-form fabrication, yet the focus on fully autonomous fabrication of complete systems is a uniquely new and enabling challenge that has not been addressed before. This phase will deliver two parts: (a) architecture of a fully autonomous deployable self-extending machine, along with a comprehensive study of required functionalities and candidate materials and components, and (b) an evaluation of architecture through a limited concept implementation. The goal is to allow an informed assessment of the merits of this approach, and decision as to pursuing a second phase of investigation validating fully autonomous fabrication of complete working robots involving actuation, sensing and logic. This research will help NASA achieve its goal of completing missions more frequently, less expensively, and with greater flexibility.

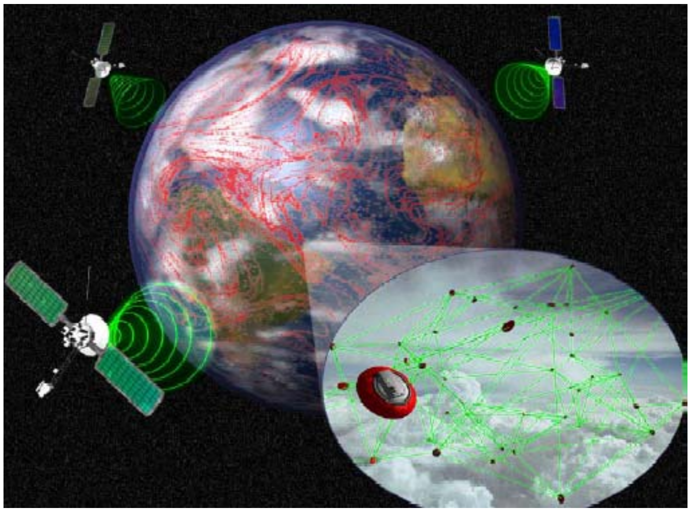


JOHN MANOBIANCO

ENSCO, Inc.

Global Environmental MEMS Sensors: A Revolutionary Observing System for the 21^{st} Century

Technological advancements in MicroElectroMechanical Systems (MEMS) have inspired ENSCO, Inc. to propose a revolutionary observing system known as Global Environmental MEMS Sensors (GEMS). The GEMS concept features *in situ*, micron-scale airborne probes that can measure atmospheric variables over all regions of the Earth with unprecedented spatial and temporal resolution. Environmental observations from a GEMS network have the potential to provide a quantum leap in our understanding of the Earth's atmosphere and improve weather forecast accuracy well beyond current capability. Our proposal responds directly to three of the NIAC grand challenges in



Conceptualization of GEMS, illustrating both a global and local distribution of probes, with communications and networking between probes and data collectors.

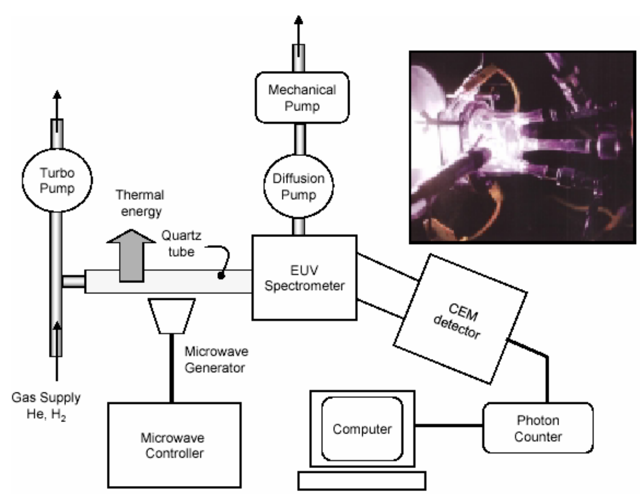
aeronautics and space and several NASA Earth Science Enterprise initiatives. Resulting improvements in forecast accuracy would translate directly into cost benefits for weather-sensitive space launch and aviation industries, and mitigate the risk factors associated with life-threatening weather phenomena such as hurricanes, floods, tornadoes and severe storms.

Assessment of the optimum probe design and deployment requires an interdisciplinary collaboration to examine complex trade-off issues such as the number of probes required in the network, development and manufacturing costs, and the impact of probe observations on forecast accuracy. We propose to explore these trade-offs within the framework of a design simulation cycle, which will allow us to validate the viability of GEMS and define the major feasibility issues for the meteorological and MEMS disciplines necessary for system design and development. ENSCO has assembled a team consisting of personnel with extensive weather expertise and a world-renowned MEMS consultant from the University of California-Berkeley. We will use observing system simulation experiments to explore issues relating to the deployment and dispersion of probes as well as the impact of probe data on regional meteorological forecasts. Our consultant will provide baseline parameters and realistic assessments/projections of MEMS technological progress to achieve probes on the order of 100 μm in size.

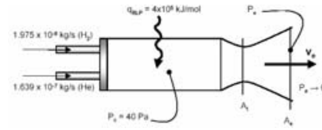
ANTHONY MARCHESE

Rowan University

The Black Light Rocket Engine



This proposal describes a Phase I feasibility study aimed at assessing the potential of Black Light Process technology toward the development of high thrust, high specific impulse space propulsion systems. The Black Light Process is a potentially revolutionary energy technology currently under development by Black Light Power, Inc. The technology is based on the hypothesis that, under certain conditions, hydrogen atoms can undergo transitions to energy levels corresponding to fractional principal quantum numbers. In support of this theory, numerous laboratories have measured excess energy from low-pressure hydrogen gas systems, and a variety of novel extreme ultraviolet emission lines have been observed at low temperatures. To date, Black Light Power, Inc. and others have sought to harness this new energy source using Calvet calorimetry, closed calorimetry and microwave excited gas plasma systems. Prior to the proposed study, however, no attempt has been made to apply this new energy source toward the development of a rocket engine. Preliminary calculations suggest that a Black Light Rocket (BLR) engine can achieve performance several orders of magnitude greater than chemical rocket propulsion (e.g., I_{sp} > 10,000 s) and, unlike other high I_{sp} engines, the BLR engine is not limited to low thrust. The Phase I study proposed herein will consist of the development of a theoretical model, identification of potential space mission applications, and development of a bench scale BLR thruster and thrust stand.



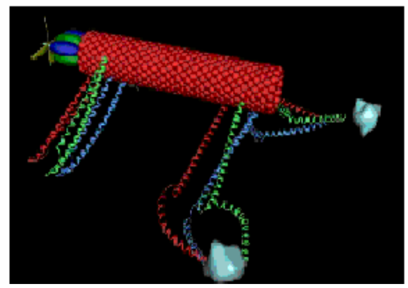
CONSTANTINOS MAVROIDIS

Rutgers University

Protein Based Nano-Machines for Space Applications

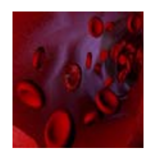
A multidisciplinary team from Rutgers University, State University of New Jersey and Shriners Hospital for Children (a Harvard Medical School affiliated hospital), has been assembled to respond to NIAC CP 01-02 research opportunity. We propose to develop novel and revolutionary biomolecular machine components that can be assembled and form multi-degree of freedom nano-devices that will be able to apply forces and manipulate objects in the nano world, transfer information from the nano to the macro world and also be able to travel in the nano environment. These machines are expected to be highly efficient, economical in mass production, work under little supervision and be controllable. The vision is that such ultra-miniature robotic systems and nano mechanical devices will be the biomolecular electromechanical hardware of future outer space and planetary exploration missions.

A few decades from now, it may be possible to establish computing stations and industries on planets within or beyond our solar system using bio-nano-molecular components and machines.



A vision of a nano-organism: Carbon nano-tubes form the main body; peptide limbs can be used for locomotion and object manipulation, a biomolecular motor located at the head can propel the device in various environments.

Some proteins, due to their structural characteristics and physicochemical properties, constitute potential candidates for this role. During Phase I, we will (a) identify such proteins that can be used as actuators, sensors, gears, joints and other machine elements in nano/micro machines and mechanisms. (For example, based on our preliminary studies, a sub-unit of the Human Immnodeficiency Virus type 1 (HIV 1) a protein known as gp41 [glycoprotein 41] can be used to produce an actuated linear joint); (b) study the protein interface to carbon-nanotubes that can be used as rigid links; (c) develop dynamic models, virtual assemblies of the proteins into mobile linkages and realistic simulations to accurately predict the performance of such nanomachines; (d) perform a series of biomolecular experiments to demonstrate the validity of the proposed concept.

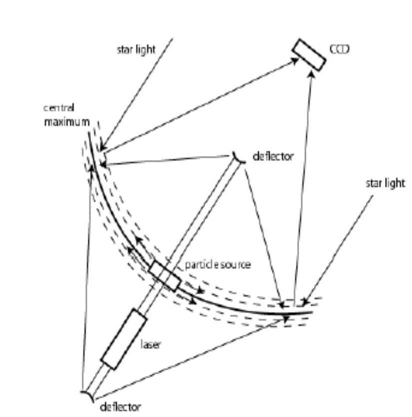


ELIZABETH McCORMACK

Bryn Mawr College

Investigation of the Feasibility of Laser Trapped Mirrors in Space

The Laser Trapped Mirror was first proposed by Antoine Labeyrie in 1979 as an innovative approach to the production of large, lightweight optics in space. Labeyrie's idea was to use counter-propagating laser beams to create large parabolic, interference fringes. By tuning the laser wavelength in single mode from red to blue in successive saw-tooth steps, the particles could be trapped and collected into a central fringe, yielding a single parabolic sheet of material. The result of this process would be a reflective surface of almost arbitrary size, which could serve as the primary of a large telescope. Remarkably, a 100-nm thick, 35-meter diameter mirror would only require about 100 grams of material.

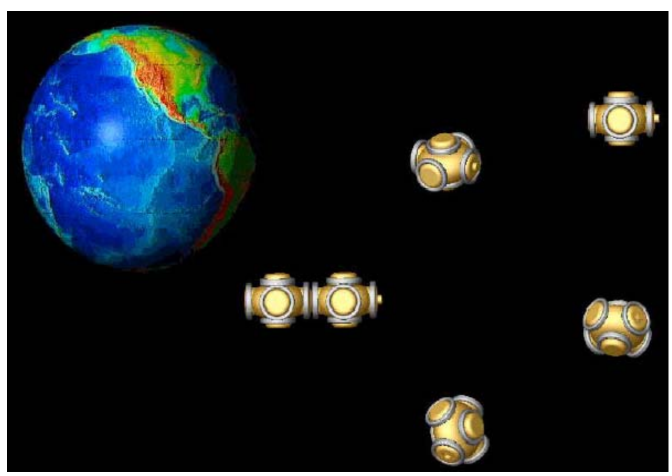


New developments in nano-technology and the optical trapping of particles, coupled with demands for increased light-gathering power and angular resolution for space research, have made it an ideal time to undertake a theoretical and experimental investigation of the challenges associated with implementing a laser trapped mirror. Here, we propose the first part of a two-phase investigation of the concept. In Phase I, we propose to explore, principally through modeling, Labeyrie's original vision and variants of it and to develop a suitable technology demonstration roadmap. The goal of this effort is to determine whether the LTM is a practical solution to the problem of building large, low mass optical systems in space. Specifically in Phase I, our goals are to 1) refine our understanding of the laser power requirements, 2) probe other major sources of technical risk to determine the presence or absence of "show-stoppers," and 3) devise an experimental plan appropriate to Phase II.

DAVID MILLER
Massachusetts Institute of Technology

Electromagnetic Formation Flight

Satellite formation flight has been identified as the next revolutionary step in remote sensing technology. This allows for the synthesis of large sensor apertures without the need for prohibitively large satellites. These systems also provide mission flexibility by being able to change their geometry to reflect the current mission needs. Furthermore, satellite formations increase reliability, ease deployment, allow staged deployment, improve coverage and lower cost. By providing these benefits, distributed satellite systems will replace many of today's single, larger satellites.



However, one of the main problems identified with distributed satellite systems is the additional propellant needed to maintain these formations. Distributed satellite systems have a much higher demand on the onboard propellant system due to the need to keep satellites properly positioned with respect to each other. Even if the geometry of the satellite formation is to remain unchanged throughout the mission, many perturbative effects including differential drag, non-uniform geo-potential (J_2), and solar pressure all contribute to changes in the formation's geometry and must be counteracted. The amount of propellant that can be carried on the satellite puts an upper limit on the mission lifetime. When the satellites have exhausted the available propellant, there will be a number of perfectly good, but generally useless, satellites continuing in their orbits.

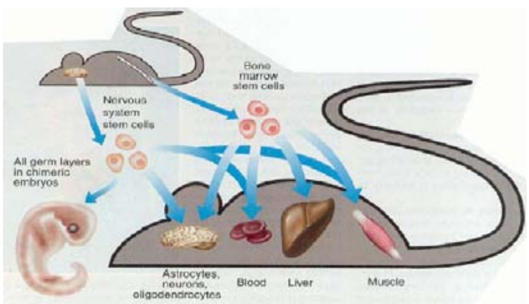
In response to this limitation, the MIT Space Systems Lab (SSL) has been exploring electromagnetic formation flight (EMFF). Electromagnets will be used to provide the necessary control authority to maintain satellite formations in the presence of disturbances. Electromagnets offer the added capability to reshape the geometry of the formation while in orbit. By changing the angle of the electromagnetic field, different forces in any direction can be produced. These forces can be used to resize or tilt a frame free orbit ellipse or reshape the satellite formation into almost any geometry. Electromagnets also have the added benefit that they provide a limitless means of control. Since the power source is electrical, it is a renewable resource and does not limit mission life. Also, unlike conventional thrusters which may leave a plume of propellant by-products around the formation that can deposit on sensitive optics, there are no contamination issues with electromagnets. Detailed studies, along with experimental testing, will verify the usefulness of EMFF and prove the ability of EMFF as a viable means of controlling satellites in formation.

SEIGO OHI

Howard University and Hospital

The Hematopoietic Stem Cell Therapy for Exploration of Space

Growing evidence indicates that hematopoietic stem cells (HSCs) possess extraordinary plasticity to differentiate not only to all types of blood cells, but also to various tissues, including bone, muscle, skin, liver and neuronal cells. Therefore, this proposal hypothesizes that the hematopoietic stem cell-based therapy, herein called the hematological abnormalities, bone and muscle losses in space, thereby maintaining astronauts' homeostasis. Our expertise lies in recombinant adeno-associated virus (rAAV)-mediated gene therapy for the hemoglobinopathies, β-thalassemia and sickle cell disease. As the requisite steps in this procedure, we established methods for purification and culture of HSCs in 1 G. Additionally, the NASA Rotating Wall Vessel (RWV) culture system is being optimized for the HSC growth/expansion. Thus, using these technologies, the above hypothesis will be tested as follows: (1) β-thalassemic mouse will be transplanted with normal isologous HSCs to correct the hematological abnormalties; (2) transgenic HSCs harboring green fluorescent protein (GFP) gene or β-galactosidase gene will be transplanted to hindlimb suspended mice, and differentiation of HSCs to bone will be traced by the marker gene expression. Repair/prevention of bone loss by the HSCT will be investigated by analyzing physical/biochemical parameters; and (3) similarly, the efficacy of HSCT for muscle loss in the unloaded mouse will be studied. In addition, using the hindlimb suspension model, effect of exercise on the HSCT for bone and muscle losses will be investigated. Our long-term goal is to automate/robotize the HSCT protocols so that astronauts would be able to treat themselves during long-duration space missions. Such a program will also be beneficial to Earth people as a self-care health system.



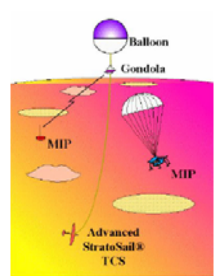
A web of possibility. In mice, stem cells from adult brain and bone marrow have shown encouraging potential for repairing a variety of tissues and organs and perhaps curing disease.

ALEXEY PANKINE

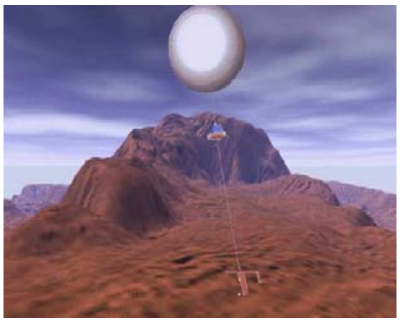
Global Aerospace Corporation

Planetary Science from Directed Aerial Robot Explorers (DARE)

Global Aerospace Corporation (GAC) is proposing to develop revolutionary system architecture for exploration of planetary atmospheres and surfaces from atmospheric altitudes. This innovative system architecture relies upon the use of Directed Aerial Robot Explorers (DARE), which essentially are autonomous balloons with trajectory control capabilities that can deploy swarms of miniature probes over multiple target areas. The balloons will follow the winds while in passive-exploring mode or steer across the winds towards regions of interest while in active-directed mode. The balloons will serve as a dual purpose – as independent explorers and as micro probes (MIPs) delivery systems for targeted observations. Trajectory control capabilities will offer unprecedented opportunities in high-resolution targeted observations of both atmospheric and surface phenomena. Multifunctional micro probes will be deployed from the balloons once over the target areas, and perform a multitude of functions, such as atmospheric profiling (Jupiter, Saturn), or surface exploration (Mars, Venus, Titan), relaying data back to the balloons. This architecture will enable low-cost, low-energy, long-term global exploration of



Illustrations courtesy of R. D. Fredericks



planetary atmospheres and surfaces. This proposed effort addresses several objectives of the NASA Enterprise for Human Exploration and Development of Space (HEDS) and of the NASA Space Science Enterprise (SSE), namely:

Understand the formation and evolution of the solar system and the Earth within it (SSE),

- Probe the evolution of life on Earth, and determine if life exists elsewhere in the solar system (SSE),
- Investigate the composition, evolution and resources of Mars, the Moon and small bodies (SSE), and
- Enable human exploration through collaborative robotic missions (HEDS).

Key elements of this new concept are:

- Low cost, low energy, long duration autonomous balloon systems,
- Balloon trajectory control capability,
- Deployable micro sensors for in-situ atmospheric profiling or surface exploration,
- Communications relay orbiter

NILANJAN SARKAR
Vanderbilt University

A Novel Interface System for Seamlessly Integrating Human-Robot Cooperative Activities in Space

A potentially revolutionary human-robot interface system for space applications is presented in this proposal. The ultimate goal of this proposed system is to provide a seamless integration of human and robot, where the robot will be expected to understand the thoughts of the human and follow implicit commands to facilitate unprecedented human-robot cooperation. This goal will be achieved through affect recognition, brainwave monitoring and characterizing, and probabilistic and heuristic analyses.

The Phase I research will attempt to address a part of the big problem. It will investigate how to recognize the affective state of a human through physiological sensing, how best to measure various physiological parameters and their relative merits, and a comparative study on the latest development in brainwave monitoring technologies. A series of human subject experiments will be conducted to generate and recognize affect. In addition, a comparative, critical review of the available (and projected) brainwave monitoring technologies will be conducted, such that we will be able to incorporate the most promising of these technologies into our efforts in the second phase of this project.

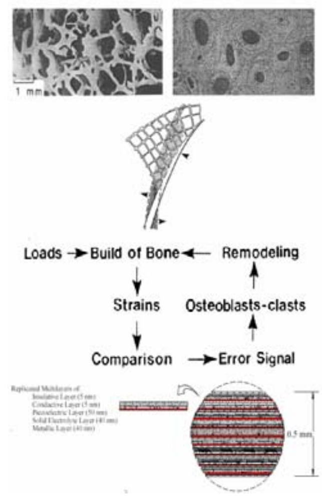
The proposed work will synergistically combine recent advances from affective computing, experimental psychology, signal-processing and control theory to develop an innovative system that is expected to revolutionize the human-robot space exploration of the future. The proposed system is expected to provide an enabling thrust to the current wearable computing and real-time signal processing technologies.

PARVIZ SOROUSHIAN

Technova Corporation

Inherently Adaptive Structural Systems

We propose to develop bio-inspired structural systems capable of adapting to altering and unpredictable service environments. Structural biomaterials such as bones, shells and teeth occur as composite materials with outstanding properties embraced by a complex structure which evolves in response to external stimuli. Conventional composite processing schemes cannot reproduce the exquisite ultra-structure of biomaterials. In an approach inspired by the development of bone structure, we propose to use a high-performance cellular (e.g., micro-cellular carbon) structure as the framework for controlled deposition of various structural and functional mono-layers in an aqueous processing environment. We will employ the ionically self-assembled mono-layer (ISAM) technique to develop a complex, multi-layer architecture with detailed molecular level control over its composition and micro-structure. The functional layers built into the system convert the mechanical energy input of service environment to electrical energy by employing either the piezoelectric effect to generate electrolytic cells or the stress-induced phase transformation to generate galvanic cells. These cells drive electrolysis processes within a solid electrolyte which eliminate locally elevated stresses by mobilizing finite material resources to best meet the structural demands of altering and unpredictable service environments. Besides novel self-adaptation qualities, our envisioned system also offers major advantages in terms of structural efficiency, economy and geometric/compositional versatility, and provides tremendous control over the load paths within the system at local and global levels, with material resources strategically positioned along these paths for optimum structural performance. The proposed Phase I research will verify the viability of our approach towards development of efficient structural systems with intrinsic adaptation attributes. We will accomplish the following objectives in Phase I research: (1) develop design methodologies for hybrid, multi-layer systems of high structural efficiency with intrinsic adaptation qualities which are amenable to ISAM processing; (2) establish processing schemes for building the hybrid, multi-layer architecture into an open-cell foam structure; and (3) experimentally verify the structural and self-adaptation features of the new system, and assess the prospects of the technology emphasizing development of autonomous and evolvable structures which perform optimally during long periods in unknown harsh and/or changing environments. Technova Corporation will join forces with Michigan State University (Composite Materials and Structures Center), Auburn University, Dupont and Airmar Technology to implement the proposed project.

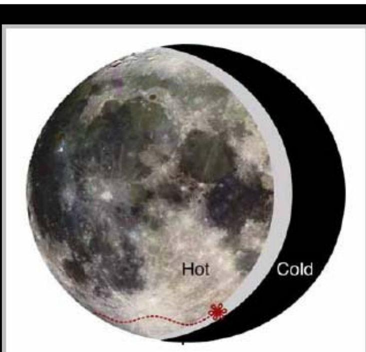


DAVID WETTERGREEN

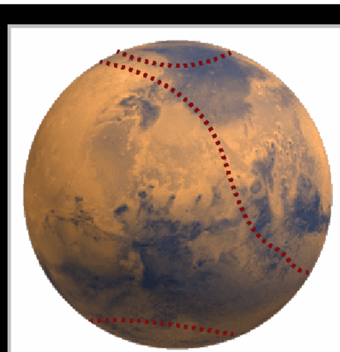
Carnegie Mellon University

Planetary Circumnavigation: A Concept for Surface Exploration of the Inner Planets

In 1522, after almost three years underway, Ferdinand Magellan's expedition returned to Spain completing the first circumnavigation of our planet. It was an almost unthinkable achievement. The concept we propose is similarly revolutionary -- the circumnavigation of the inner planets of our solar system. If achievable, the potential for missions of surface exploration is profound. Through this study, we may discover: technological benefits to power for long-duration, long-distance operations and to thermal regulation between planetary extremes, scientific benefits in rich observations and comprehensive examination of vast regions, economic benefits to the typical short-duration mission profile and eventual commercial development of the planets, and social benefits from the spirit of great adventure and the familiarization of our neighborhood of planets. The proposed study will examine the viability of the concept of planetary circumnavigation and identify the major issues for consideration.



MOON: Circumnavigation of the Polar Regions could follow the terminator in a region of moderate temperature to encounter rills, exposed bedrock, and ground ice trapped in perpetually shadowed craters.



MARS: Axial inclination similar to Earth provides extended periods of sunlight in the Polar Regions where the investigation of annual water ice and evidence of life could proceed before crossing the equatorial volcanic plateaus and alluvial features enroute to the other polar circle.

VENUS: Intense heat and pressure are challenges in circumnavigation. The period of rotation (retrograde) is slow to effort investigation of atmospherics, tectonics and corrosive erosion in what may be the least understood, but most Earth-like of planets.

Enabling Technologies Summary Tables and Fellows Responses

The sixteen Phase II concepts with responses were grouped by NASA Enterprises as shown in Table 13. This grouping is for convenience only, as there is some overlap or redundancies between concept and NASA Enterprise.

NASA Enterprise	NIAC Fellow and Concept Title
EARTH SCIENCE	Ross Hoffman, Controlling Global Weather Kerry Nock, Global Stratospheric Balloon Constellation
SPACE FLIGHT	Kerry Nock, Astrotel Eric Rice, Mars Colonization
AEROSPACE TECHNOLOGY	Steven Dubowsky, Self-Transforming Robots Brad Edwards, Space Elevator Terry Kammash, Laser Accelerated Plasma Propulsion
SPACE SCIENCE	Webster Cash, X-Ray Interferometer Anthony Colozza, Entomopter for Mars Paul Gorenstein, Advanced X-Ray Observatory Robert Hoyt, Tether Transportation System George Maise, Jovian Flyer Ralph McNutt, Realistic Interstellar Mission Robert Winglee, Mini-Magnetospheric Plasma Propulsion System, M2P2
BIOLOGICAL AND PHYSICAL RESEARCH	Ed Hodgson, Chameleon Suit Terri Lomax, Architecture for Planet Genomics in Space

TABLE 13. NIAC Fellows' Responses Grouped by NASA Enterprises

Broader categories were compiled to organize the enabling technologies. These categories are:

INFRASTRUCTURE	Broad term referring to advances in multiple disciplines or progress that affects systemic approaches to aeronautics and space exploration
MATERIALS	Advances in the material sciences, including composites, structures, nano-materials, polymers, etc.
SPACE TRANSPORTATION	Broad term referring to advances in aeronautics and space, including propulsion and transportation systems
GNC	Disciplines concerned with guidance, navigation and control of aerospace concepts
POWER	Technologies supporting creation, conditioning, and delivery of power in quantities from microwatts to megawatts
ELECTRONICS	Advances in the state-of-the-art for electronic systems, to include circuit miniaturization, low power and radiation-resistant components, etc.
MEMS	Micro-Electro-Mechanical Systems (MEMS) – the miniaturization of integrated mechanical elements, sensors, actuators and electronics
OPTICS	Advances in optical systems and components, including advances in laser system technologies
ISRU	In situ resource utilization – the use of local resources to enhance mission capability
ROBOTICS	Advances that promote new levels of robotic autonomy, reliability and robustness
LIFE SCIENCE	Advances that support fundamental and applied research to enable humans to live and work in the harsh environment of outer space
EARTH SCIENCE	Advances that support the scientific understanding of the Earth system and its response to natural or human-induced changes to enable improved prediction capability for climate, weather and natural hazards

Table 14 provides a short phrase to identify the primary and secondary enabling technologies submitted by each of the Fellows.

Principal Investigator and Concept Title	Primary Enabling Technology	Secondary Enabling Technology
ROSS HOFFMAN Controlling the Global Weather	➲ Improved atmospheric forecasting capability ➲ Advanced computational capability ➲ Engineering capability for very large controllable surfaces in space	
KERRY NOCK Stratospheric Balloon	➲ Ultra-long duration balloon technology ➲ Balloon trajectory control systems ➲ Constellation geometry management	➲ Flight termination systems ➲ Stratospheric Earth science sensors ➲ Advanced trajectory prediction
KERRY NOCK Astrotel	➲ Human physiology and life support in space ➲ Automation and robotics ➲ Assembly and operations in space	➲ Aero-assist aero-capture at Earth and Mars ➲ High-power ion propulsion systems ➲ Space resource mining, processing and manufacture
ERIC RICE Mars Colonization	➲ CO/LOX hybrid and bi-propellant liquid propulsion systems ➲ CO/LOX propellant processing systems ➲ Mars ISRU-based materials production and manufacturing ➲ Aero-braking ➲ Water recovery from indigenous materials ➲ Orbital power beaming systems	➲ Orbiting nuclear power systems ➲ Nuclear propulsion and power reactors ➲ Large bio-dome structures ➲ Aero-brakes with microwave power recovery antennas integrated ➲ Mars mining operations and technologies ➲ Oxygen production from carbon dioxide gas breathing packs ➲ Low-g effects on humans, animals and plants ➲ Radiation effects and shielding ➲ Animal habitats and greenhouses ➲ ISRU-based Mars ascent vehicle systems for follow-on sample return missions ➲ Mars personnel and cargo rovers ➲ Defining the colony needs for animals, sports, recreation, etc. ➲ Human psychological issues and human factors ➲ Martian ice/soil simulator to support technology development ➲ Self-cleaning solar energy and greenhouse surface systems ➲ Rocket backpacks for Mars explorers/colonists ➲ Mars resource identification and discovery as needed for ISRU ➲ Mars terraforming technologies and modeling
STEVEN DUBOWSKY Self-Transforming Robots	➲ Polymer actuators ➲ Distributed micro power sources	
BRAD EDWARDS The Space Elevator	➲ Carbon nano-tube composites ➲ High-power lasers ➲ Space activities	
TERRY KAMMASH Laser-Accelerated Plasma Propulsion	➲ High efficiency, high-power diode pump lasers ➲ Advanced crystal growth technology ➲ Cooling technology for thermally stable crystals ➲ Large-scale “thin target” technology	➲ Development of lightweight multi megawatt nuclear power systems ➲ Fabrication technology for making “large scale” electro-optics to be employed in the laser system ➲ Develop technology for “dampening” transverse lasing that detracts from the axial lasing required for these applications
WEBSTER CASH X-Ray Interferometer	➲ Precision line of sight ➲ Formation flying ➲ Internal metrology	
ANTHONY COLOZZA Entomopter for Mars	➲ Flapping wing aerodynamics ➲ Autonomous flight control ➲ Miniature sensors and payloads	

Table 14 continues on the next page …

Principal Investigator and Concept Title	Primary Enabling Technology	Secondary Enabling Technology
PAUL GORENSTEIN Advanced X-Ray Observatory	➲ Formation flying to high accuracy ➲ Precision propulsion ➲ Robotic dexterity ➲ Formation flying of 2 or 3 S/C over very long distances ➲ High impulse, quick response propulsion ➲ Transportation to the Moon ➲ Existence of a lunar base with infrastructure ➲ Robotic dexterity for assembly of telescope	
ROBERT HOYT Tether Transportation System	➲ High-accuracy orbital propagation of space tethers ➲ Payload/tether grappling technologies ➲ High voltage, high power space power systems	
GEORGE MAISE Exploration of Jovian Atmosphere using Nuclear Ramjet Flyer	➲ Compact, light-weight nuclear engine ➲ Autonomous control of remote explorers ➲ Radiation-hardened instruments	
RALPH McNUTT Realistic Interstellar Mission	➲ Integrated thermal shield/heat exchanger for solar thermal power ➲ Ultra-low power and/or ultra-low power consumption electronics ➲ Integrated laser communications and guidance control system for high bandwidth, very deep space communications	➲ A low-mass structure that can deal with launch load and thermal environment ➲ Americium-241-fueled radioisotope thermoelectric generator ➲ Development of the wireless bus ➲ Low-mass, cold gas propulsion system components ➲ Low-power electronics
ROBERT WINGLEE Mini-Magnetospheric Plasma Propulsion System, M2P2	➲ Optimize plasma resources for M^2P^2 and solar wind surrogate ➲ Access to larger chambers – the problem is trying to simulate space ➲ Force measurements	
EDWARD HODGSON The Chameleon Suit	➲ Shape-change polymers ➲ Selective chemical transport membranes ➲ Flexible (thin film and polymeric) photovoltaic systems	➲ Photo-catalytic and electro-catalytic polymers ➲ Conductive polymers, electro textiles ➲ Manufacturing technology for large-scale polymer systems ➲ Thin film/polymeric low temperature thermo-electric materials ➲ Infrared electrochromic polymers ➲ Flexible, polymer-based, energy storage devices ➲ Directional shading MEMS louvers
TERRI LOMAX Architecture for Plant Genomics in Space	➲ Bioinformatics ➲ Automated microfluidics ➲ Remote sample monitoring and manipulation	

TABLE 14. Primary and Secondary Enabling Technologies Submitted by NIAC Fellows

Two additional tables were prepared to provide a cross-reference between the studies and the general response areas. Table 15 sorts the responses by the characterization of technology areas.

Concept Enabling Technology	Primary or Secondary

INFRASTRUCTURES	1 Advanced computational capability	P
	2 Flight termination systems	S
	3 Assembly and operations in space	P
	4 Mars mining operations and technologies	S
	4 Mars personnel and cargo rovers	S
	4 Defining the colony needs for animals, sports, recreation, etc.	S
	6 Space activities	P
	10 Transportation to the Moon	P
	10 Existence of a lunar base with infrastructure	P
	11 Payload/tether grappling technologies	P
MATERIALS	2 Ultra-long duration balloon technology	P
	4 Large bio-dome structures	S
	6 Carbon nanotube composites	P
	7 Advanced crystal growth technology	P
	7 Cooling technology for thermally stable crystals	P
	7 Large-scale "thin target" technology	P
	13 A low-mass structure that can deal with launch load and thermal environment	S
	15 Shape-change polymers	P
	15 Flexible (thin film and polymeric) photovoltaic system	P
	15 Selective chemical transport membranes	P
	15 Photo-catalytic and electro-catalytic polymers	S
	15 Conductive polymers/electro-textiles	S
	15 Manufacturing technology for large-scale polymer systems	S
	15 Thin film/polymeric low temperature thermo-electric materials	S
	15 Infrared electrochromic polymers	S
SPACE TRANSPORTATION	3 Aero-assist aero-capture at Earth and Mars	S
	3 High-power ion propulsion systems	S
	4 CO/LOX hybrid and bi-propellant liquid propulsion systems	P
	4 CO/LOX propellant processing systems	P
	4 Aero-braking	P
	4 Aero-brakes with microwave power recovery antennas integrated	S
	4 Rocket backpacks for Mars explorers/colonists	S
	4 Nuclear propulsion and power reactors	S
	4 ISRU-based Mars ascent vehicle systems	S
	9 Flapping wing aerodynamics	P
	10 Precision propulsion	P
	10 Transportation to the Moon	P
	10 High impulse/quick response propulsion	P
	11 Payload/tether grappling technologies	P
	11 High voltage/high-power space power systems	P
	11 High-accuracy orbital propagation of space tethers	P
	12 Compact, light-weight nuclear engine	P
	13 Integrated thermal shield/heat exchanger for solar thermal power	P
	13 Low-mass, cold gas propulsion system components	S
	14 Optimize plasma sources for M2P2 and solar wind surrogate	P
	14 Access to larger chambers – the problem is trying to simulate space	P
	14 Force measurements	P
POWER	4 Orbital power beaming systems	P
	4 Orbiting nuclear power systems	S
	4 Nuclear propulsion and power reactors	S
	4 Self-cleaning solar energy and greenhouse surface systems	S
	5 Distributed micro-power sources	P
	7 Cooling technology for thermally stable crystals	P
	7 Development of lightweight multi-megawatt nuclear power systems	S
	11 High voltage/high-power space power systems	P
	13 Integrated thermal shield/heat exchanger for solar thermal power	P
	13 Americium-241-fueled radioisotope thermo-electric generator	S
	15 Flexible (thin film and polymeric) photovoltaic system	P
	15 Flexible, polymer-based energy storage devices	S

Table 15 continues on the following page …

Concept Enabling Technology *(continued)*	Primary or Secondary

GNC	1 Engineering capability for very large controllable surfaces in space	P
	2 Balloon trajectory control systems	P
	2 Constellation geometry management	P
	8 Precision line of sight	P
	8 Formation flying	P
	8 Internal metrology	P
	9 Autonomous flight control	P
	10 Formation flying to high accuracy	P
	10 Formation flying of two or three S/C over very long distances	P
	10 Precision propulsion	P
	13 Integrated laser-communications and guidance-control system	P
	13 Development of the wireless bus	S
ELECTRONICS	9 Miniature sensors and payloads	P
	12 Radiation hardened instruments	P
	13 Ultra-lower power and/or ultra-low power consumption electronics	P
	13 Low-power electronics	S
MEMS	5 Polymer actuators	P
	5 Distributed micro-power sources	P
	9 Miniature sensors and payloads	P
	15 Directional shading MEMS louvers	S
	16 Automated microfluidics	P
OPTICS	4 Orbital power beaming systems	P
	6 High-power lasers	P
	7 High efficiency, high-power diode pump lasers	P
	7 Fabrication technology for making "large scale" electro-optics	S
	7 Develop technology for "dampening" transverse lasing	S
ISRU	3 Space resource mining, processing and manufacturing	S
	4 Water recovery from indigenous materials	P
	4 Mars ISRU-based materials production and manufacturing	P
	4 ISRU-based Mars ascent vehicle systems	S
	4 Martian ice/soil simulator to support technology development	S
	4 Mars resource identification and discovery as needed for ISRU	S
ROBOTICS	3 Automation and robotics	P
	10 Robotic dexterity	P
	10 Robotic dexterity for assembly of telescope	P
	12 Autonomous control of remote explorers	P
	16 Remote sample monitoring and manipulation	P
LIFE SCIENCES	3 Human physiology and life support in space	P
	4 Oxygen production from carbon dioxide gas-breathing packs	S
	4 Low-g effects on humans, animals and plants	S
	4 Radiation effects and shielding	S
	4 Animal habitats and greenhouses	S
	4 Human psychological issues and human factors	S
	4 Mars terraforming technologies and modeling	S
	16 Bioinformatics	P
EARTH SCIENCES	1 Improved atmospheric forecasting capability	P
	2 Stratospheric Earth science sensors	S
	2 Advanced trajectory prediction	S

TABLE 15. Enabling Technologies Sorted by Categories

Table 16 shows the concepts with primary (P) or secondary (S) enabling technologies in the indicated categories. If a concept has more than one Primary or Secondary enabling technology within a category, it is indicated with the symbol *n*P or *n*S. For example, Kerry Nock's Astrotel concept had two secondary technologies in the Earth Sciences, indicated in the table by "2S."

Principal Investigator and Concept Title	Infrastructure	Materials	Propulsion	GNC	Power	Electronics	MEMS	Optics	ISRU	Robotics	Life Science	Earth Science
ROSS HOFFMAN Controlling the Global Weather	P			P								P
KERRY NOCK Global Constellation of Stratospheric Scientific Platforms	S	P		2P								2S
KERRY NOCK Cyclical Visits to Mars via Astronaut Hotels	P		2S						S	P	P	
ERIC RICE Advanced System Concept for Total ISRU-Based Propulsion & Power	3S	S	3P 4S		P 3S			P	2P 3S		6S	
STEVEN DUBOWSKY Self-Transforming Robotic Planetary Explorers					P		2P					
BRAD EDWARDS The Space Elevator	P	P						P				
TERRY KAMMASH Ultrafast Laser-Driven Plasma for Space Propulsion		3P			P S			P 2S				
WEBSTER CASH X-Ray Interferometry Telescope				3P								
ANTHONY COLOZZA Planetary Exploration using Biomimetics			P	P		P	P					
PAUL GORENSTEIN An Ultra High Throughput X-Ray Astronomy Observatory with a New Mission Architecture	2P		2P	3P						2P		
ROBERT HOYT Moon & Mars Orbiting Spinning Tether Transport	P		3P		P							
GEORGE MAISE Exploration of Jovian Atmosphere using Nuclear Ramjet Flyer			P			P				P		
RALPH McNUTT Realistic Interstellar Mission		S	P S	P S	P S	P S						
ROBERT WINGLEE Mini-Magnetospheric Plasma Propulsion System - M2P2			3P									
EDWARD HODGSON A Chameleon Suit to Liberate Human Exploration of Space Environments		3P 5S			2P S		S					
TERRI LOMAX A Flexible Architecture for Plant Functional Genomics in Space Environments							P			P	P	

TABLE 16. Depiction of Concepts with Primary or Secondary Enabling Technologies

Descriptions of Enabling Technologies Received from NIAC Phase II Fellows

Controlling the Global Weather
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Top Three Enabling Technologies

Improved atmospheric forecasting capability. This includes numerical weather prediction, data assimilation, and observing the atmosphere. Wind profiles (probably from a space-based lidar system) are the most important. We cannot change the real atmosphere unless we can predict what will happen with and without the proposed change.

Advanced computational capability. This is a critical support for point 1.

Engineering capability for very large controllable surfaces in space. Both reflected sunlight and microwave downlinks from SSP depend on collecting and aiming large amounts of solar energy.

Global Constellation of Stratospheric Scientific Platforms
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Top Three Enabling Technologies

Balloon Technology

The entire StratCon concept hinges on the initial successful development of the Ultra-long Duration Balloon (ULDB) technology. After four failures in a row of large ULDB systems (the last just this March in Australia), this technology is in jeopardy. The NASA Balloon Program has focused on extremely large balloon systems. They have not capitalized on the one successful sub-scale ULDB test that they carried out in June 2000. The balloon in the sub-scale ULDB test is very nearly the planned size of StratCon balloons. The failures of the large balloons can be attributed to insufficient resources for a technology development program and serious technical challenge combined with insufficient design expertise; questionable redesigns insufficient material testing, and the lack of external oversight. Many balloon technology advances beyond ULDB are necessary before the StratCon architecture concept can be realized. These technology advances include:

- advanced, lightweight films that are protected against the UV environment for 3-10 years and that have low solar thermal radiation absorptivity and low permeability;
- new envelope structural designs optimized for small balloon (film thickness, load tendon size); and finally
- advanced, automated manufacturing technologies to reduce leakage of gases through seams, and to dramatically reduce the cost of balloons.

Advanced Balloon Trajectory Control Systems (TCS)

Trajectory control systems are essential to both the promise of the ULDB Program and the StratCon concept. Unfortunately, with the failures in the ULDB Program, there has been no NASA balloon program resource made available for continued development and prototype testing of the first generation trajectory control system whose initial development was accomplished under SBIR funding. Once prototype testing of this first generation system is successful, development of advanced TCS designs can proceed. Advanced dual wing designs need to have long lifetimes (3-10 years), be very lightweight, be able to achieve high lift forces without rising into low-density air, and be inexpensive to fabricate and fly.

Constellation Geometry Management

A small portion of the NIAC effort (< 1 work-year) was devoted to the development and evaluation of simple constellation management algorithms in the context of the StratCon concept. Areas that need to proceed in order to make the StratCon concept possible include (a) continued identification and testing of biologic and other advanced control algorithms, (b) continued development of atmospheric feature identification techniques, (c) the development of advanced control algorithms that can take advantage of identified atmospheric features in managing networks of balloons, and (d) the integration of environment and control models to develop optimal constellation control methodologies.

Other Important Technologies

Guided Payload Flight Termination Systems. Safety issues drive the need for guided payload flight termination systems. Current NASA scientific balloons generally fly over remote areas of the globe. Upon mission termination or catastrophic failure, payloads are released and carried to the ground via simple, unguided parachutes. The probability of damage to property and injury to persons on the ground is currently high enough to prohibit cut down over moderately populated areas, and it limits over-flight of highly populated metropolitan cities because of the concern for unplanned balloon failure. The StratCon concept has up to hundreds of globally distributed balloon platforms for Earth science applications (e.g., radiation balance). Thus, guided payload recovery, in the event of catastrophic balloon failure, is needed to provide precision payload landings in safe locations (e.g., airports or open fields) even in high population density areas (cities).

Advanced Stratospheric Earth Science Sensors. In general, there needs to be development of new Earth Science sensors that can take advantage of the stratospheric view point, for example, new radiation balance sensors (active cavity radiometers) that can make direct flux measurements (currently only radiances measurements are made from space). Dropsondes can make revolutionary, adaptive, inexpensive and high-resolution global upper air sounding measurements that cannot be equaled by space satellites. Technology and advanced engineering development of ultra-lightweight dropsondes and their sensors (including water vapor, ozone, CO and other trace gases) could enable balloon platforms to carry a thousand or more packages for deployment over periods of years.

Advanced Trajectory Prediction. Combine in-situ data from a network of in-situ platforms with existing satellite weather data to provide unprecedented accuracy in stratospheric forecast models. Then, utilize this improved weather data with advanced stratospheric balloon trajectory prediction software to produce much more accurate path predictions. Development in this technology area can significantly enhance constellation geometry management technology.

Cyclical Visits to Mars via Astronaut Hotels

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Top Three Enabling Technologies

Human physiology and life support in space

It needs to demonstrate that humans can take the five months to go to Mars, stay four years and take five months to return safely. Primary issues are the need for artificial gravity and radiation environment effects on physiology and their impact on shielding requirements in space and at Mars.

Automation and robotics

Many of the things we propose cannot be done with just humans. As it is, 2.5 humans are needed to operate the ISS. If there are three people there, only one-half person is doing science. It does not make sense to have humans do anything that a future automated machine or robot can do. This includes monitoring, maintenance, assembly of systems, processing of resources, cleaning, initial exploration as pathfinders to extend Man's reach and increase safety, operate in hazardous environments (e.g., near reactors), etc. I would think that since it will cost so much to get humans to Mars, the only thing you want them doing is science and exploration.

Assembly and operations in space

It is critical that a number of activities are automated and/or simplified in space. These include the following activities: structural assembly; propellant refueling and life support consumables re-supply; cargo transfer; and vehicle checkout, maintenance and repair. This area will be enhanced by technology advance in # 2.

Other Important Technologies

Aero-assist. Taxi aerocapture at Earth and Mars, new moderate lift shapes (AFE-type elliptical raked cone).
High-power ion propulsion systems. Low-thrust cargo freighter transport to re-supply Mars and astrotels.
Space resource mining, processing and manufacture. Use of in-situ resources to reduce cost of transport ofEarth propellants to space. If launch costs could be made less than $1,000 per kg, it's questionable whether ISRU makes sense. But, there is no plan to get to those levels of costs. New launchers are expensive, and somebody wants to make a profit.

Advanced System Concept for Total ISRU-Based Propulsion & Power

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The top three plus other critical technologies are listed and briefly discussed below. See the final report for more information.

- CO/LOX hybrid and bi-propellant liquid propulsion systems. Significant important work to develop these technologies is needed to get the technology to the proper technology readiness level so that it can be considered when it is time to proceed.
- CO/LOX propellant processing systems. Detailed system designs and technology demonstrations should be conducted for the CO/O_2 propellant production systems in their full-scale configuration to improve the accuracy of the total estimated mass and energy requirements. The effects of reduced gravity on the processes need to be studied and evaluated.
- Mars ISRU-based materials production and manufacturing. General infrastructure was found to account for a significant amount of the total colony cost. The general infrastructure costs are independent of the propellant used. It is recommended that the following processing technologies be developed: hydrocarbon materials development (plastics, etc.), concrete, inflatable materials, regolith sintering, metal separation and casting, terrestrial components, etc.
- Aero-braking. Aero-brake systems design and technology development work should be a priority, as this technology is vital to keeping costs down.
- Water recovery. Technology needs to be developed for finding and removing water from under the surface of Mars.
- Orbital power beaming systems. Further in-depth analysis of beamed power from Mars orbit to the surface is required.

Other Important Technologies

- Orbiting nuclear power systems
- Nuclear propulsion and power reactors
- Large bio-dome structures
- Aero-brakes with microwave power recovery antennas integrated
- Mars mining operations and technologies
- Oxygen production from carbon dioxide gas-breathing packs
- Low-g effects on humans, animals and plants
- Radiation effects and shielding
- Animal habitats and greenhouses
- ISRU-based Mars Ascent Vehicle systems for follow-on sample return missions
- Mars personnel and cargo rovers
- Defining the colony needs for animals, sports, recreation, etc.
- Human psychological issues and human factors
- Martian ice/soil simulator to support technology development
- Self-cleaning solar energy and greenhouse surface systems
- Rocket backpacks for Mars explorers/colonists
- Mars resource identification and discovery as needed for ISRU
- Mars terraforming technologies and modeling

Self-Transforming Robotic Planetary Explorers

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Polymer Actuators, particularly combined with distributed micro power sources, such as micro fuel cells and bi-stable mechanisms.

Our Binary Actuated Robots – that we now call Digital Mechantronics, are robust, failure-resistant, and lots of other good things, but they require a relatively large number of bi-stable actuators. Polymer actuator particularly combined with distributed micro power sources, such as a micro fuel cell and bi-stable mechanisms would be ideal for this.

The Space Elevator

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Top Three Enabling Technologies

- Carbon nano-tube composites
- High-power lasers
- Space activities

The carbon nano-tube composites are required for constructing the space elevator ribbon which is the heart of the system. No other material is strong enough to construct the space elevator. This technology is advancing and will have fantastic commercial applications. At the moment, the research and development effort in CNT composites is uncoordinated and unfocused with researchers pursuing the same and different tracks with little interaction. The current leaders in the field have small, unstable funding because the investments have been spread thin. Production of CNTs (themselves), are making great strides and commercial production is now beginning on large scales. With the increase in CNT availability, we should be able to make fast strides in CNT composite development. High-power lasers are also an important technology, but not quite as critical as the CNT composites. In our system, the lasers are used to transmit power efficiently to the climbers and deployment spacecraft. Alternative power delivery systems may be possible, but we would give up performance and have higher risk of failure.

Space activities are listed as the next most critical technology. This covers on-orbit assembly and tether tests. These are not so much technologies that yet need to be developed, but more mature to limit our construction risk. The technologies above are really the most critical. We have engineering issues, testing issues, political issues, feasibility tests, etc. that need to be done, but none of these really fall under the heading of technology development.

Ultrafast Laser-Driven Plasma for Space Propulsion

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The ultra-fast laser-accelerated plasma propulsion system (LAPPS) makes use of very short pulse length lasers to accelerate charged particles to relativistic energies. For a meaningful propulsion system to be employed in interplanetary and/or interstellar missions, a kilo joule laser that operates at a kilohertz rep rate appears to be especially desirable. Because efficiencies of such present-day lasers are quite small, multi megawatt nuclear power systems that are quite massive would be required to drive them. To alleviate this and other problems associated with the potential use of these lasers for space propulsion applications, the following critical technologies need to be developed:

- Increase significantly the efficiency of high-power diode pump lasers. For a fixed rep rate, an increase in the laser efficiency is readily reflected in a corresponding decrease in the mass of the [nuclear] electric power system needed to drive it.
- With large rep rates required on the laser side in a propulsion system, a similar requirement is needed on the target side. Jet targets with near continuous flow might provide the answer. Hence, the development of large scale “thin target” technology is critical for this application.

Other important technologies:

- Development of multi megawatt nuclear power systems [reactor plus power conversion components] to drive LAPPS. This includes development and testing of cermet-type fast nuclear reactors [or components thereof], and efficient “light-weight” radiators that are safe, compact and of relatively small mass.
- Fabrication technology for “dampening” transverse lasing that detracts from the axial lasing required for these applications.

X-Ray Interferometry Telescope

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Top Three Enabling Technologies

Line of Sight

To achieve very high resolution imaging, the detector must be held on the line that starts at the star and passes through the center of the interferometric array. This is best done without reference to the sky as in star trackers because, at micro-arcseconds, everything is shifting. Instead, we place a laser on the array and a telescope on the detector craft (no big problem here). The problem is that we need super gyroscopes to track the angular drift of the detector craft. We would like drift rates of no more than a micro-arcsecond per hour. This is a challenging, but achievable goal.

Formation Flying

X-ray Interferometry is fundamentally dependent on multiple spacecraft flying in formation. We have developed optical techniques that will allow pointing of the craft to be as poor as 10 arcseconds. We do, however, need to hold the positions of the craft over distances as high as tens of kilometers to above 10 micron stability.

Internal Metrology

We need lambda over 200 optics in sizes of roughly a square foot to hold their quality into orbit. We also need to be able to move the mirrors to achieve phase locking across the array, which will involve scanning the mirrors until optical paths are all nulled on the detector. We are re-inventing the telescope here, so many of the technologies one associates with astronomy remain relevant for us. We need to fly a fleet of up to a few dozen small craft out to L2 or beyond. There, we must achieve and maintain a precision array that can be pointed at any place in the sky. This involves not just the formation flying, but remote and probably autonomous formation maintenance. The craft need to communicate with each other and send only relevant information to the ground. Improved x-ray detectors are always welcome.

Planetary Exploration Using Biomimetics

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Top Three Enabling Technologies

Flapping Wing Aerodynamics

A detailed understanding of the aerodynamics of insect flight and the subsequent flapping motion is critical to an optimized entomopters design. The lift generating mechanisms of insect flight are not completely understood. Detailed CFD modeling, wind tunnel testing and analytical modeling can be used to further the understanding of how insects generate lift as well as provide an optimized wing geometry and motion for the entomopters vehicle. The work done to-date on the entomopters aerodynamics has provided a basis for the concept's design, but now needs to be refined with increased fidelity to work toward an optimized design.

Autonomous Flight Control and Artificial Intelligence System

The entomopters missions will have fairly short flight times, on the order of 10 minutes. These short flight times mean that the mission will have to be flown completely autonomously. The vehicle will have to identify its objective target, and perform its mission with little or no commands from Earth. Therefore, the entomopters will need to be able to navigate, avoid obstacles and deal with unforeseen circumstances using artificial intelligence capabilities. The flight control and AI to guide and operate the entomopters will need to be capable of dealing with the unique flight characteristics of the entomopters as well as with the environment on Mars. These characteristics will make it unlike any other flight control system that has previously been implemented.

Sensors and Payload

The entomopters will provide a science platform for Mars exploration with unprecedented capabilities. It will be able to fly slow near the surface, land, collect samples and return them to a central vehicle for detailed study. With these capabilities come limitations. The entomopters flight times will be short and the payload capacity will be limited. The minimization of power consumption and the miniaturization of sensors and science packages are critical to making the entomopters a viable science platform. Also integrating the sensors so that they may be capable of performing multiple tasks, either science tasks or flight related tasks is also desirable. Identifying viable science objectives that can be carried out with compact, light weight, low power sensors is a critical element to making the entomopters a useable science platform.

An Ultra High Throughput X-Ray Astronomy Observatory with a New Mission Architecture

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My final report described three concepts for a high throughout x-ray telescope. One was a very large, modular, grazing incidence telescope. The second was a lightweight x-ray telescope consisting of diffractive-refractive elements, in which I became increasingly interested during the course of the study. The third was a lunar-based observatory based upon a modular grazing incidence telescope. Their technology needs are not identical. Each is discussed below.

Large Modular Grazing Incidence Telescope

- Formation flying between a large, massive (~ 30 ton) telescope spacecraft (S/C) and a much smaller detector SC

  Separation: ~ 100 m

  Alignment accuracy between telescope S/C and active detector S/C is a few millimeters along the optic (z) axis and in the (x,y) plane. ~ 100 m accuracy in stationing of detector S/C that are not currently active, but will be called upon later for other types of measurements (e.g., for change from imaging to high resolution spectroscopy).

Propulsion

Move detector spacecraft to the position of the new focus as the telescope points to a new target. Detector S/C moves about 200 m in 1 to 2 hours. Detector S/C requires propulsion system to accelerate, coast, and decelerate to stop at new position. Displacement may be along any direction as determined by the celestial position of the new target.

Telescope is too large and massive to be launched as a complete integrated unit, and we would not wish to do so if that were possible. A single telescope module or a batch of a few assembled on Earth with mass of few hundred kg each will be lifted to the Sun-Earth L2 region. One year is allowed to rendezvous with the observatory. Propulsion system is required. The one year allowance may permit an energy efficient mode of lifting (e.g. solar energy to power ion engine to exert thrust at optimum times and perhaps even solar sailing to L2).

Robotic Dexterity

For attaching and integrating telescope modules following their rendezvous with the site. Telerobotic control with vision for human operator is preferable.

Diffractive-Refractive X-Ray Telescope System

- Formation Flying of two or three S/C over very long distance
  All S/C are long the optic axis. There are several different configurations characterized by their separations.
  One S/C has the diffractive element, the second S/C contains a refractive element, and the third the detector.
  Separations vary from 500 km to 20,000 km.
  Spacing accuracy along z axis is 5 to 10 meters.
  Alignment accuracy in (x,y) plane is determined by the detector format. Imaging detectors have format of 1 meter.
  Alignment tolerance in (x,y) plane is 20 cm. Spectroscopy detectors have format of a few cm resulting in (x,y) tolerance of a few millimeters.

- Propulsion
  Target changes require displacements of, the diffractive element S/C plus the detector S/C, or just the detector S/C (depending on the configuration). Displacements are in range 1000 km to 50000 km. We desire that target changes be completed in 100,000 seconds or less.

  Telescope elements are relatively low mass, few hundred kg and relatively low cost to fabricate. No unusual launch requirements. Telescope is launched fully assembled for launch. No special robotic dexterity required.

Lunar-Based Observatory for Heavy, Modular Grazing Incidence Telescope

- Transportation to the Moon to deliver telescope modules
- Telescope is essentially the same as the one described above, but is mounted on elevator that can move between 10 and 100 m from the ground and can rotate about vertical axis. Detectors are mounted on rovers that move slowly to remain at the focus while the telescope.
- Existence of a lunar base with infrastructure that provides ground clearing services for observatory site, construction services to erect tower and elevator platform and provide power to heat the telescope, especially during the 14 Earth-day lunar night.
- Robotic dexterity for assembly of telescope, see 1.3.

Moon & Mars Orbiting Spinning Tether Transport

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Top Three Enabling Technologies

Capability for high-accuracy orbital propagation of space tethers
The tether transport system concepts require the ability to enable payloads to reliably and safely rendezvous with an orbiting tether. This will require a capability to accurately predict the motion of a complex tether system. In addition to the development of computer simulation tools for this purpose, developing this capability will also require conducting several test flights of tether systems to enable these tools to be validated.

Payload/Tether Grappling Technologies
Payload/tether rendezvous will require the development of a mechanism that can enable a payload to dock with the end of a tether reliably within a very short time window (a few seconds) with very high load capabilities.

High Voltage/High Power Space Power Systems
The MXER tether concept will require a power system able to supply many kilowatts of power at rather high voltages (5 kV or more) to the electrodynamic tether re-boost system.

Exploration of Jovian Atmosphere using Nuclear Ramjet Flyer

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There are several enabling technologies which are needed to bring the Nuclear-Powered Ramjet Flyer concept to fruition. Three of the most relevant are listed below. It should be noted that only the first, development of compact light-weight nuclear engine, is not already receiving adequate funding and support.
Compact Lightweight Nuclear Engine

The foremost technology needed for implementation of the ramjet flyer concept is the development of the compact light-weight nuclear engine. It is unlikely that Jupiter atmospheric science experiments alone can justify the cost of developing such a space reactor (~$800M over 6 years); however, if a compact NTP rocket engine were developed for other space exploration missions, it could be readily modified to serve a ramjet to power the Jovian flyer.

To summarize the current situation with regard to nuclear engines for aerospace applications, in the 1960s and 70s, the U.S. developed both a nuclear powered rocket engine (NERVA at Los Alamos) and a nuclear powered ramjet engine (Tory II at Livermore). Both were successfully ground tested at full power in the Nevada desert. Unfortunately, these engines are much too heavy and too large to be practical for the space science applications. Furthermore, because of their inherent design features, these reactors cannot be effectively downscaled to smaller size. During the period 1985-1993 the SDIO (commonly known as "Star Wars"), sponsored the development of a light-weight high-thrust nuclear rocket engine based on the particle bed reactor (PBR) concept. The PBR was invented by James Powell, then a scientist at Brookhaven National Laboratory. The DoD spent approximately $145M on the development of this concept. While the program did not test a full-up engine, low power critical reactor tests were carried out and the various components of hardware developed and tested. Work on the PBR stopped in 1993 when its mission need disappeared at the end of the Cold War. While the PBR program was technically successful, the nuclear engine was still too large and heavy to be useful for present-day space exploration missions. A new compact, ultra lightweight nuclear engine concept, termed MITEE (Miniature ReacTor EnginE) was conceived to meet the need of space exploration missions (e.g. see *Acta Astronautica,* Jan-Feb 1999, p. 159; and *Scientific American*, Feb 1999, p. 72). MITEE is derived from the PBR, with modifications to substantially reduce the weight of the engine, simplify construction, and enhance performance. The mass of the MITEE reactor is only ~ 75 kg when fueled by U-235. With more exotic fuels such as Am-235m, the mass can be reduced to ~ 25 kg. We believe the MITEE engine is very suitable for powering many new space science missions, either as a space rocket or a ramjet engine. It can enable much faster exploration missions to outer planets, with much lower launch costs, and eliminates the need for complex, high-risk planetary gravity assists. Moreover, it enables fundamentally new kinds of missions not possible with chemical rockets or combustion ramjets. Among the latter are the Nuclear Ramjet Flyer and the Europa sample return mission (a NIAC Phase I study conducted by Plus Ultra Technologies, Inc.)

Autonomous Control of the Flyer

During its mapping mission in the Jovian atmosphere, the Ramjet Flyer will have to respond autonomously to changing flight conditions. Any commands from Earth have a 55 minute built-in delay. Thus, the flyer must be capable of not only executing pre-programmed flight maneuvers to conduct the mapping missions, but must also be able to recover autonomously from any unforeseen atmospheric perturbations (e.g. wind shear). It may be noted that the U.S. military is developing robust technology for unmanned flight. This technology will have direct applications for guidance and control of the Ramjet Flyer. There are several ongoing unmanned air vehicle (UAV) development programs. Because UAV technology is maturing so rapidly, it is widely believed that the JSF will be the last manned fighter aircraft. This enabling technology will undoubtedly be available when it will be needed for the Jovian Flyer.

Radiation Hardened Instruments

The nuclear reactor, which powers the ramjet flyer, is unshielded. This, combined with the small dimensions of the flyer, means that the scientific instruments carried on board the flyer, as well as the vehicle control system, will be exposed to significant radiation fluxes. Consequently, the instruments and guidance electronics, which are subject to radiation damage, must be shielded. Radiation hardened instruments/electronics permit elimination, or at least reduction, in the shielding requirements resulting in overall weight reduction of the vehicle.

Extensive research is already ongoing in developing radiation hardened instruments and electronics. This technology will probably be available when it will be needed for the Jovian flyer.

Realistic Interstellar Mission
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Thermal shield/heat exchanger for solar thermal propulsion – An integrated design in the correct shape taking into account all transition manifolds is required. Of even higher priority is the development of manufacturing/fabrication techniques to provide the appropriate low-mass channels and to uniformly coat these with a thin protective cover of rhenium. This is a key technology for this concept as well as other configurations using a solar thermal propulsion system at the highest temperatures; and hence, highest specific impulse achievable with this approach. Fabrication of test hardware is required. Some of the details of the analysis to-date are given in Lyman, R. W., M. E. Ewing, R. S. Krishnan, D. M. Lester, and R. L. McNutt, Jr., Solar thermal propulsion for an interstellar probe, AIAA 2001-3377, 37th AIAA/ASME/SAE/ASE Joint Propulsion Conference, Salt Lake City, UT, July 8-11, 2001.

Ultra-low power and/or power consumption electronics – A generic issue for the proposed spacecraft, as well as other deep-space, highly-capable spacecraft with low mass and very-long lifetimes, is developing electronics implementations and packaging techniques needed to run cold and at sub-volt primary power levels. At the same time, available electronics and/or electronics fabrications techniques need to be used that can both be built and tested under non-cryogenic conditions. Again, fabrication of test hardware is required. Required power levels by sub-system are given in McNutt, R. L., Jr., G. B. Andrews, R. E. Gold, R. S. Bokulic, B. G. Boone, D. R. Haley, J. V. McAdams, B. D. Williams, M. P. Boyle, G. Starstrom, J. Riggin, D. Lester, R. Lyman, M. Ewing, R. Krishnan, D. Read, L. Naes, M. McPherson, and R. Deters, A realistic interstellar explorer, *Adv. Space Res*., in press, 2003.

Integrated laser-communications and guidance-control system for high-bandwidth, very deep-space communications – This includes both laser array development and development of the dielectric “Fresnel-lens” primary optic and its deployment mechanism. This also includes implementation with low-power electronics (see item 2). Some details of what has been done and what is needed are documented in Boone, B. G., R. S. Bokulic, G. B. Andrews, R. L. McNutt, Jr., and N. Dagalakis, Optical and microwave communications system conceptual design for a realistic interstellar explorer, *SPIE*, 4821, 225-236, 2002.

A low-mass structure that can deal with launch load and the thermal environment – The envisioned beryllium structure for the probe and the heat exchanger/thermal shield for the carrier both remain heavy (especially the latter). A fully-integrated mechanical model needs to be designed that uses the current configuration as a starting point, incorporates launch-load vibrational characteristics, and ends up with a self-consistent configuration light enough to launch, but strong enough to survive launch and the demanding thermal environment near the Sun (see reference given under point 2 above).

Americium-241-fueled radioisotope thermoelectric generator – This development would include both the cladding of Am-241 or its oxide and the development of a thermal design that can produce efficient power output at the reduced power level (down by a factor ~5 from Pu-238 heat output). A key development will be insulation system and the integrated converter design. This effort would need to be carried out by the Department of Energy and its designated contractors.

Development of the wireless bus – Some work is continuing at a low-level under other advanced technology development monies. Developed software needs to be ported to rad-hard low-power processors and demonstrated at low-power levels in a noisy (realistic) radio-frequency environment.

Low-mass, cold gas propulsion system components that combine a very low leakage rate and lower-power latch valves – The projected leakage rate the valve seats of current technology needs to be improved. There also needs to be development work on bringing down the required, albeit short-term, power required for opening and closing the latch valves.

Low-power electronics for an appropriate set of instruments – Follows from items 2 and 7 (correct interfaces are required).

Each of these "next steps" involves some combination of detailed engineering design and/or prototype development that incorporates development of new fabrication and/or manufacturing techniques. This suggests that any of these steps would require ~ $250,000 to ~ $500,000 each (up to ~ $4M for all of these) in order to make credible, substantive progress. This is a rough guess, not a cost proposal; if there is interest in actually following up on any of these tasks at the suggested funding level, an appropriate cost proposal and corresponding statement of work could be generated.

Mini-Magnetospheric Plasma Propulsion System, M2P2

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Top Three Enabling Technologies

Optimize plasma sources for M2P2 and solar wind surrogate – Substantial progress has been made over the last few years to build and optimize these sources and results to date are very encouraging, but more work is still required to decide which one is the best configuration for space qualification.

Access to larger chambers – The problem is trying to simulate space-like conditions - we can already prove that we are into the walls in 100 microseconds. After that all the results are due to wall interactions and extrapolation to space operation becomes almost impossible.

Force measurements – Because of above chamber wall interactions, thrust measurements are limited to short time scales. While thrust stands are available for impulse devices all are made for small devices. M2P2 can yield large thrust but also requires significantly more mass than typical plasma thrusters, so accurate measurements for the regime M2P2 has to operate in have never been developed.

What are the other technologies that are important for the further development of your concept?

Because of budget constraints are equipment has been scourged from spare parts from other labs (and even from dumpsters). Thus the device is developed only for laboratory applications and no consideration has really been made for conversion to light weight space qualified parts, no to minimize weight and thermal issues.

We are slowly converging on optimizing fuel, both with respect to type of gas, it s storage and consumption rate, but there is still a lot more work to fully optimize this critical parameter and verify it experimentally.

A Chameleon Suit to Liberate Human Exploration of Space Environments

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Top Three Enabling Technologies

Shape Change Polymers

Mechanically active polymers play an essential role in most of the concept implementations we have considered. They are the key to variable loft insulation that makes it practical to harness the space-suit's surface area to manage metabolic waste heat and control system thermal balance. Critical development here is increased energy efficiency, especially in holding position against small force loads, and increased environmental tolerance. Shape change polymers are also vital for active suit fit and assisted mobility aspects of the concept. Here, the importance of energy efficiency is increased, and greater force capability is required.

Selective chemical transport membranes

Advancing selective chemical transport membrane technology is essential to move the chemical aspects of atmospheric revitalization out of the backpack and into the suit. In turn, this is the key to reducing gas circulation energy requirements and simplifying interfaces between the pressure suit and life support system. Selective transport membranes will be required, not only for passive or active transport of carbon dioxide and water vapor out of the suit for rejection, but also for the management and separation of reactants and products as an integral part of any oxygen recovery implementation we have envisioned. Biomimetic membrane technology is included here.

Flexible (thin film and polymeric) photovoltaic systems

Increasing power availability is at the heart of advanced aspects of the Chameleon Suit concept, and the fundamental limitations of chemical storage systems make the use of harvested power essential. This will only be really attractive to the extent that much of the pressure suit surface area can be used for this purpose. This demands flexibility, increased durability. Increased efficiency is required both to increase the energy available and to limit adverse impacts on system thermal management.

Additional Enabling Technologies

- Photo-catalytic and electro-catalytic polymers will be essential for the implementation of in-suit oxygen recovery. These are seen as one part of the advancing science and technology broadly grouped under the term "artificial photosynthesis" that could enable the most advanced implementations of our concept.
- Conductive polymers/electro-textiles are essential for the practical implementation of the distributed functions and controls that our concept requires. These are not listed among the top three only because they are believed to be heavily supported for many other potential applications.
- Manufacturing technology for large-scale, polymer systems analogous to printed circuit boards/integrated circuits will be needed for practical Chameleon Suit manufacture. Both deposition/printing and photo-lithographic etching/diffusion techniques will be involved. This is anticipated as an evolutionary outgrowth of current conductive polymer / electro-textile development.
- Thin film/polymeric low temperature thermo-electric materials will be required for the integration of active heat pumping into the pressure suit walls to allow operation at high work rates in worst case thermal environments for some mission scenarios. The performance gains promised for these technologies will also enable energy harvesting at useful levels from waste heat.
- Infrared electro-chromic polymers will require further improvement in durability and performance to increase the level of heat transport control achievable with variable loft insulation. This is highly desirable, though not essential for Chameleon Suit thermal control concepts.
- Flexible, polymer-based, energy storage devices (both chemical batteries and "ultra-capacitor" type systems) are required to permit integrated local energy storage distributed over the pressure suit to minimize power

distribution penalties while dealing with time varying local supply (energy harvesting) and demand typical of most missions.

- Directional shading MEMS louvers conceived for operation on hot planetary surfaces (or near large hot vehicle surfaces) needs to be developed from concept to operational design. MEMS louvers have been produced experimentally for active control of space radiators, but integration of required surface reflectivity and directional (corner reflector) features as well as device integration with a flexible fabric structure is required for the envisioned Chameleon Suit use.

A Flexible Architecture for Plant Functional Genomics in Space Environments

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Top Three Enabling Technologies

Bioinformatics
Biological systems are much too complex to assess merely by looking at the expression of a few genes, especially for drawing meaningful conclusions about physiology and plant health. Not only measurements of mRNA levels, but proteomics and other developing measurements have the potential to drown us in data without giving any real insight. It is only when enormous datasets from different sources and different kinds of measurements on different species under different conditions are combined and organized in some sort of meaningful way that patterns and cause-and-effect scenarios will be worked out. A large amount of technology development in the area of bioinformatics will be necessary before this is possible.

Automated micro-fluidics
The ability to move micro- and nano-liter volumes around automatically and do chemistry with them will be essential to develop automated systems for assessing plant genetic responses. There currently are primitive advances in this direction including the "lab on a disk" concept which combines micro-fluidics with CD-ROM technology, but there are other ways that might bring "revolutionary, not incremental" progress. This is a field that will be important for any other NIAC (or NASA, for that matter) projects that involve doing any sort of automated chemistry. For example, an automated roving lab on Mars looking at different soil and rock samples or submersible testing water chemistry under the ice on Europa could use this kind of technology. The technology will also be important for the sort of medical monitoring that will be important in supporting human exploration of space.

Robotics and/or remote sensing
Robotics will be essential for the tasks needed to achieve plant genetic assessment, including visualization, sample collection, tending/harvest, environmental sensing, etc. Alternatively, if there was a way to make assessments of physiology without having to take a physical sample, that would ultimately make the process simpler and more useable, but more technology development would be needed upfront.