Space Transportation Architecture Studies
Final Review
NASA Headquarters

February 4, 1999

ORBITAL NON-PROPRIETARY

NORTHROP GRUMMAN

990202.02

Preface

"There is nothing more difficult to take in hand, nor perilous to conduct, nor more uncertain in its success, than to take the lead in the introduction of a new order of things … because the innovator has for enemies all those who have done well under the old conditions, and lukewarm defenders in those who may do well under the new"

- Machiavelli

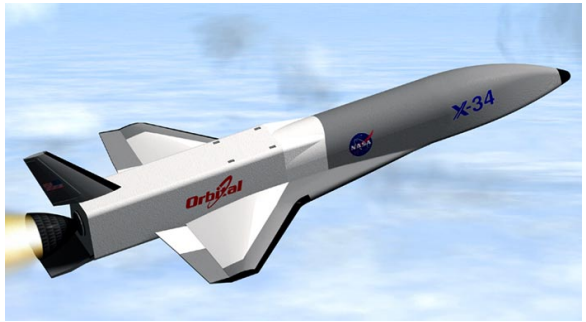
Agenda

- Study Approach
- Mission Analysis
- Master Investment Model
- Architecture Analysis
  - Scenario 1 Preferred Architecture (Shuttle-Based)
  - Scenario 2 and 3 Preferred Architectures
    - Space Taxi Approach
    - Multi-Role Reusable Vehicle (MRRV) Approach
    - Evaluation Criteria
- Finance/Regulatory Analysis
- Concluding Remarks

Study Approach

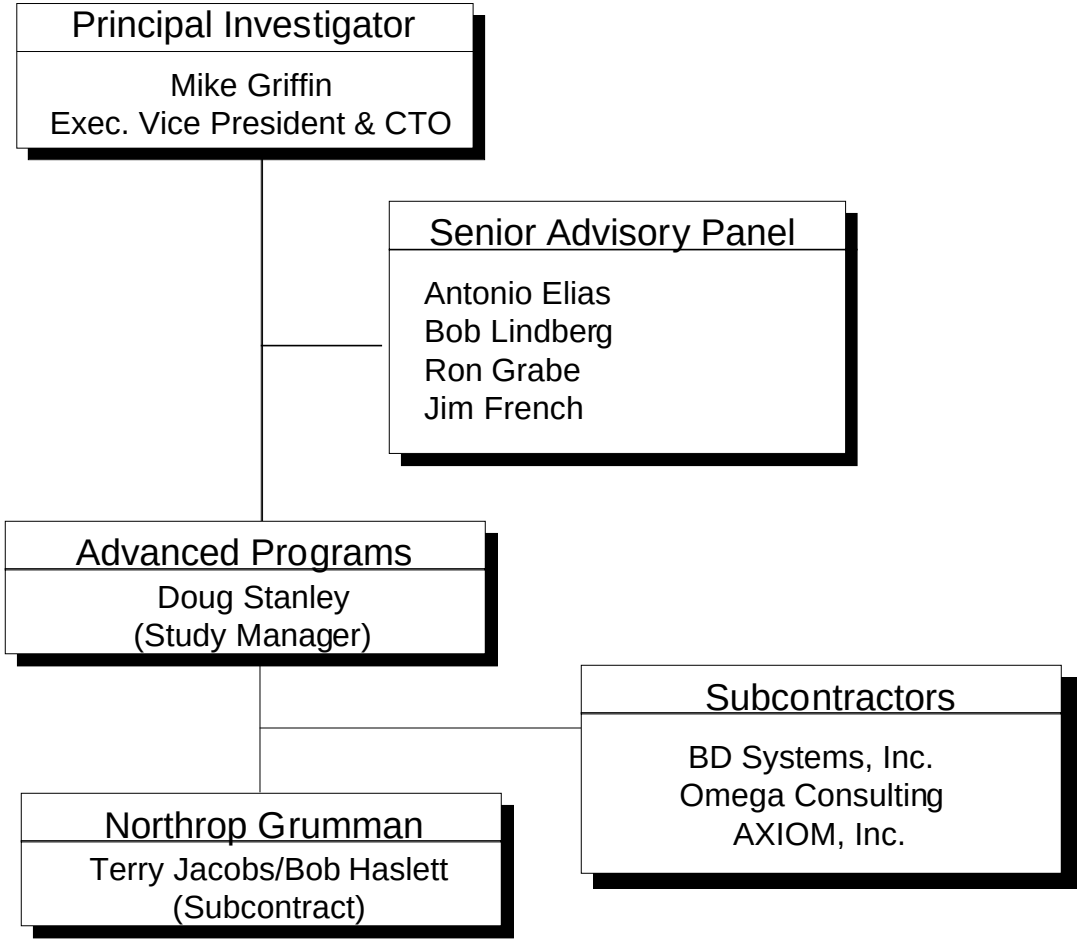
Why Orbital for STAS?

- No Vested Interest in Space Shuttle, LFBB or VentureStar
- Entrepreneurial, Innovative Approaches and Commercial Practices
- Launch Vehicle Development/Operations Experience
- X-34 RLV Experience
  - RLV Technology Testbed
  - Low-cost Operations Testbed
  - Autonomous Flight Control
  - All Composite Airframe
  - Reusable/Operable TPS



- Northrop Grumman as Study Partner
  - Strong History in Human Spaceflight (Apollo, STS, ISS)
  - State-of-the-Art Airframe Manufacturing Technology
  - Advanced Systems Study Experience (Vision Vehicle, MSP)

STAS Study Organization Chart



STAS Study Approach

Architecture Definition/Analysis
- Data Base Analysis
- Element/ Architecture Development
- Launch Costs for Baseline
- Launch Costs for Alternates
- Architecture Choices

Financing Alternatives
- Define Initial Options
- Create Master Investment Model (MIM)
- Iterate MIM with Various Options
- Summarize Results

Regulatory/Policy Considerations
- Identify Issues
- Define Needed Policy Changes
- Define Needed Regulatory Changes

NASA Investment Options

Technologies

Infrastructure

Commercial Partnerships

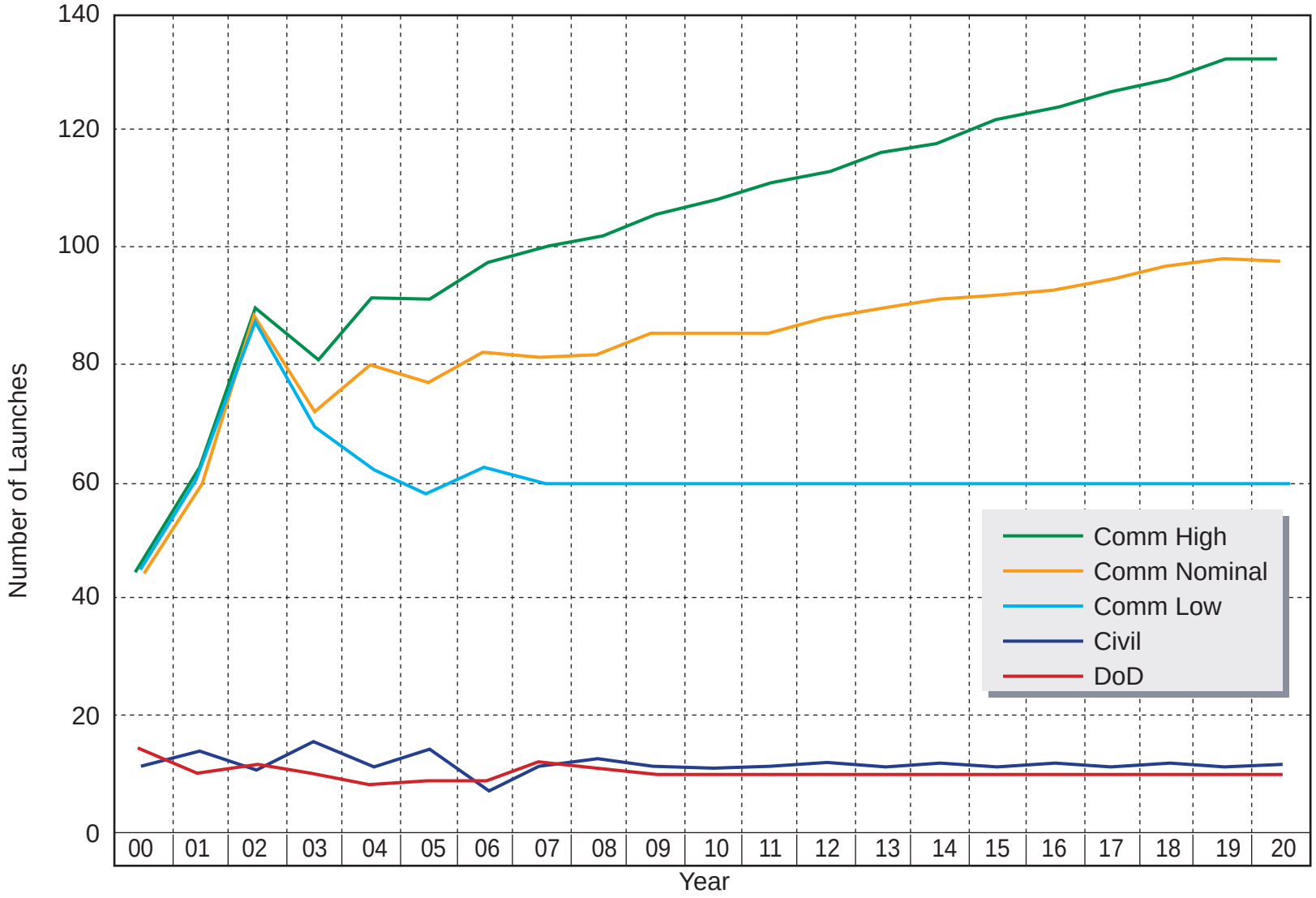
Mission Analysis

Mission Model Definition

- STAS Mission Model Defined from 2000-2020 by:
  - Payload Class (Small, Medium, Heavy)
  - Customer (DoD, NASA, Commercial)
  - Mission Category (Human, Human Cargo, Govt & Comm Cargo)
  - Nominal, High and Low Market Scenarios
  - Launch and Return

- Sources
  - STAS Document B
  - AFSC National Mission Model
  - OCST COMSTAC Mission Model
  - OCST LEO Commercial Market Projections
  - Aerospace Corp Future Spacelift Requirements Study
  - Commercial Space Transportation Study
  - DAC-6 and DAC-7 ISS Traffic Models
  - Orbital's Commercial Market Projections

Total Capturable Market by Customer (Non-ISS)



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Top Level ISS Requirements

- ISS Crew
  - Rotate at Least Three ISS Crew Members Every 90 Days
- Shuttle Crew (Seven Total)
  - Rotate Three Deconditioned Crew Members + One to Assist
  - Three Crew to Operate Shuttle and Perform ISS Maintenance
- Science
  - Provide 180 Days of Microgravity per Year
  - Provide Multiple 30 Day Microgravity Periods
  - Provide Late/Early Access to Middeck Locker Cargo
    - Within 72 Hours Prior to Launch
    - Approximately Two Hours After Landing
- Up Cargo Total = 94,490 lb/year
  - Pressurized = 71,500 lb (4 Shuttle Flights)
  - Unpressurized = 22,990 lb (1 Shuttle Flight)
- Down Cargo Total = 68,530 lb/year

ISS Resupply Requirements by Category

Cargo Type	Up Mass (kg)	Return Cargo (Downmass)	
		Recoverable (kg)	Non-Recoverable (kg)
Frozen Food	2,400	500	250
Ambient Food	1,150	300	300
Crew Clothes	2,400	1,450	950
Crew Miscellaneous	1,350	150	1,150
Crew Health Care System (CHeCS)	500	400	200
Pressurized Maintenance Logistics	4,550	3,900	650
Unpressurized Maintenance Logistics	6,650	4,300	2,350
Pressurized Scientific Utilization	13,800	12,250	1,550
Unpressurized Scientific Utilization	3,800	3,150	650
Extravehicular Activity (EVA) Equipment	1,100	1,100	—
Crew Rotation Gear	3,650	3,650	—
Water	1,050	—	—
Oxygen	350	—	—
Nitrogen	200	—	—
Total	**42,950**	**31,150**	**8,050**

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Mission Model Issues

- Non-ISS Mission Model Includes Orbital's Assumptions to Resolve:
  - Inconsistencies Between Mission Models
  - TBD's in STAS Document B
  - Lack of Visibility in Commercial Market after 2004
  - Lack of Visibility in All Markets After 2010
  - Capturable Foreign Market

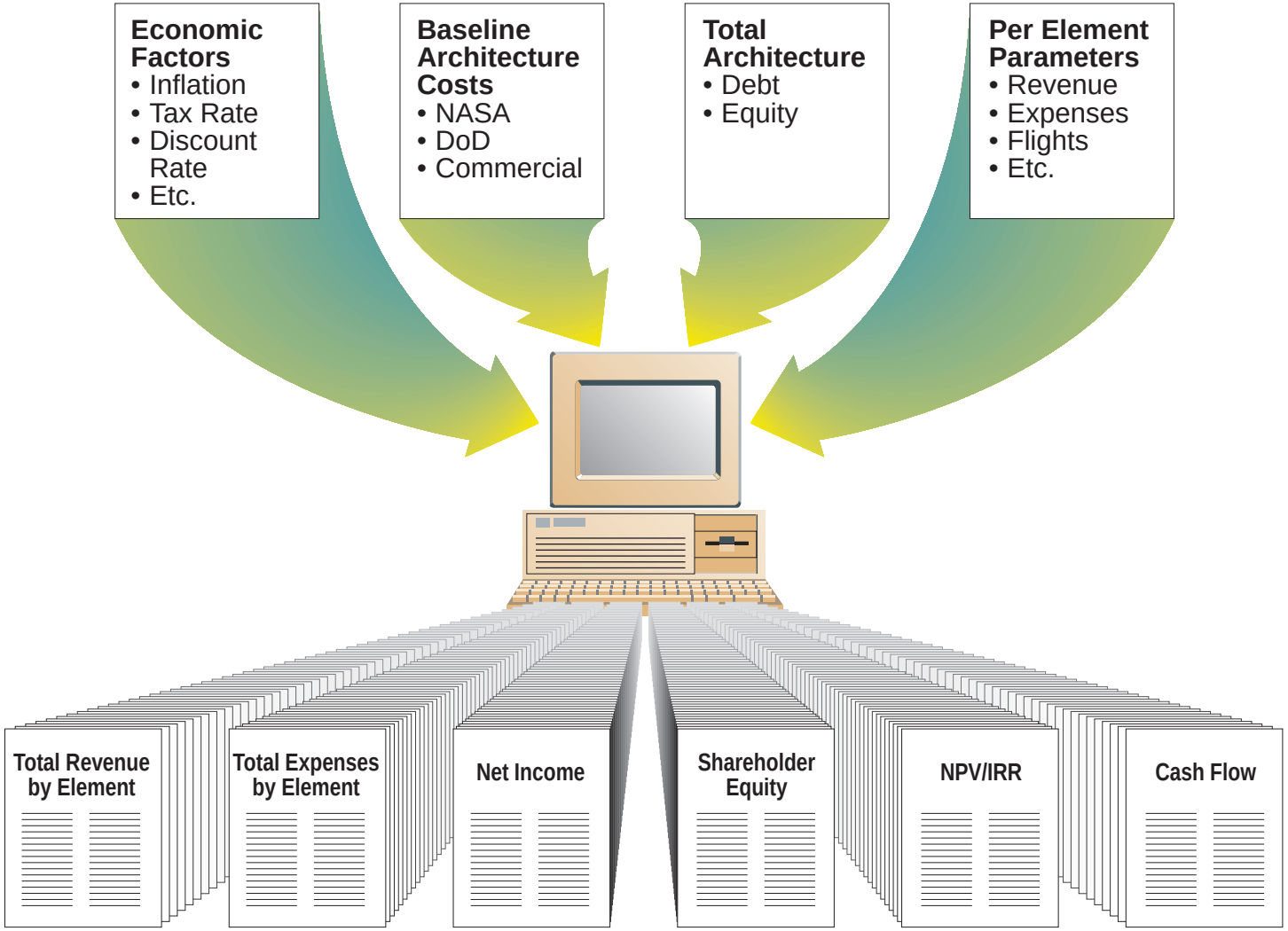
- Developed Price-Elasticity Models (One-Third of CSTS Elasticity)

- Developed Price-Capture Models (More Conservative Than CSTS)

- ISS Resupply Requirements Designed Around Shuttle
  - Sensitivity to Down-Payload Requirements
  - Cost of Expending Carriers, Instruments, Facilities, Etc.
  - Alternate Logistics Carrier Options
  - Design to Replace Rather Than Refurbish Maintenance Items

Master Investment Model

Master Investment Model Inputs/Outputs



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Architecture Analysis

"Architecture" Definition Issues

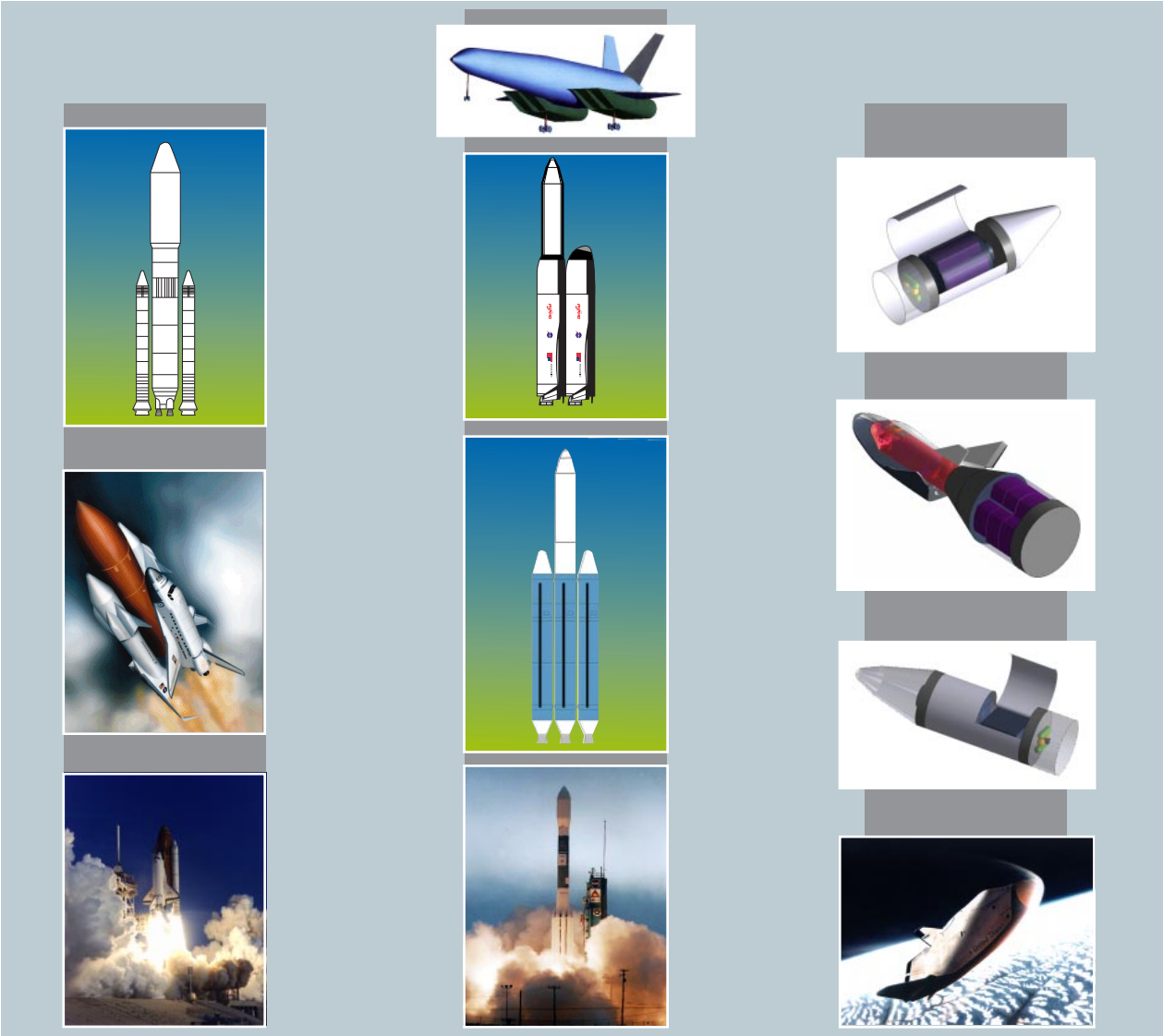
Scenario / Mission Set	Keep Shuttle Operational Until 2020	Replace Shuttle When Cost Effective	Assume NASA's FY99 Budget
Human Access	Architecture #1	Architecture #2	Architecture #3
Human-Related Cargo	Architecture #4	Architecture #5	Architecture #6
Government and Comm Cargo	Architecture #7	Architecture #8	Architecture #9

Sub-Architecture or Set of Elements

Global Architecture

- A True Architecture is a Set of Time-Phased Elements for a Given Scenario
- Individual Boxes are Really Sub-Architectures for a Given Mission Set
  - High Degree of Commonality Between Elements for Each Mission Set
  - Interactions Make Them Impossible/Undesirable to Analyze Separately
- We Will present a Preferred Global Architecture for Each Scenario

Sample Architecture Elements



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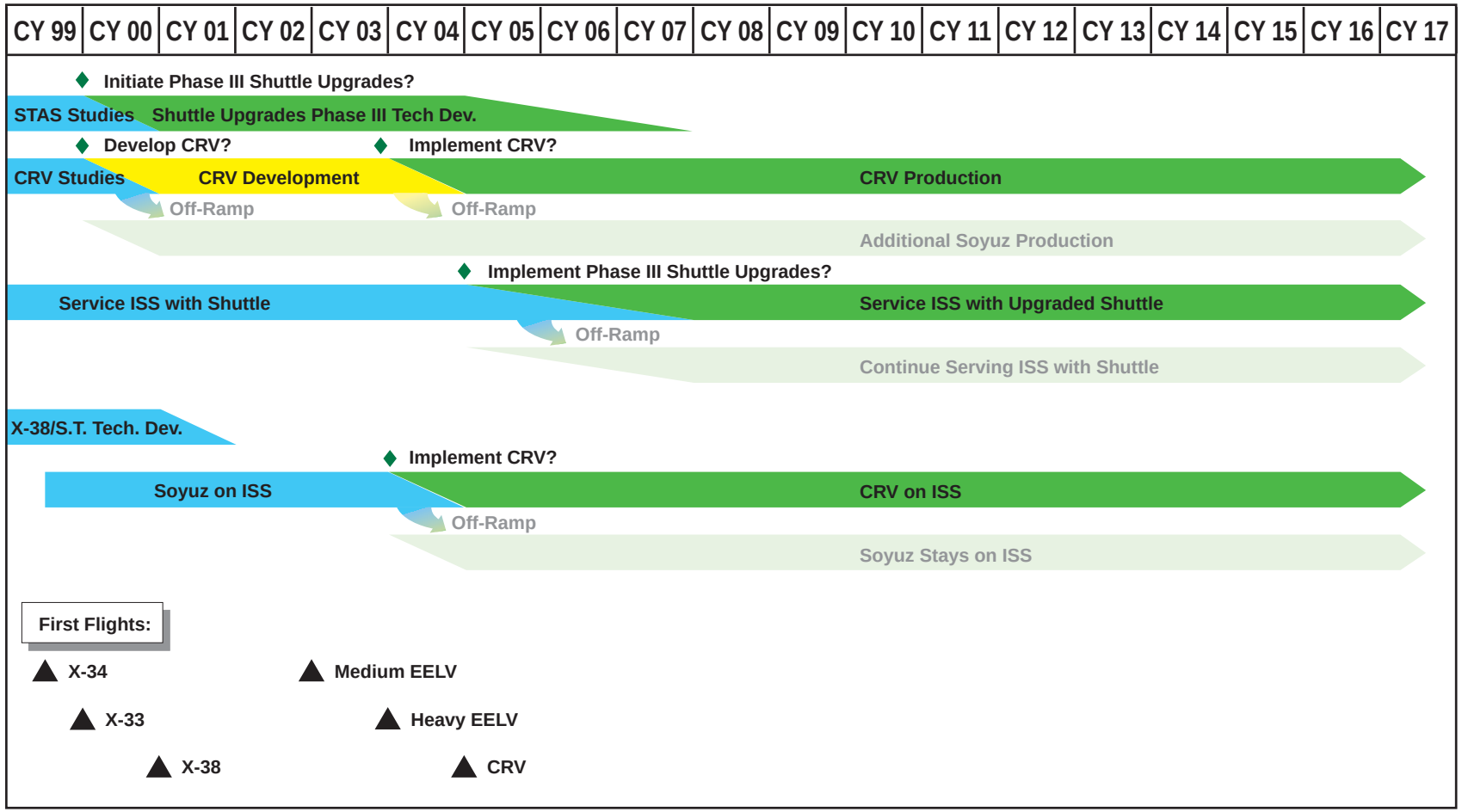
Scenario 1 Preferred Architecture

Scenario 1 Preferred Architecture Implementation Roadmap



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Human Rating Requirements

Area	Requirement
General	
1) Design for Human Space Flight	• Specifically Address Requirements for Human Rating
2) Aerospace Design Practice	• Comply with JSCM 8080.5 and Applicable MIL-STDs • Alternate Approaches Require Verification of Exceeding Accepted Approaches
3) Crew Habitability	• Comply with NASA Standard 3000 and NASA Space Flight Health Requirements
4) Flight Test	• Comprehensive Flight Test Program Prior to First Operational Flight with Humans
5) Proximity Operations	• Comply with Joint Requirements to Not Pose a Hazard to Either Vehicle • Provisions Shall Be Made to Enable Abort, Breakout, and Separation by Either Vehicle without Requirements Violation • Uncrewed Vehicles Must Permit Safety Critical Commanding from Crewed Vehicle
Safety & Reliability	
6) Crew Survival	• Cumulative Probability of Safe Crew Return >0.99
7) Crew Escape	• Provide Crew Escape Across Entire Flight Envelope • Escape System Probability of Successful Crew Return Is ≥0.99
8) Aborts	• For ETO, Abort Modes Provided for All Flight Phases
9) Flight Termination	• Provide for Safe Crew Recovery if a Flight Termination System Is Required
10) Flight Tolerance	• Crew Safety Critical Systems Shall Be Two-Fault Tolerant
11) Reliability Verification	• Verify by Test, Backed Up by Analysis, Prior to First Human Flight • Flight-Based Analysis and Health Monitoring on Each Flight
12) Software Reliability	• Testbed on Flight Equivalent Avionics Testbed Across Entire Flight Envelope Plus IV&V
Human-In-The-Loop	
13) Crew Role and Insight	• Provide Flight Crew with Command and Control Capability
14) Manual Control	• Crew Capable of Taking Manual Control During All Flight Phases • Vehicle to Exhibit Level I Handling Qualities (Cooper-Harper)
15) Human/Machine Interface	• Appropriate Use of Human Factors Engineering
16) Task Analysis	• Tasking Shall Not Adversely Impact Crew's Ability to Operate Vehicle

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Shuttle Human Rating Compliance

Requirement	Compliance
General	
1) Design for Human Space Flight	• Complies
2) Aerospace Design Practice	• Complies
3) Crew Habitability	• Complies
4) Flight Test	• STS Did Not Strictly Comply with This Requirement. While a Successful, Comprehensive Analysis, Simulation, and Ground Test Program Was Completed, There Was Very Limited Human Flight Testing
5) Proximity Operations	• Complies
Safety & Reliability	
6) Crew Survival	• STS Does Not Comply. Estimate of Overall Probability of Crew Survival Through 2020 Is Significantly Less Than .99
7) Crew Escape	• STS Does Not Comply. STS Provides Pre-Launch Crew Escape Provisions with a Slide-wire System, Post-Landing Emergency Egress Systems, and an In-Flight Crew Escape System That Is Usable Only During Controlled Gliding Flight
8) Aborts	• STS Partially Complies with This Requirement. STS Does Not Have Abort Modes During the First Stage Burn and Does Not Have a Launch Escape System
9) Flight Termination	• N/A
10) Flight Tolerance	• Complies
11) Reliability Verification	• Complies
12) Software Reliability	• Complies
Human-In-The-Loop	
13) Crew Role and Insight	• Complies
14) Manual Control	• Complies
15) Human/Machine Interface	• Complies
16) Task Analysis	• Complies

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CRV Human Rating Compliance

Requirement	Compliance
General	
1) Design for Human Space Flight	• Complies
2) Aerospace Design Practice	• Complies
3) Crew Habitability	• Complies
4) Flight Test	• Complies. Comprehensive Flight Test Program Described in Reference 21
5) Proximity Operations	• Complies
Safety & Reliability	
6) Crew Survival	• Partially Complies. The CRV Is Being Designed with the Probability of Crew Survival for a Single Return Mission of .99. If Multiple Missions Are Required before 2020, the Requirement Might Not Be Met
7) Crew Escape	• N/A
8) Aborts	• N/A
9) Flight Termination	• N/A
10) Flight Tolerance	• Partially Complies. CRV Designed for Minimum Single Fault Tolerance at End of 3-Year Mission Life. Probably Acceptable Given Short Reentry Mission Duration
11) Reliability Verification	• Complies (Reference 21)
12) Software Reliability	• Complies (Reference 21)
Human-In-The-Loop	
13) Crew Role and Insight	• Complies
14) Manual Control	• Does Not Comply. Does Not Exhibit Required Handling Qualities, But the Crew Will Have the Capability for Intervention During All Flight Phases. Probably Acceptable Given Infrequent Contingency Nature of CRV Function
15) Human/Machine Interface	• Complies
16) Task Analysis	• Complies, but Crew Does Not Strictly Operate the Vehicle

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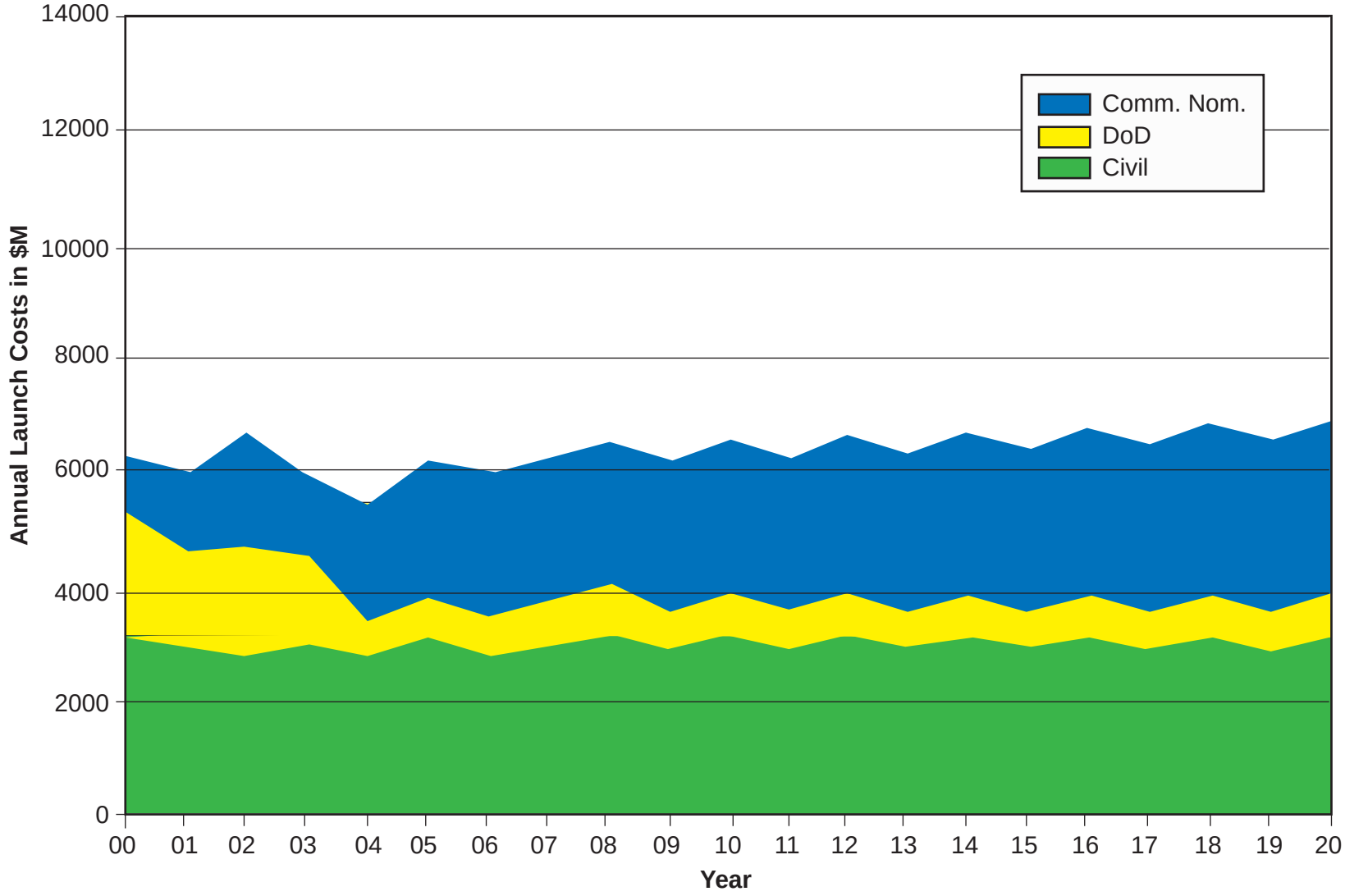
Cost of Launching Scenario 1 Mission Model ('00 Dollars)



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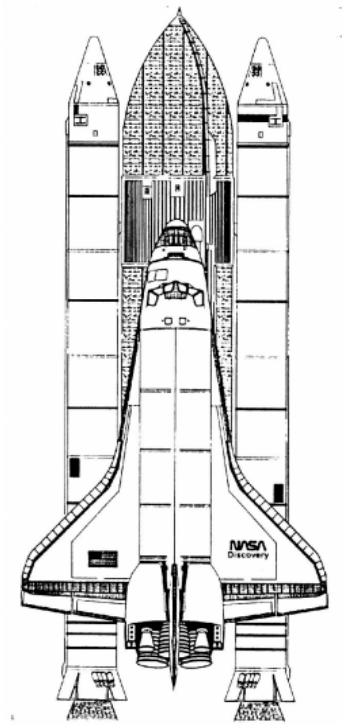
Liquid Flyback Booster

- Increases Payload
  - Increase ISS P/L Capability by 45 klbs
  - Shuttle Landing Capability Limits to 9 klbs
- Potentially Enhances Safety
  - Eliminates RTLS and TAL Aborts
  - Crewed First Flight Adds Risk
- Enhances Growth Capability (HLLV)
- Cost Estimates (NPV = -$2.3 B)
  - $5.2B DDT&E (Includes Three Shipsets)
  - $40M Decrease in Shuttle Ops Cost per Flight
  - $3-7B DDT&E Leads To NPV of -$211M to -$4B
  - $60-20M Ops Savings Leads to NPV of -$984M to -$3.6B

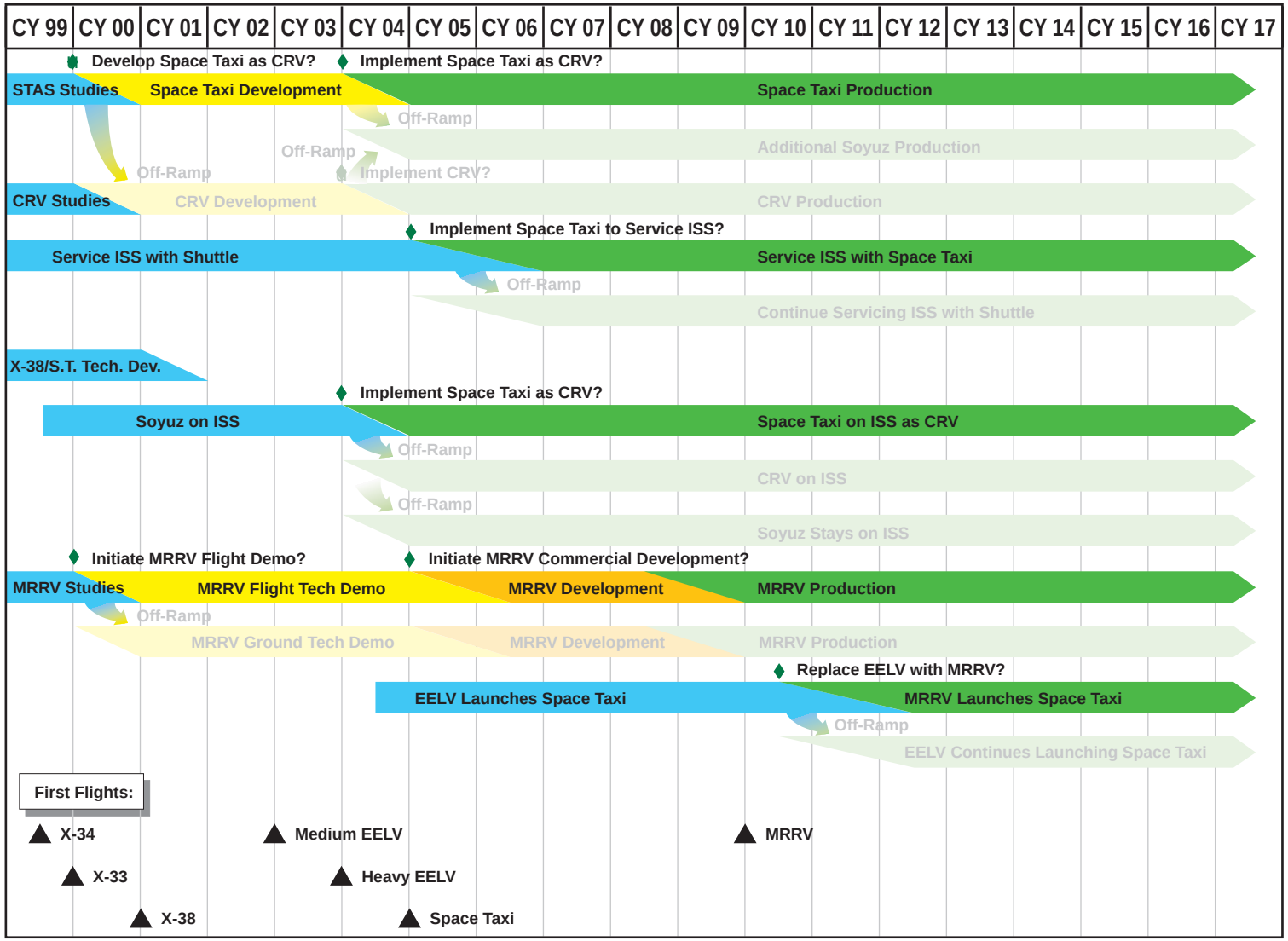
Five Segment Solid Rocket Booster

- Increased Payload
  - Increase ISS P/L by 19 klbs
  - Shuttle Landing Capability Limits to 9 klbs
- Enhances Safety
  - Eliminates Deep Throttling of SSME
  - Reduces RTLS Abort Window
  - Crewed First Flight Adds Risk
- Enhances Growth Capability (HLLV)
- Cost Estimates (NPV = -$1.2 B)
  - $700M DDT&E
  - $8M Increase in Shuttle Ops Cost per Flight
  - $500M to $1B DDT&E Leads To NPV of -$1 to -1.5B
  - $0-16M Ops Cost Increase Leads to NPV of -$670M to -$1.7B



Scenario 2 Preferred Architecture

Scenario 2 and 3 Preferred Architecture Implementation Roadmap



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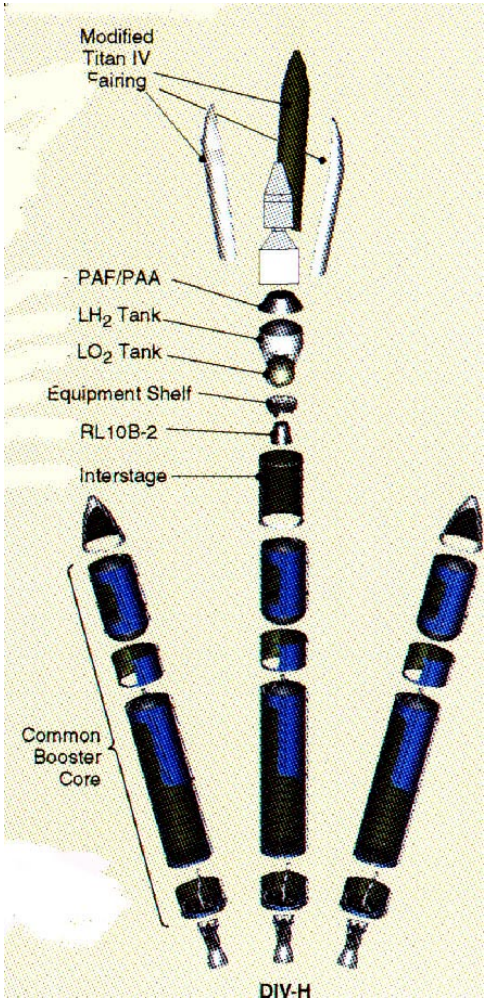
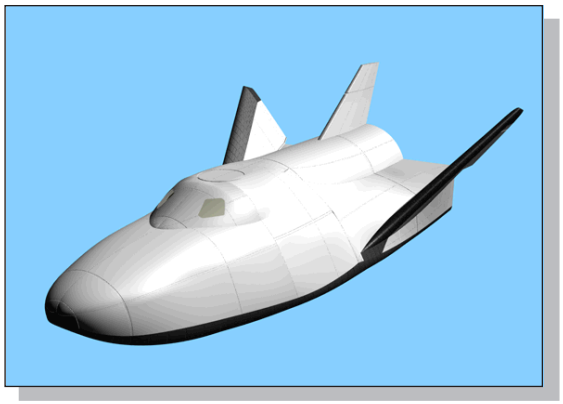
Space Taxi System Approach

Heavy-Lift EELV

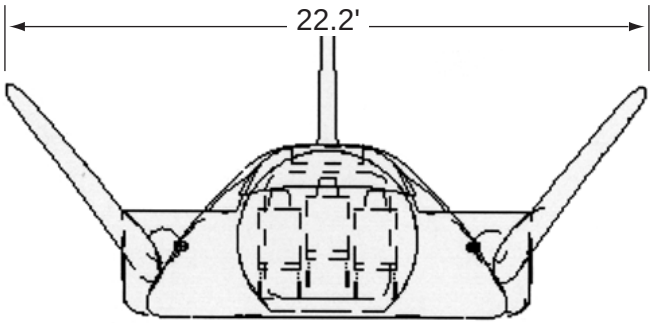
- Baseline is Delta IV
  - Ref: Boeing Payload Planners Guide
  - Lockheed EELV Provides Alternate Option
- Payload to ISS (5.1m second stage)
  - Orbit 460 km, 51.6 deg
  - Payload Wgt = 50,000 lbs
  - Fairing (65 ft) Wgt = 8,544 lbs
  - Attach Fitting Wgt = 1,146 lbs
  - Total Wgt to ISS > 59,000 lbs
- Initial Operating Capability 2003 - 2004
- Launch Cost ~ $135M
- Reliability > .98



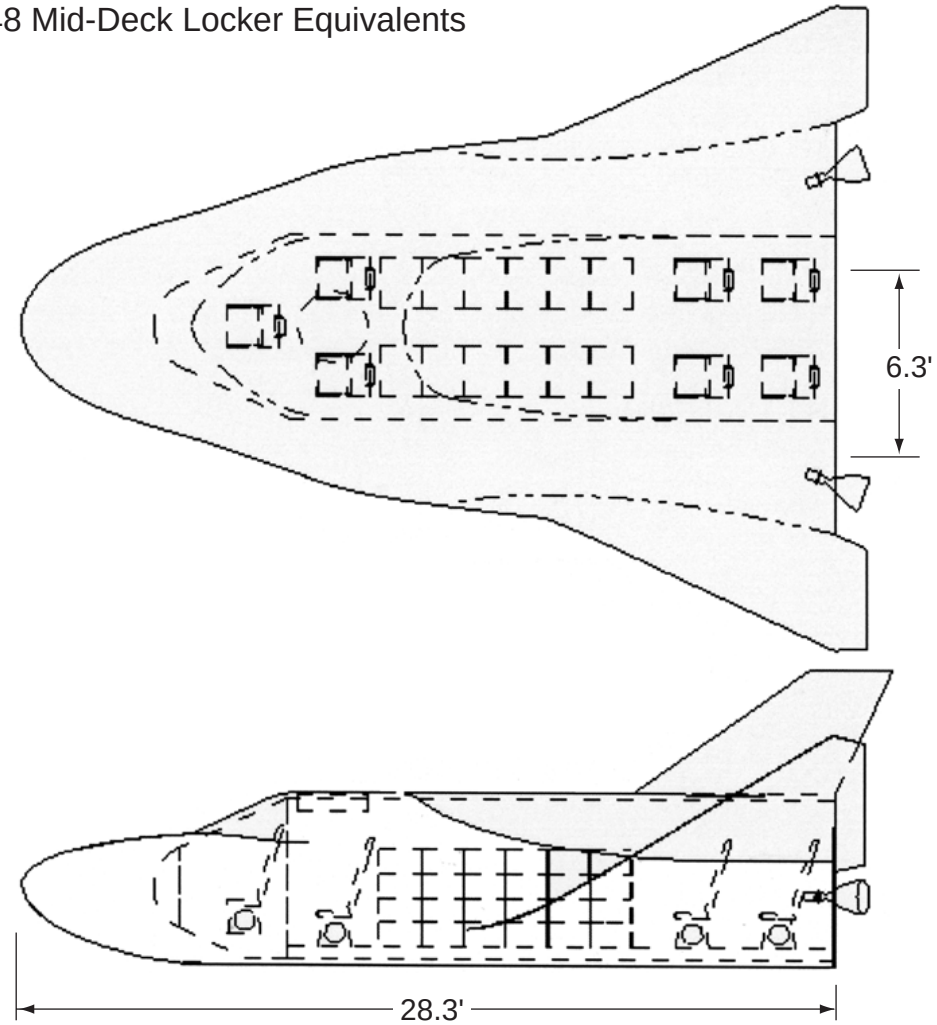
Space Taxi Reference Configuration



Weight Empty (Dry)	19,667 lb
Crew and Payload	3,974 lb
Fluids and Residuals	400 lb
Consumables	4,500 lb
Glider TOGW	28,541 lb
Abort Stage Plus Adapter	8,700 lb
Total Launch Weight	37,241 lb



Seven Crew
48 Mid-Deck Locker Equivalents



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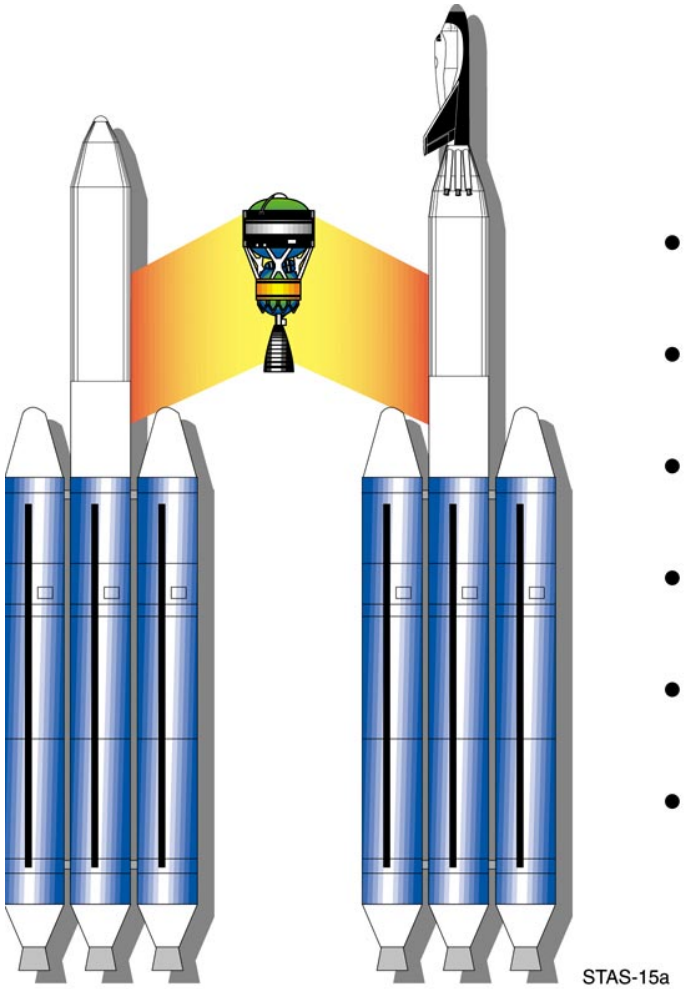
Space Taxi Approach



- Separate Crew and Most Cargo
- Launch on Delta IV Heavy EELV
- Delta III Upper Stage
- Abort Throughout Flight Regime
- Synergy with Commercial GEO
- Cargo Carrier Behind Space Taxi

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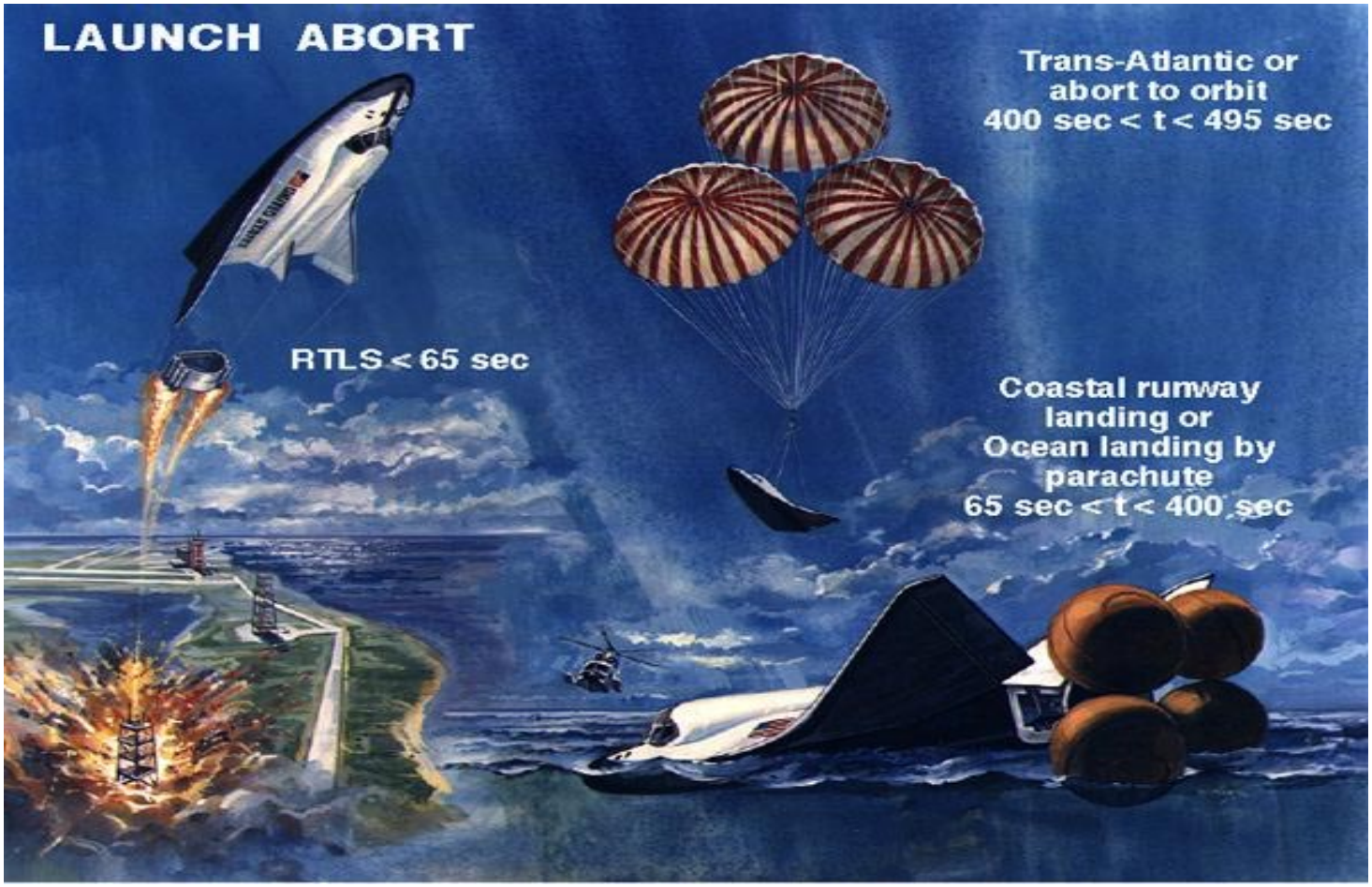
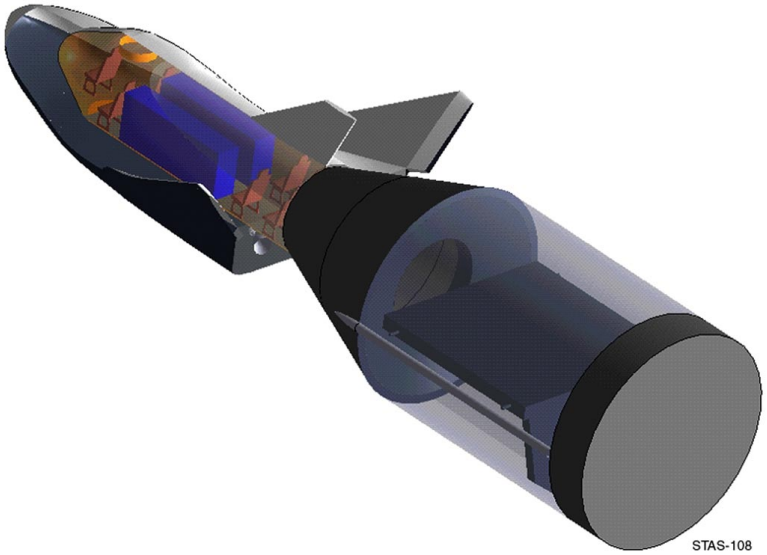
Space Taxi Abort Approach

- Recoverable Throughout Flight Profile (Human Rated)

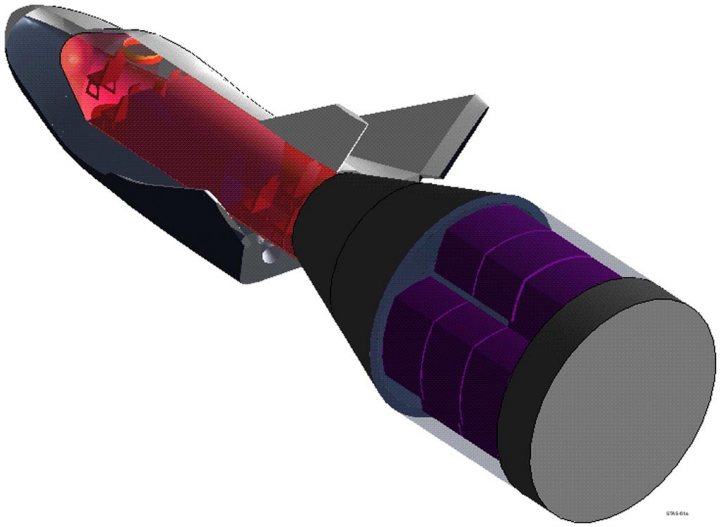


Space Taxi PLV/UPLV Configuration

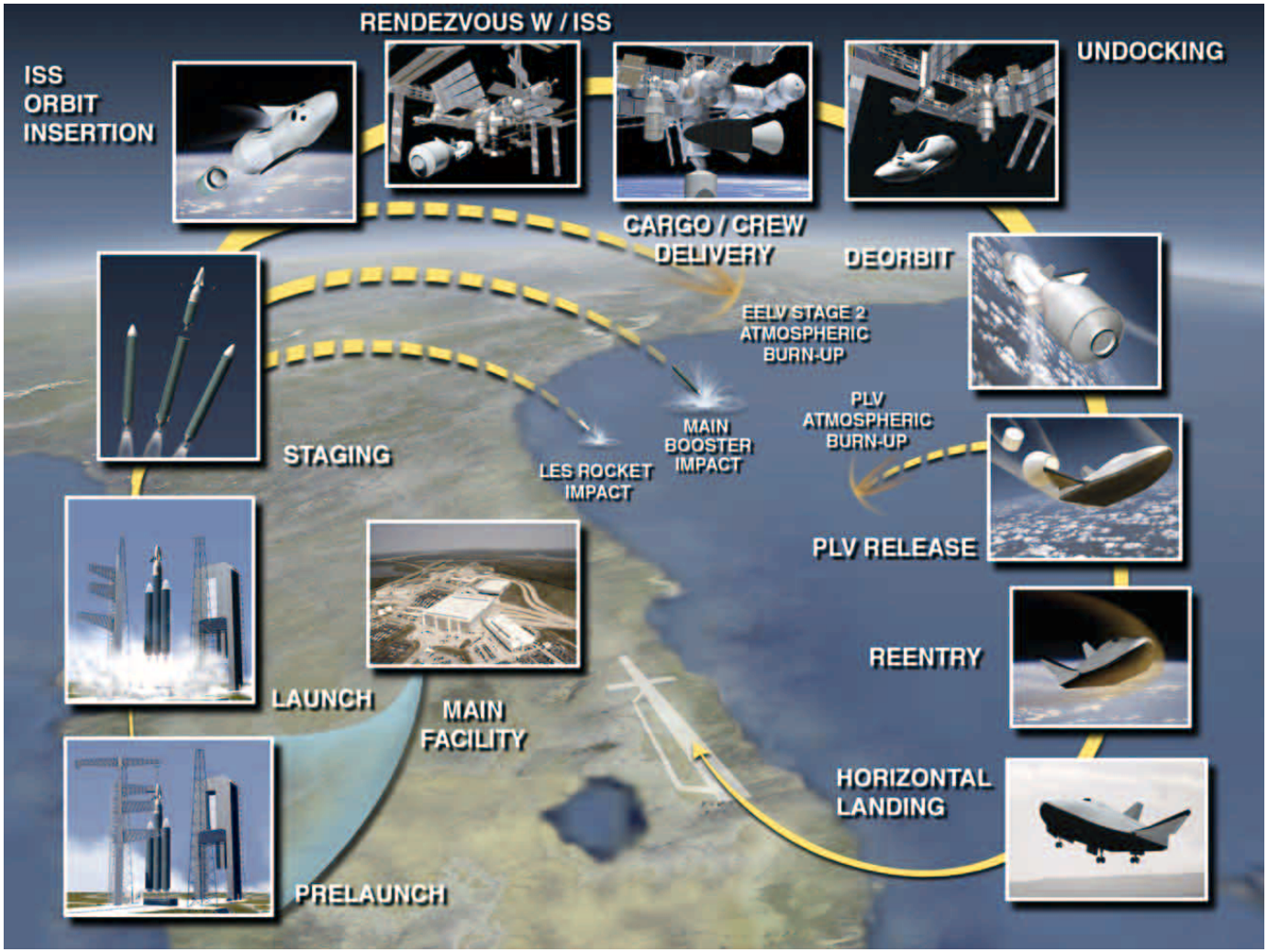
Space Taxi w/UPLV



Space Taxi w/PLV



Space Taxi/EELV Mission Profile



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Space Taxi Technology Requirements

Vehicle Systems	Current TRL	Reference	Back-Up
Cabin Pressure Vessel	6	Aluminum-Lithium	Aluminum
External Body Structure	5	Graphite-BMI	Graphite-Epoxy
Lower TPS	5	AETB/TUFI Tile	HTP-6 (FRCI) Tile
Upper TPS	5	PBI Blanket	FRSI Blanket
Nose/Leading Edge TPS	5	C/SiC Hot Structure	ACC Hot Structure
Fins	5	Graphite-BMI/TPS	Graphite-Epoxy/TPS
Landing Gear	6	Adapted Electric Fighter Gear	Adapted Hydraulic Fighter Gear
Actuators	5	Electromechanical	Hydraulic
Avionics	6	SOA w/IVHM/DGPS	SOA w/DGPS
RCS Propulsion	5	H202 Mono-propellant	Hydrazine
OMS Propulsion	5	H202/JP-4	MMH/N202
Prime Power	5	Rechargeable Batteries (Ag-Zn)	H202 APU
ECLSS	6	Shuttle SOA	Shuttle SOA
Recovery/Abort	6	SOA Chutes/Solids	SOA Chutes/Solids
Personnel Accommodations	6	Apollo SOA	Apollo SOA

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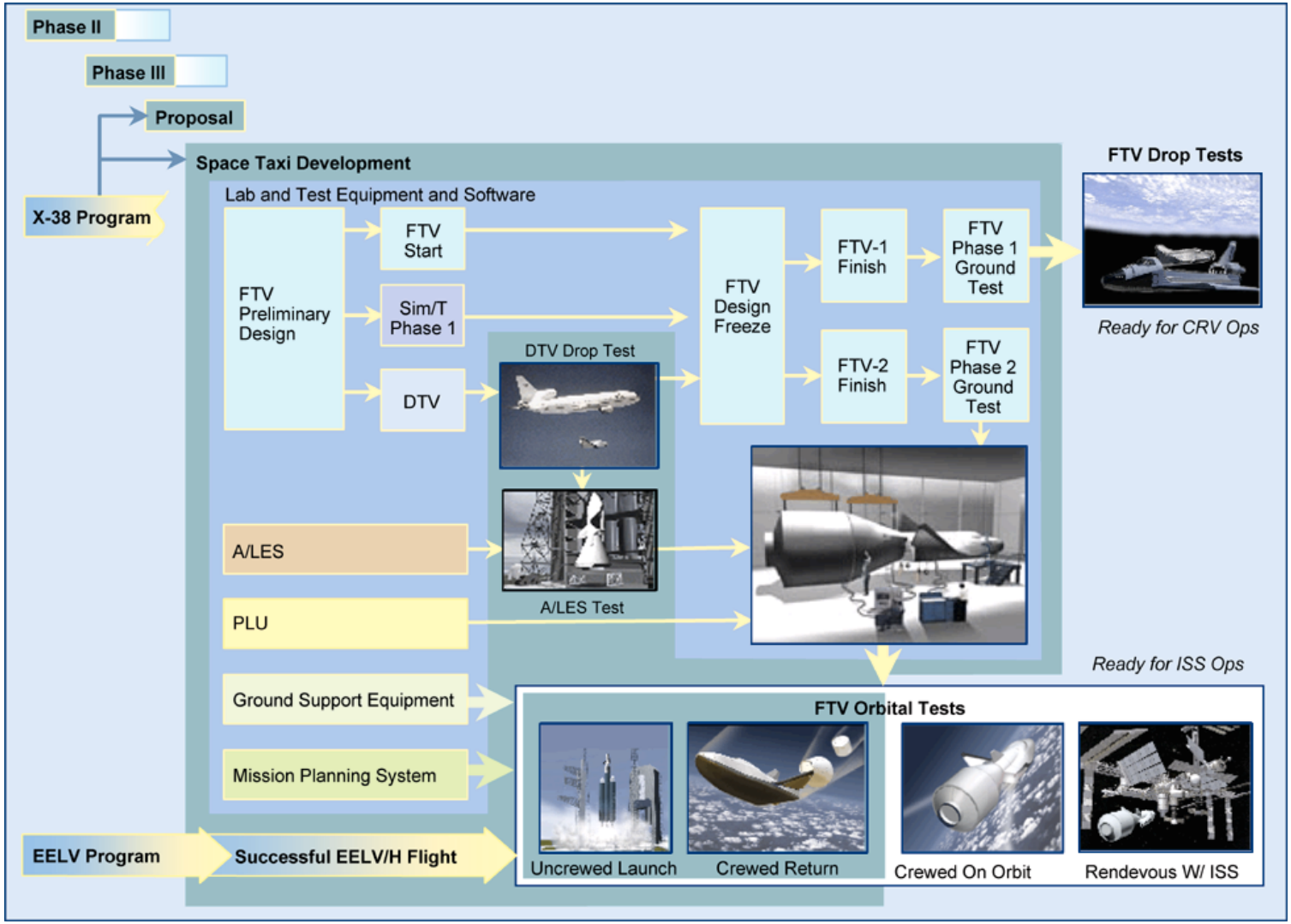
Space Taxi Development Program



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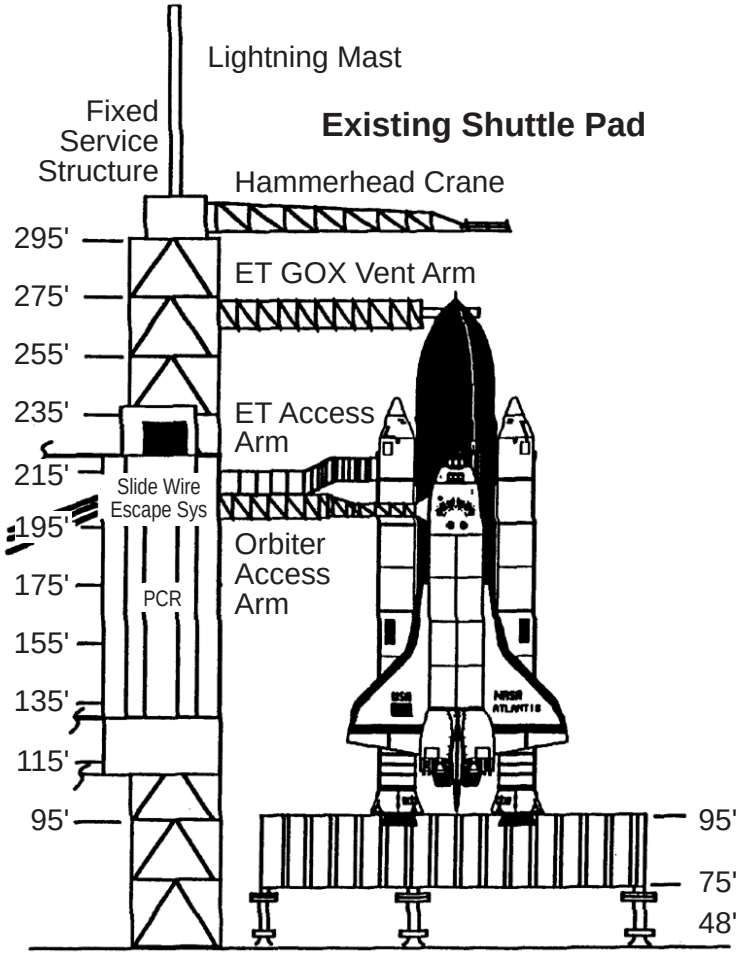
Shuttle/Space Taxi Launch Facilities



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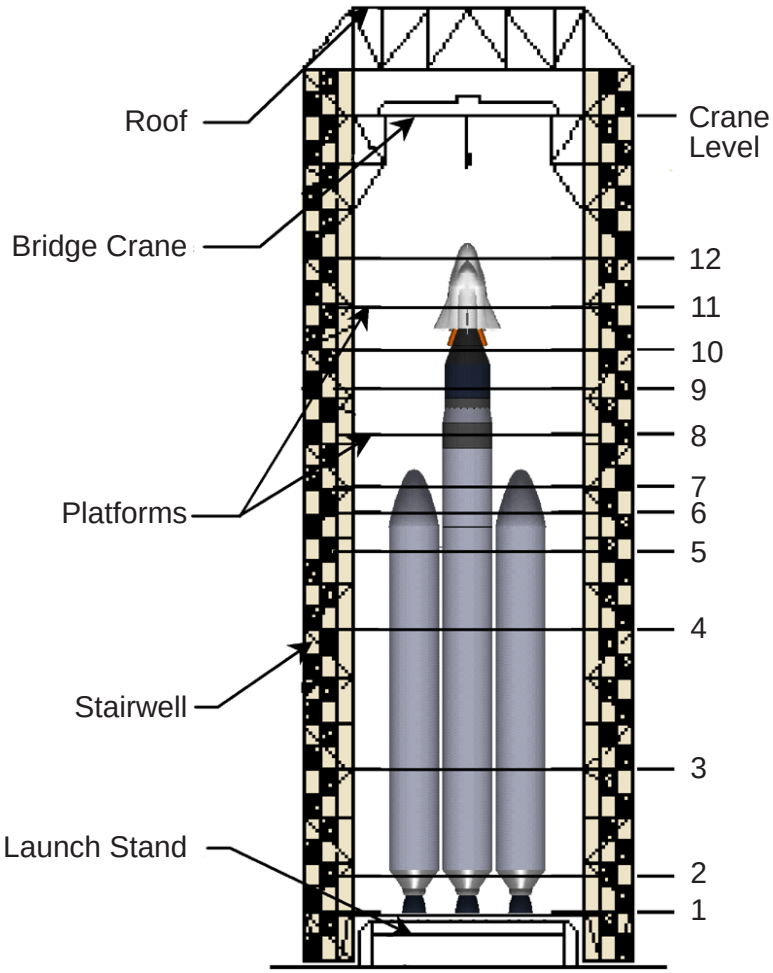

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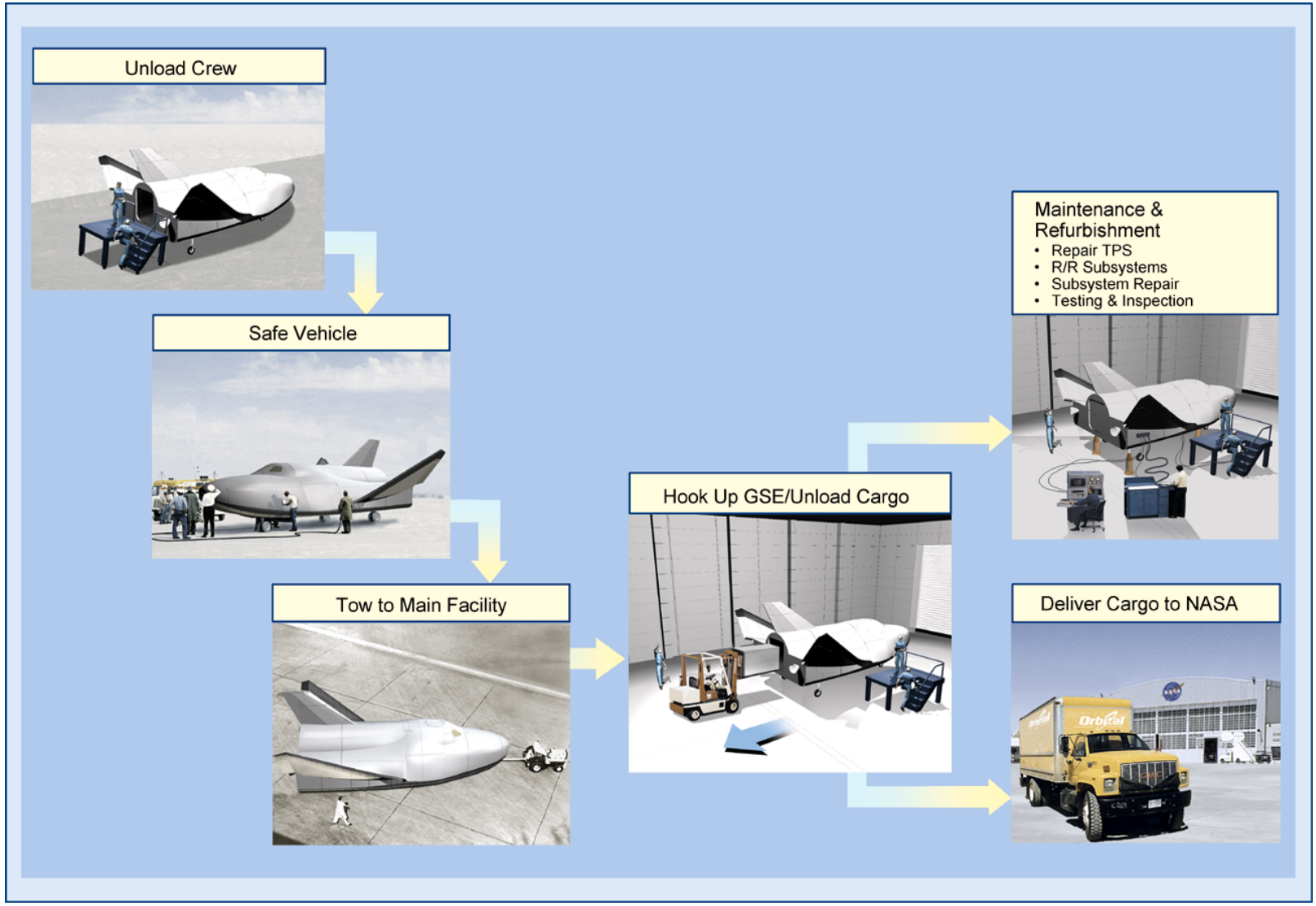
Space Taxi/EELV Recovery Operations



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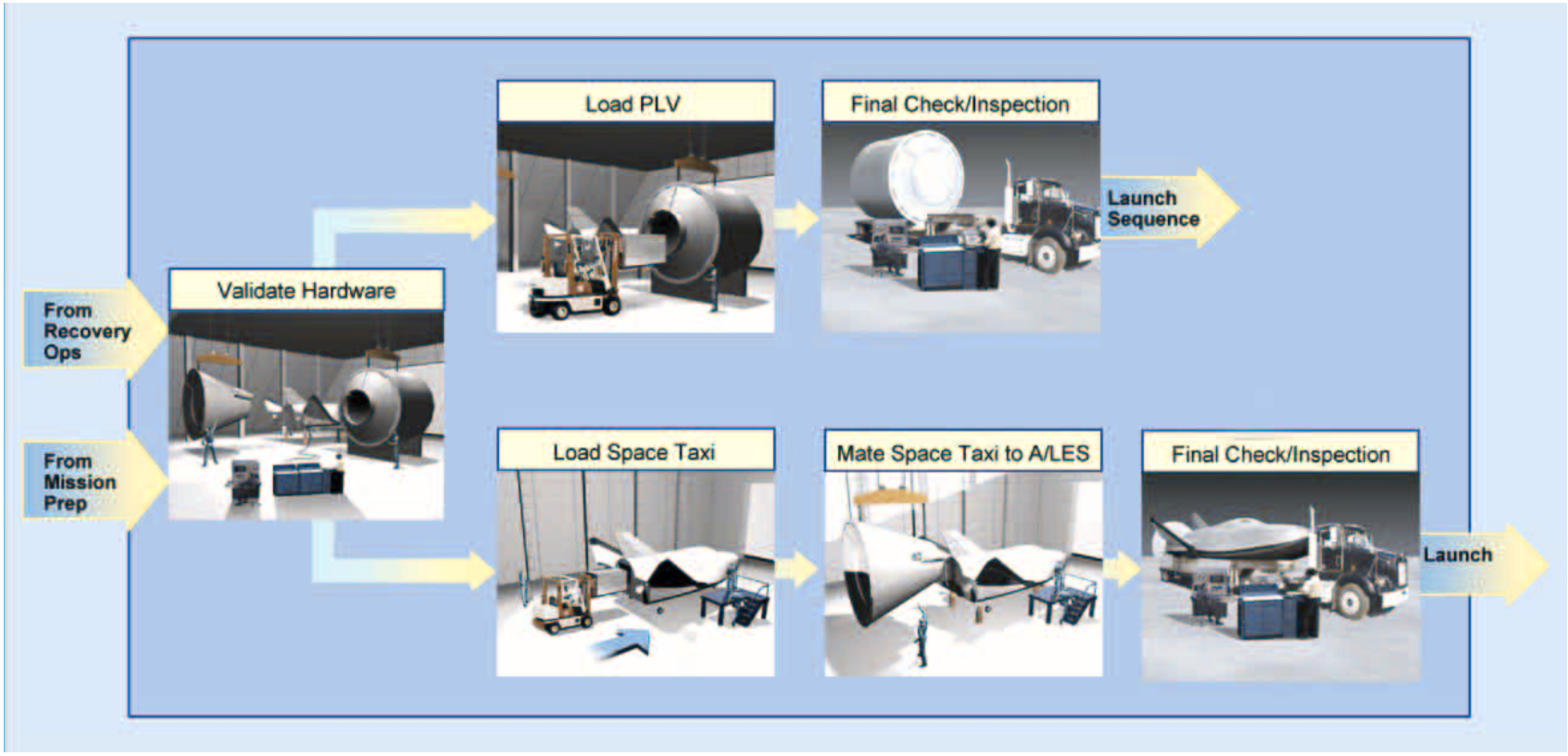
Space Taxi/EELV Hardware Preparation



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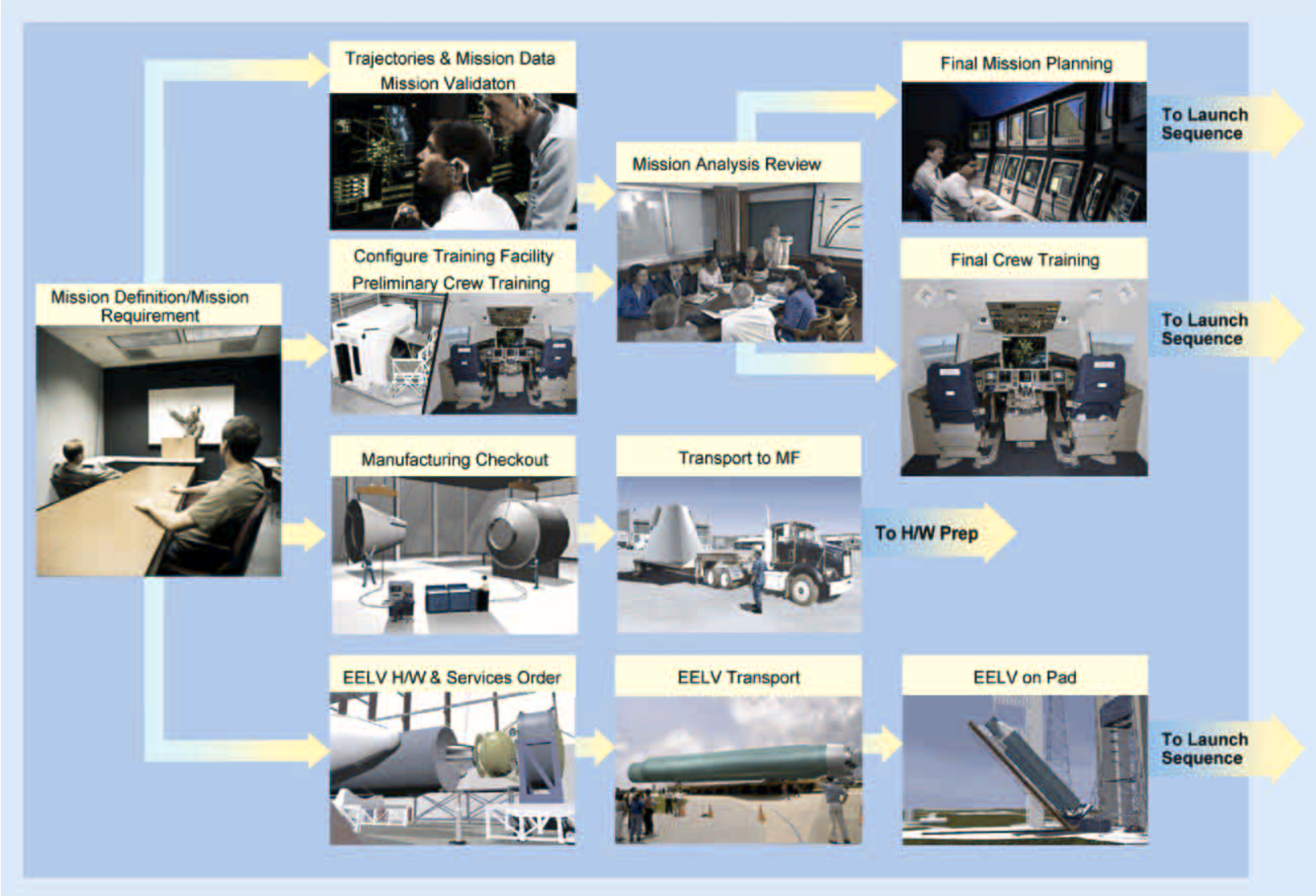
Space Taxi/EELV Mission Preparation



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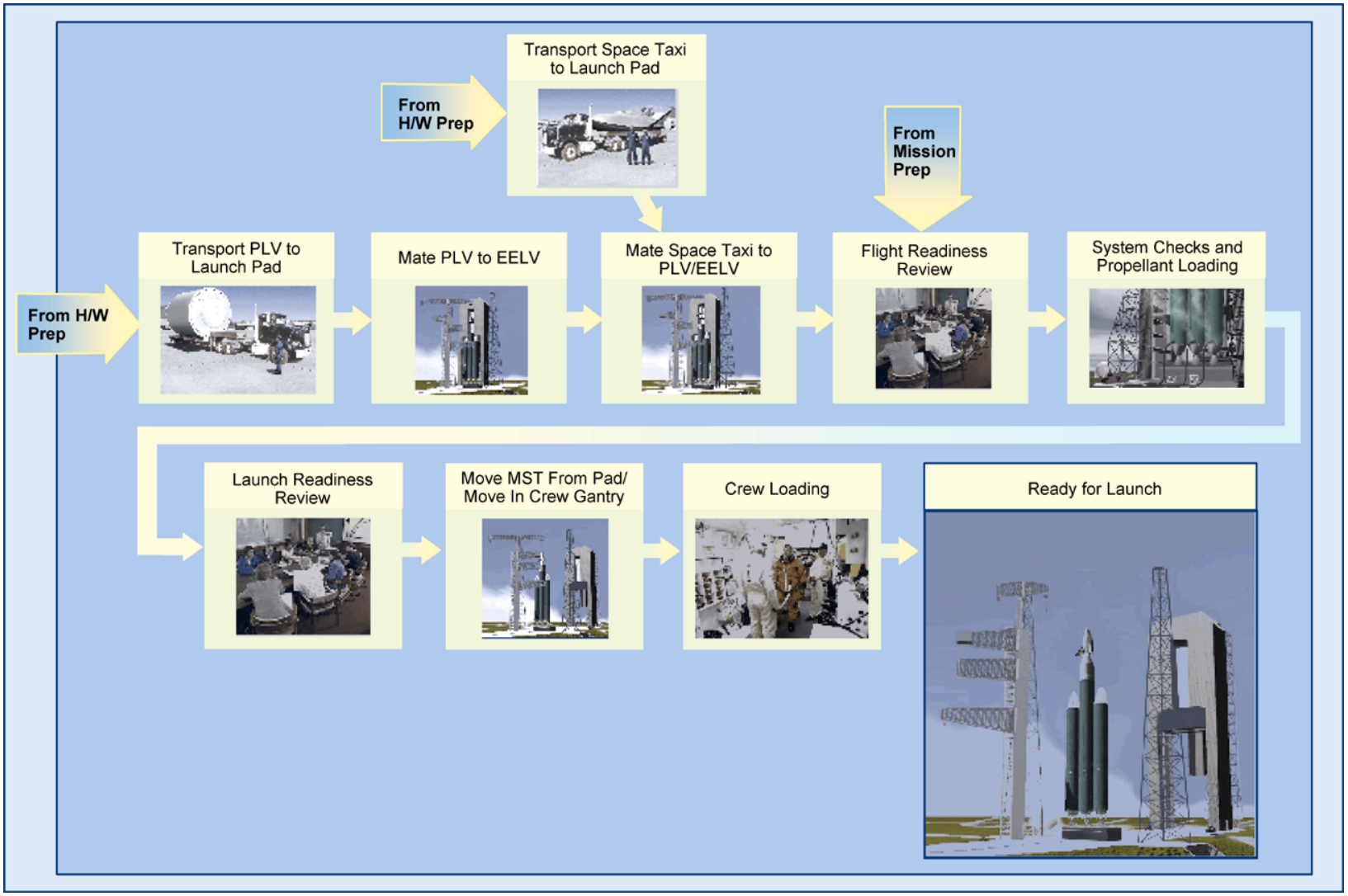
Space Taxi/EELV Launch Sequence



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Space Taxi Advantages

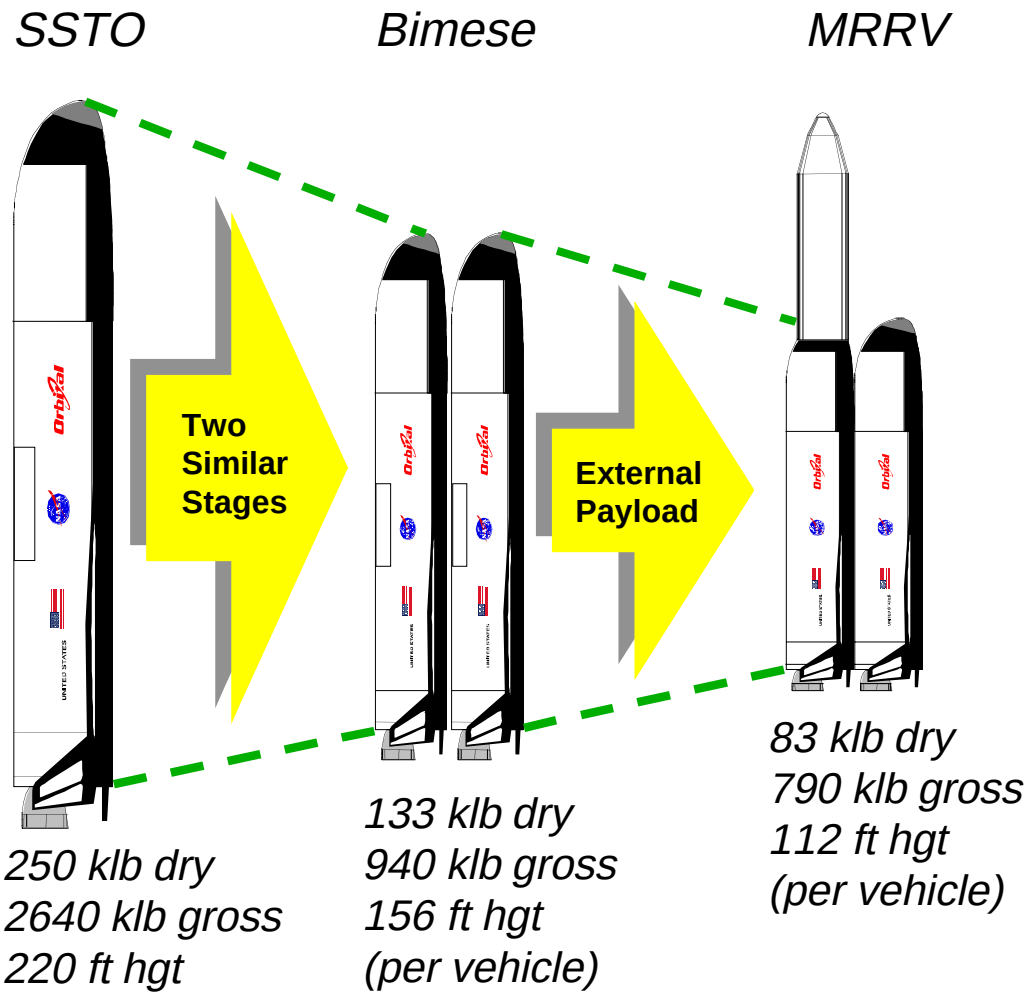
- "Right-Sized" Vehicle for Crew Rotation (Don't Risk Crew on Cargo Flights)
- Multi-Functionality Reduces Cost (CTV, CRV, RLV Crew Module)
  - Low Marginal Cost Over Required CRV
  - Reduces Peak Year Funding
  - Eases Shuttle Transition
- Can Be Launched on Multiple Boosters
  - EELV
  - Foreign Vehicles (Ariane V, Proton, HII)
  - Future RLV
- Relatively Inexpensive Alternate Access for ISS
- Smaller, Lighter Vehicle for Orbital Maneuvers and ISS Docking
- Low Technical Risk Compared to Near-Term SSTO

Space Taxi Advantages (Cont.)

- Meets All Human Rating Requirements
  - Safe Abort/Crew Recovery Throughout Flight Regime
  - Pilot Can Fly and Land on Conventional Runway with Direct Visibility
- Detailed Database from HL-20 and Russian Heritage
  - Aerodynamics
  - Aerothermal
  - Flight Control
- High Hypersonic and Subsonic L/D
  - High Crossrange for Landing Flexibility
  - Runway Landing at Reasonable Speed
- Low-g Entry for Injured, Sick, or Deconditioned Crew Member
- Alternate Applications (Commercial, Military, and Exploration)

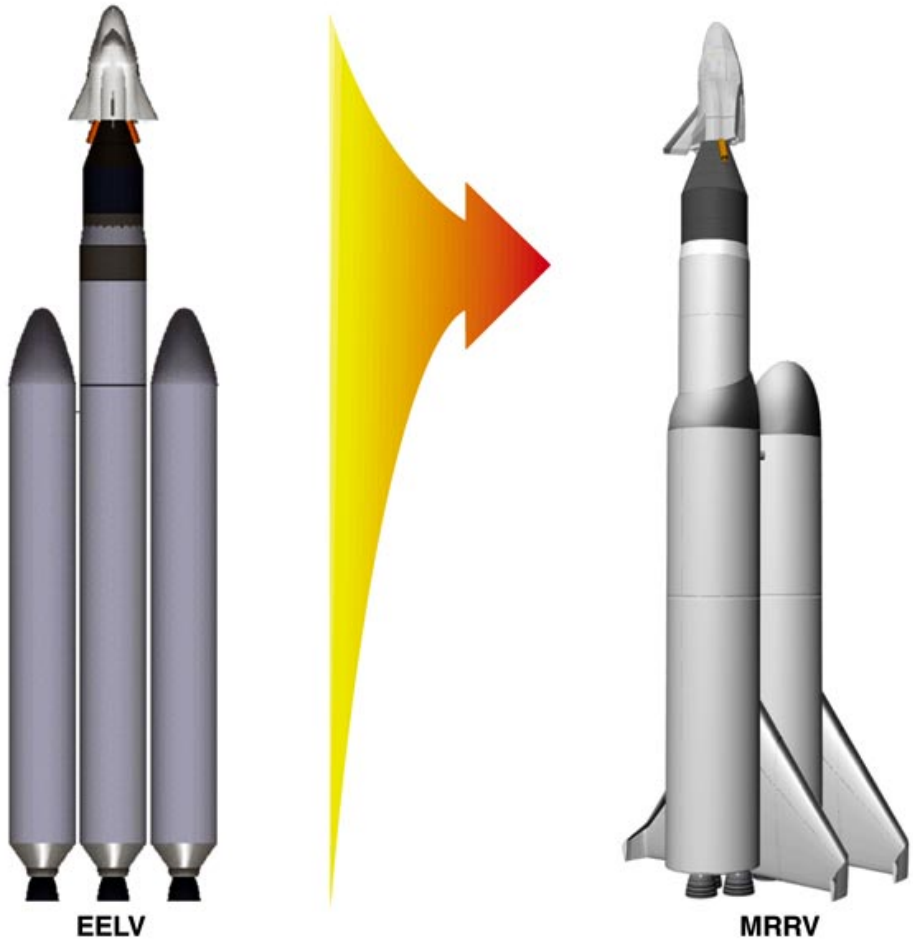
Multi-Role Reusable Vehicle (MRRV) Approach

Multi-Role Reusable Vehicle (MRRV) Approach



- *Sized for 25 klb Cargo Delivery to ISS*
- *X-33/X-34 Program Technologies*

Transition from EELV to MRRV



- Same Space Taxi
- Same Upper Stages
- Same Fairings

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Space Taxi/MRRV Mission Profile

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MRRV Technology Requirements

Vehicle Systems	Current TRL	Reference	Back-Up
LH2/LO2 Cryogenic Tanks	5	Aluminum-Lithium Isogrid	Aluminum Skin/Stringer
Fuselage Structure	4	Graphite-Polyimide Honeycomb	Graphite-BMI Honeycomb
Wing Structure	4	Graphite-Polyimide Honeycomb	Graphite-BMI Honeycomb
Payload Fairing	6	Graphite-Epoxy	Aluminum-Lithium
Lower TPS	4	AETB/CMC Tile	AETB/TUFI Tile
Upper TPS	5	PBI Blanket	FRSI Blanket
Nose/Leading Edge TPS	5	C/SiC Hot Structure	SIRCA
Body Flap/Elevons	5	C/SiC Hot Structure	Graphite-BMI w/AETB/TUFI Tile
Landing Gear	5	All-Electric Gear	Hydraulic Gear
Actuators	5	Electromechanical	Hydraulic
Avionics	5	SOA w/IVHM/DGPS/AGN&C	SOA w/IVHM/DGPS
RCS Propulsion	4	Gaseous O2/H2	Gaseous Methane/O2
OMS Propulsion	4	Liquid O2/H2	Liquid Methane/O2
Prime Power	4	High Power O2/H2 Fuel Cells	SOA Fuel Cells/APUs
Main Propulsion	4	RS-2100 FFSCC	Modified SSME
Propellant Feed Lines	5	Graphite-Epoxy	Inconel

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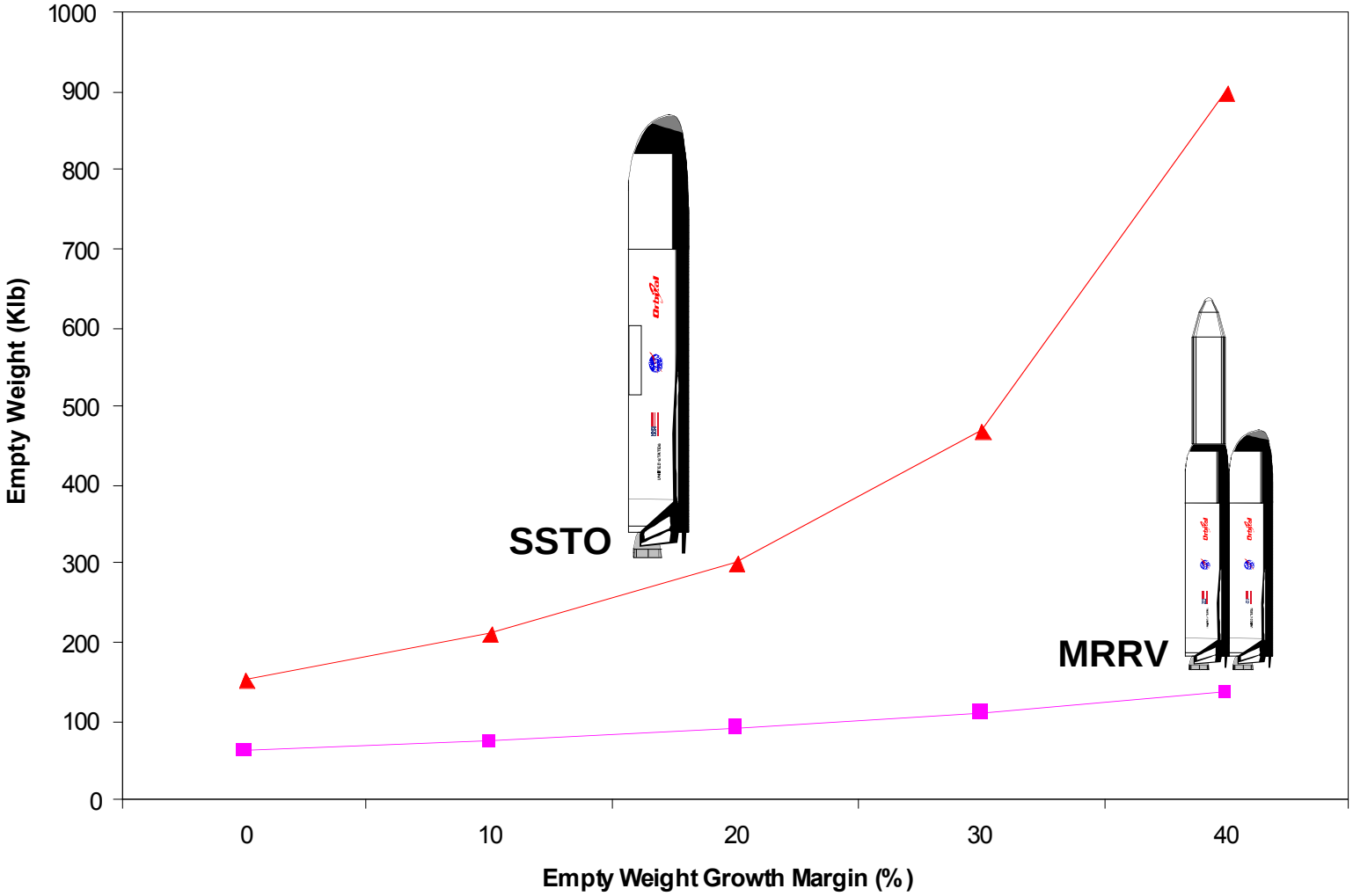
SSTO vs. MRRV Weight Sensitivity



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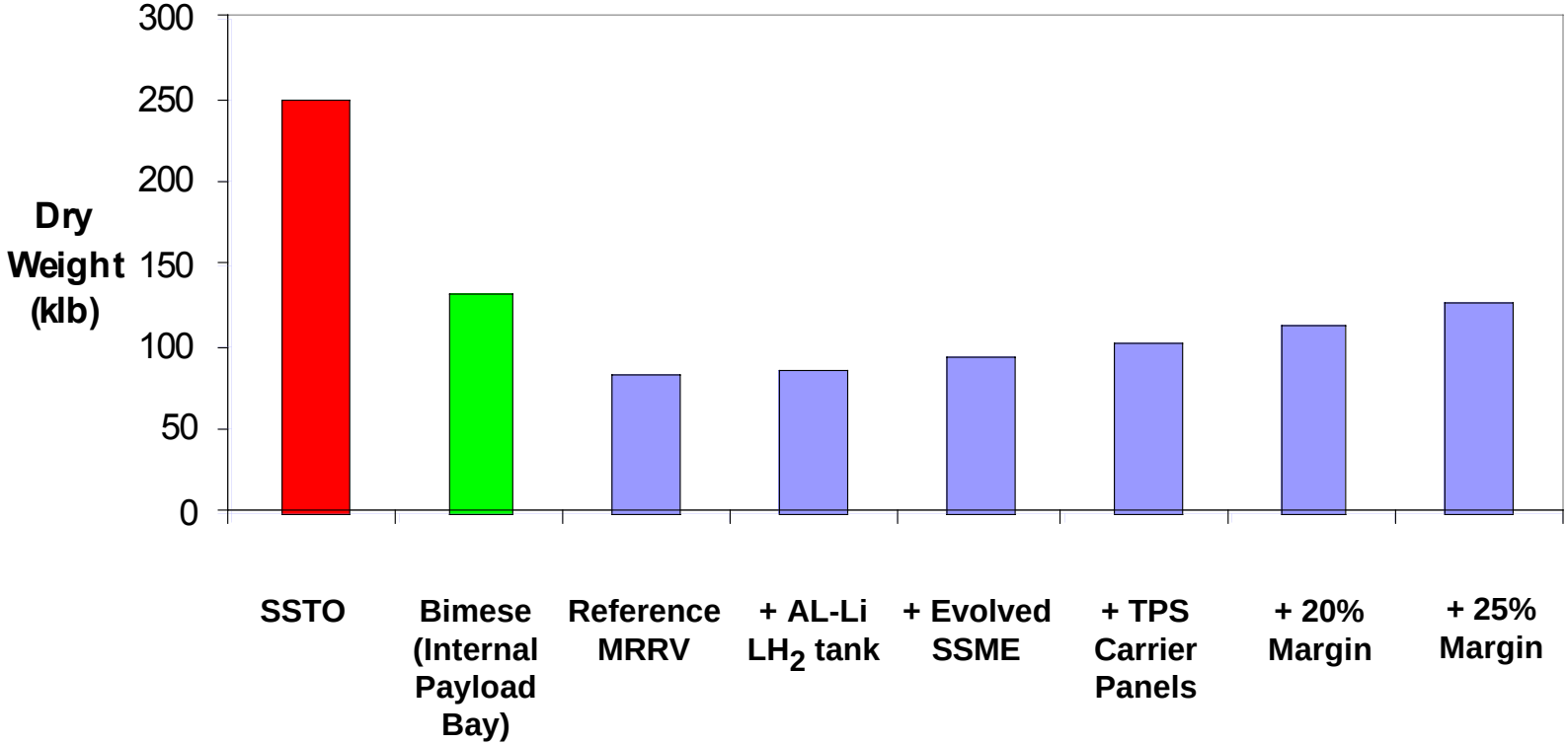
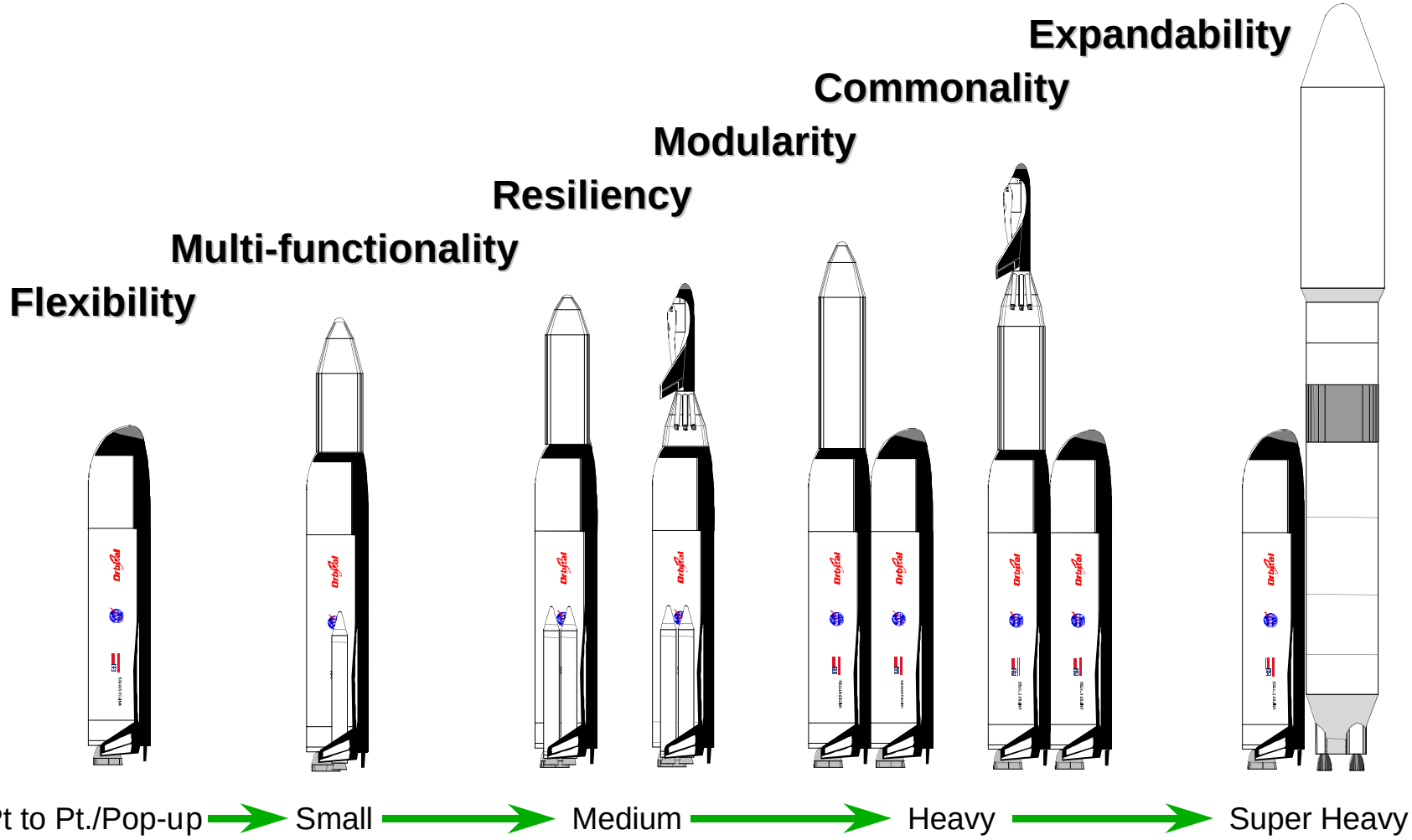
Robustness of MRRV Approach

- *Low Sensitivity to Weight Growth*
- *Design in Robustness Via Increased Weight and Technology Margin*



MRRV Architecture Approach



MRRV Operations Philosophy

Common Fuels for All Systems

All-Electric Vehicle

Off-Line Payload Processing

Automated Mission Planning

Standard Payload Containers/Interfaces

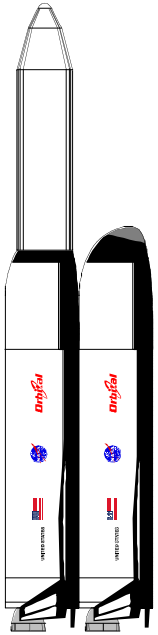
Integrated Health Management

Autonomous/Adaptive GN&C

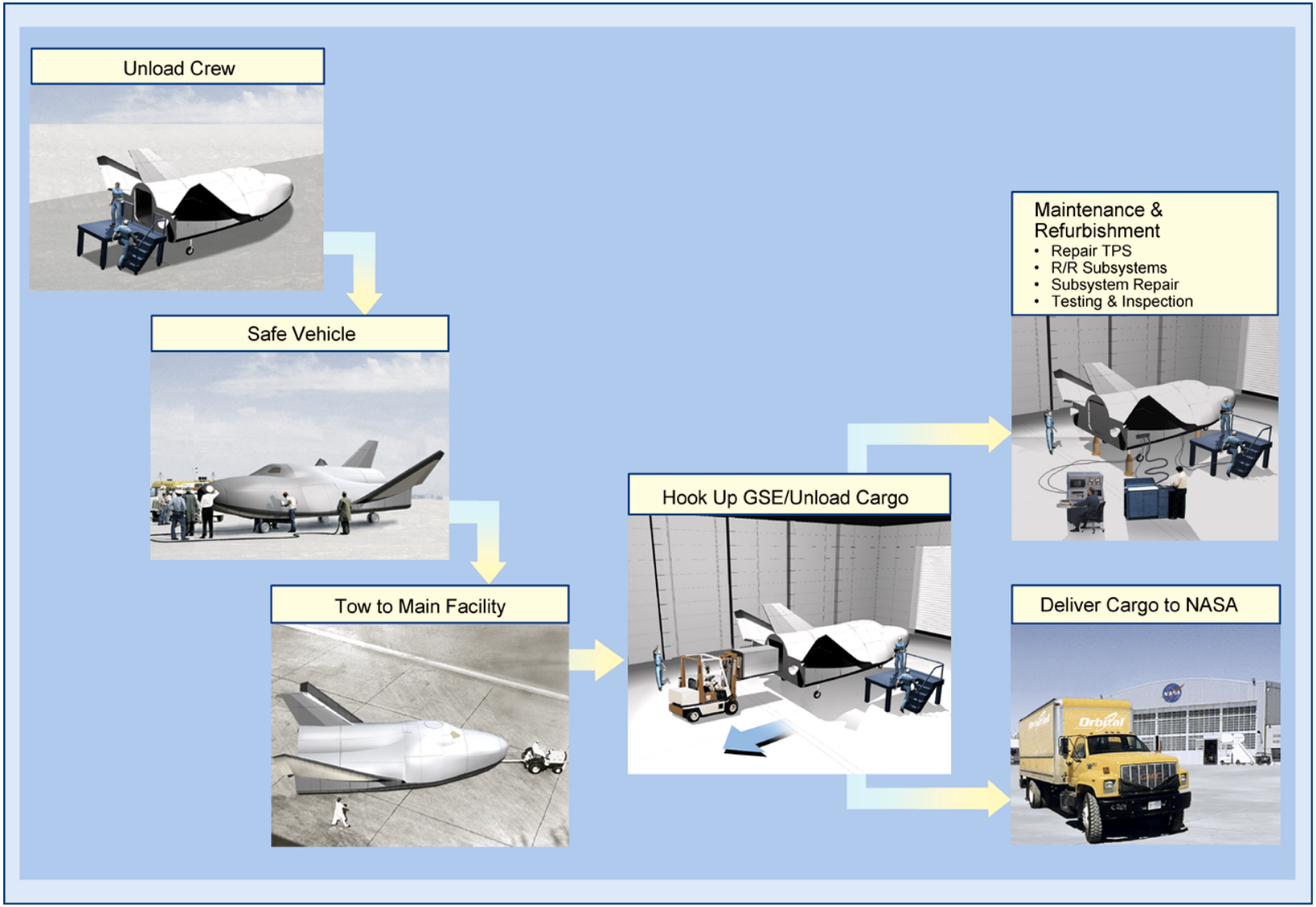
Modular/Fault-Tolerant Architectures

One-Time Vehicle Certification

Paperless Data Management



Space Taxi/MRRV Recovery Operations



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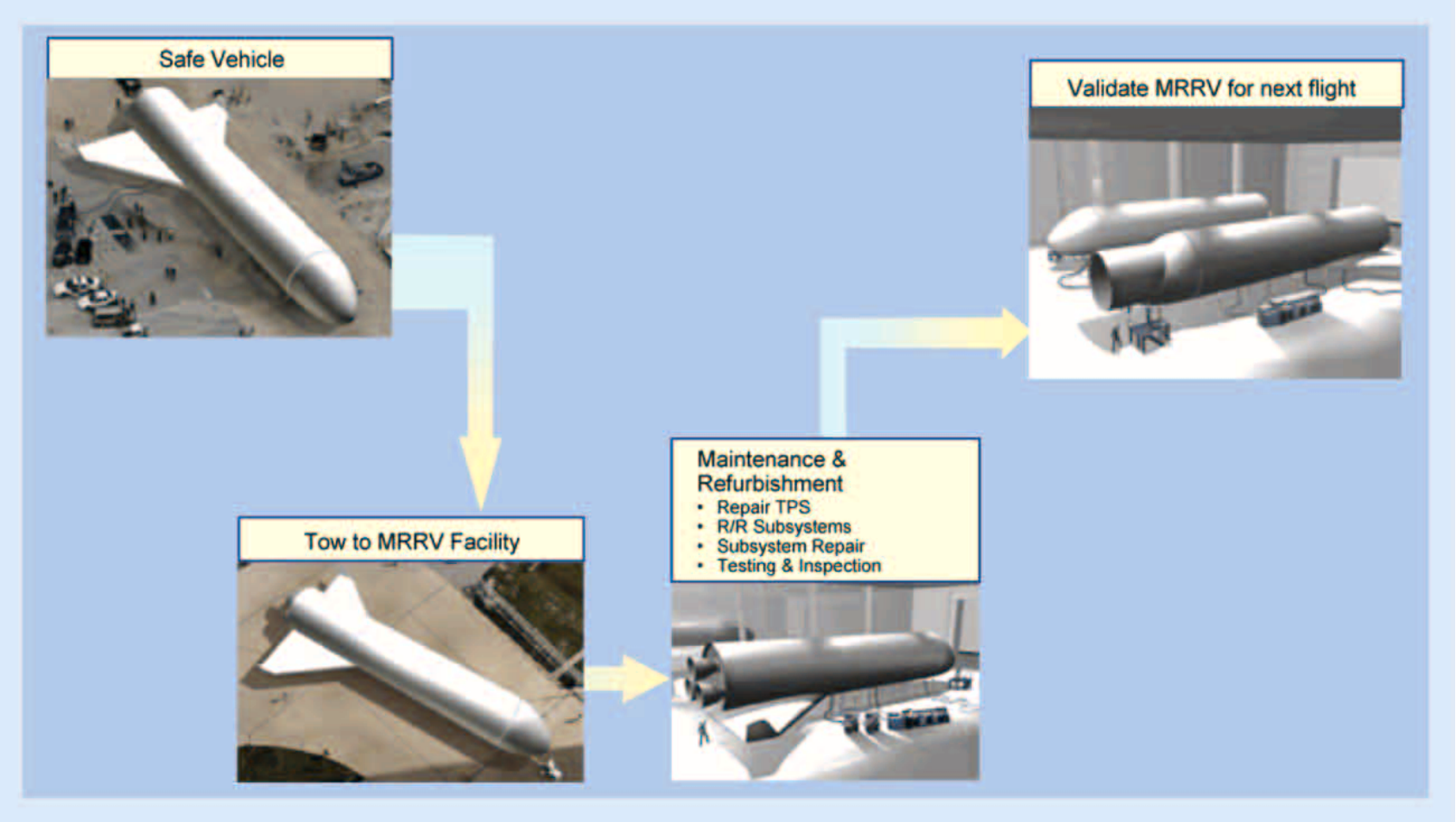
MRRV Recovery Operations



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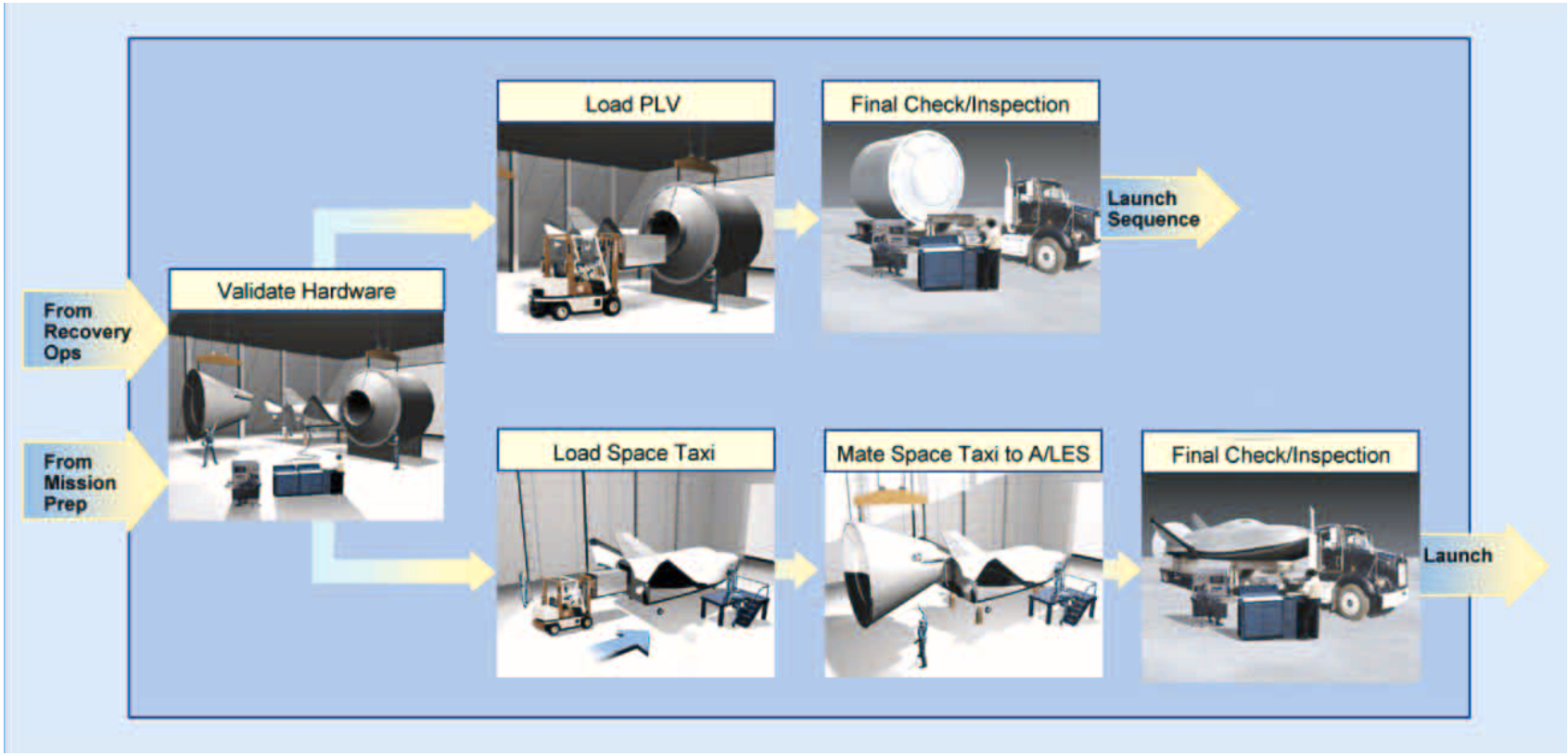
Space Taxi/MRRV Hardware Preparation



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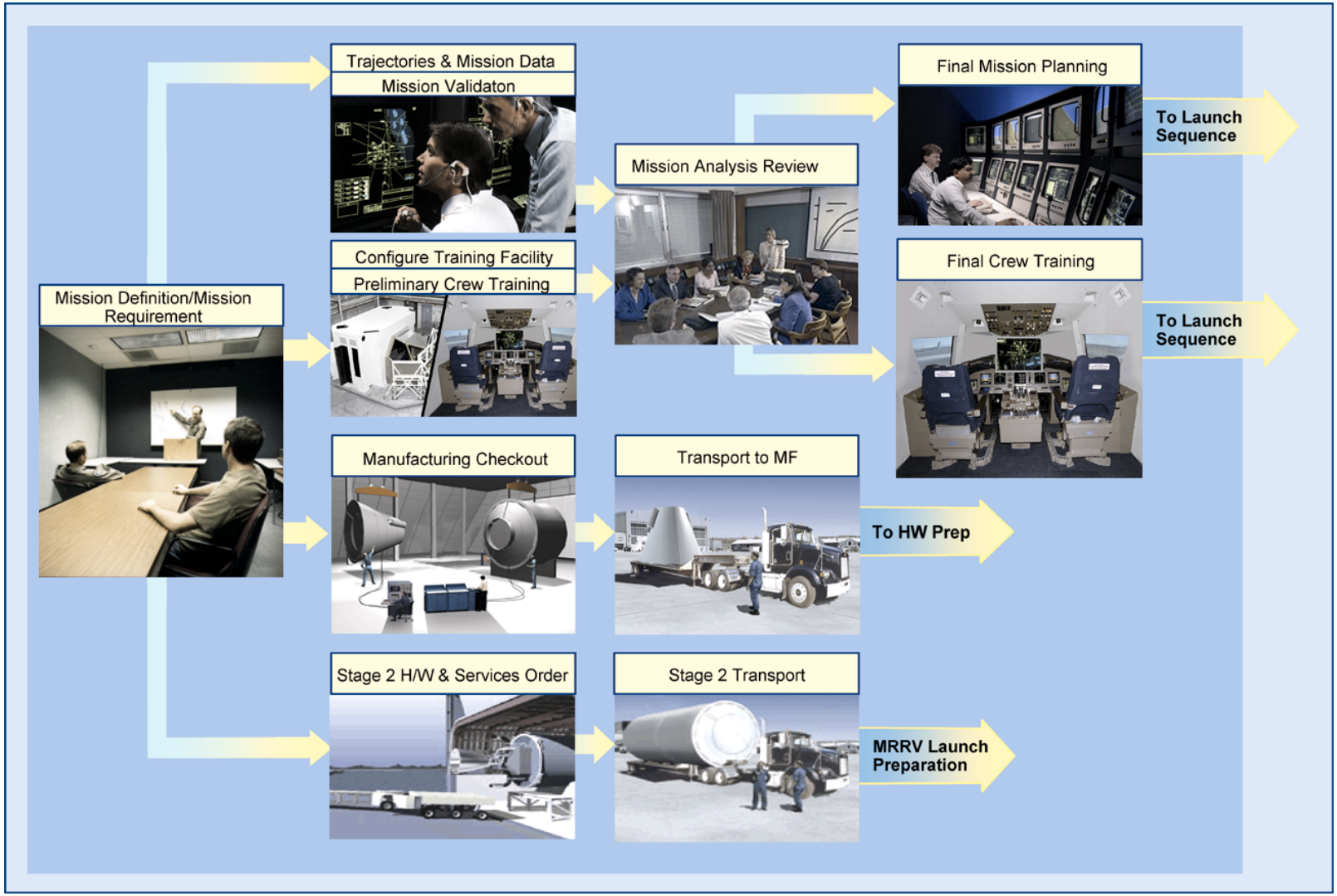
Space Taxi/MRRV Mission Preparation



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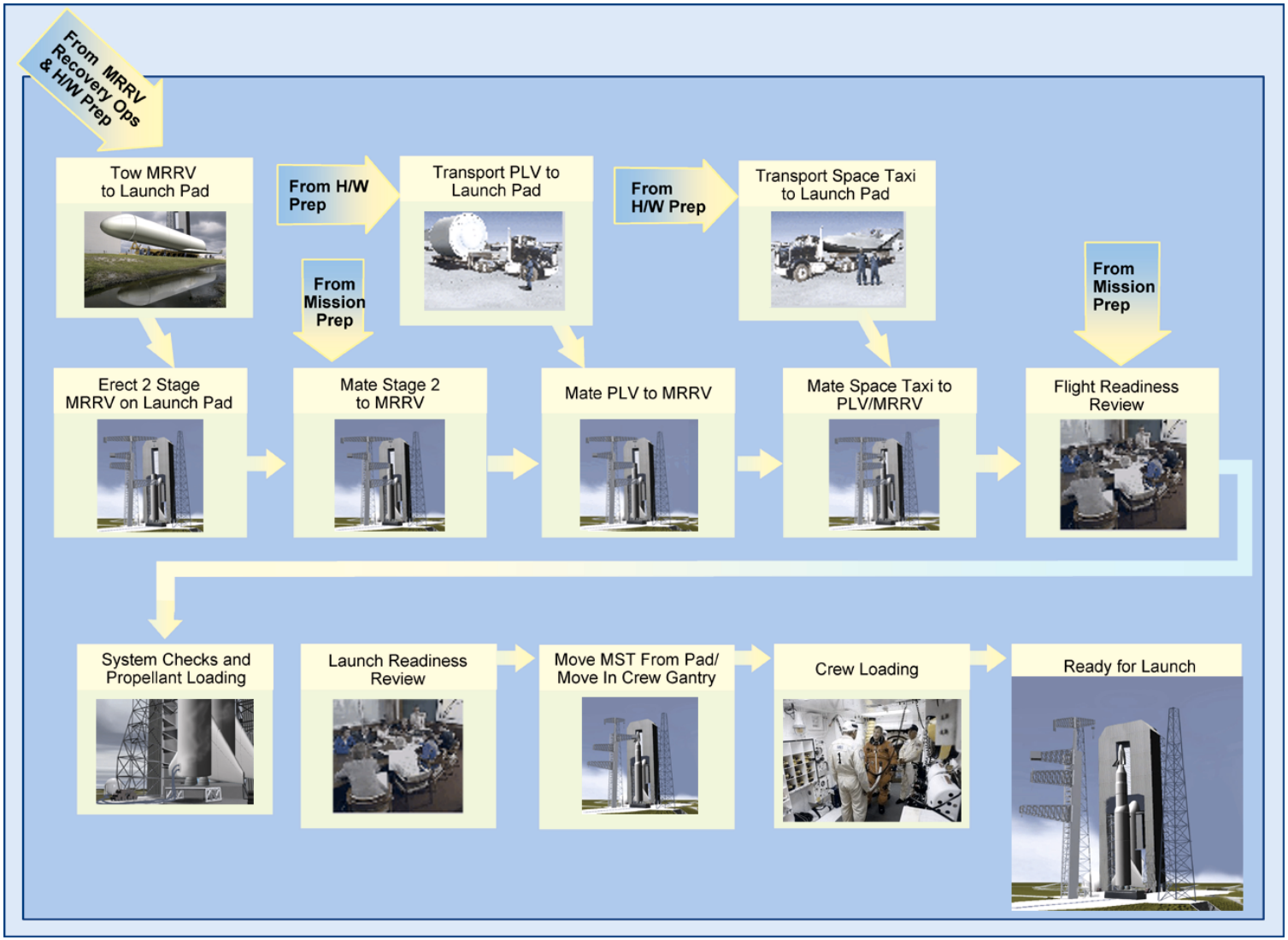
Space Taxi/MRRV Launch Sequence



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Multi-Role Reusable Vehicle Advantages

- Low-Risk TSTO Approach With External Payload Reduces Orbiter Size
  - Less Weight Growth Sensitivity
    - Higher Margins
    - Lower, More Conservative Technologies
    - Design to Cost
  - Reduced Orbiter Size
    - Less OMS Propellant Required
    - Less Sensitivity to Orbit Inclination
  - Recover Only High-Cost Items (Engines, Tanks, Avionics, Etc.)
  - Allows Efficient Propellant Packaging (>75 Percent)
  - Eliminates P/L-In, P/L-Out Entry c.g. Issues
- Lower DDT&E Cost than SSTO or Dissimilar TSTO (Small, Light Vehicle)
- Low Operations Cost
  - Similar Facilities/GSE for Vehicles
  - Smaller Vehicle/Facilities
  - Less TPS to Waterproof, Inspect and Replace
  - Glide-Back Booster (No Ferry or Additional Engines)

Multi-Role Reusable Vehicle Advantages

- Joint Industry/Government Full-Scale X-Vehicle Feasible
  - Lower Development Cost/Risk
  - Lower Development Schedule Risk
  - Possible Future-X Trailblazer Demonstrator
- Modular, Multifunction Architecture Allows High Degree of Resiliency
  - Payload Wgt Flexibility (Pop-up to Heavy GTO to Exploration)
  - Payload Size Flexibility (Existing Shrouds or Space Taxi)
- Simple Transition from EELV-Based Space Taxi Architecture
  - Use Existing Upper Stages, Fairings, P/L integration, Space Taxi
  - In-Line Mounted Space Taxi Meets Human Rating Requirements
  - Don't Tie Up Commercial RLV at ISS
- Circular Cross Section Wing-Body
  - Lightest Weight Approach
  - Easy to Manufacture
  - Proven Entry Control Design (Access to Space Study)

Architecture Evaluation Criteria

Architecture Evaluation Criteria

- Requirements
- Cost Savings
- Resiliency
- Industry Role
- Commercial Convergence
- Competition
- National Benefits

Requirements

ISS Return Mass Reduction Philosophy

- No Near-Term Commercial Requirement to Return Payloads
- Space Taxi Approach Provides $1-2 Billion in Annual Savings
- Economics Drives Towards Large Reductions in Return Mass
- Annual Replacement Costs of Instruments, Equipment, and Logistics Carriers Appear to Be Order of Magnitude Less Than Potential Savings
- Replace
  - Failed Equipment
  - Logistics Carriers
  - Clothes, Food, and Misc. Crew Supplies
  - Science Instruments, Facilities, and Some Experiments
- Recover
  - Experiment Results (Animals, Crystals, Samples, Etc.)
  - Some Crew-Related Supplies (e.g. CHeCS)
  - Other Cost-Effective Items (EMU/EVA?)
- Designing for Replacement Can Reduce Cost/Weight

ISS Upload/Download Payload Mass Allocation

	Upload	Download		Upload Allocation			Download Allocation
		Recoverable	Non-Recoverable	Space Taxi	PLV	UPLV	Space Taxi
Frozen Food	2400	500	250		2400		0
Ambient Food	1150	300	300		1150		0
Crew Clothes	2400	1450	950	2400			0
Crew Miscellaneous	1350	150	1150	1350			75
Crew Health Care System	500	400	200	250	250		225
Pressurized Maint. Logistics	4550	3900	650		4550		0
Unpressurized Maint. Logistics	6650	4300	2350			6650	0
Pressurized Science Logistics	13800	12250	1550		13800		7350
Unpressurized Scientific	3800	3150	650			3800	1890
Utilization							
EVA Equipment	1100	1100		1100			1100
Crew Rotation Gear	3650	3650		2242	1408		3650*
Water	1050			1050			0
Oxygen	350			350			0
Nitrogen	200			200			0
Total	**42950**	**31150**	**8050**	**8942**	**23558**	**10450**	**14290***

*Includes 2994 kg of Crew and Supplies Already Accounted For in Space Taxi Weights

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Shuttle/Space Taxi
ISS Resupply Volumetric Comparison

Flights		Shuttle					Space Taxi/PLV					
No.	Type	Racks	ASC	Lockers	ULC	Fluids (kg)	Racks	ASC	Lockers	SCC*	ULC	Fluids (kg)
4	Pressurized	64	16	160		1280	48	12	192	4		
1	Unpressurized				2	320						
2	Unpressurized						4	8	48	4	2	1600
	Total	64	16	160	2	1600	52	20	240	8	2	1600
	Volume (m^3)**	64	16	9.28	57.8	1.6	52	20	14.4	4	57.8	1.6
Total Volume (m^3)		**148.7**					**149.3**					

* A New Type of Soft Cargo Carrier (SCC) Will Be Employed by the Space Taxi to Store Soft Compressible Items in Otherwise Wasted Space, Such as Above the Lockers

** The Following Volumes Were Used: Rack Volume = 1 m^3 ; ASC Volume = 1 m^3 ; Locker Volume = 0.058 m^3 ; ULC = 28.9 m^3 ; SCC = 0.5 m^3 ; Fluid Density = .001 m^3/kg

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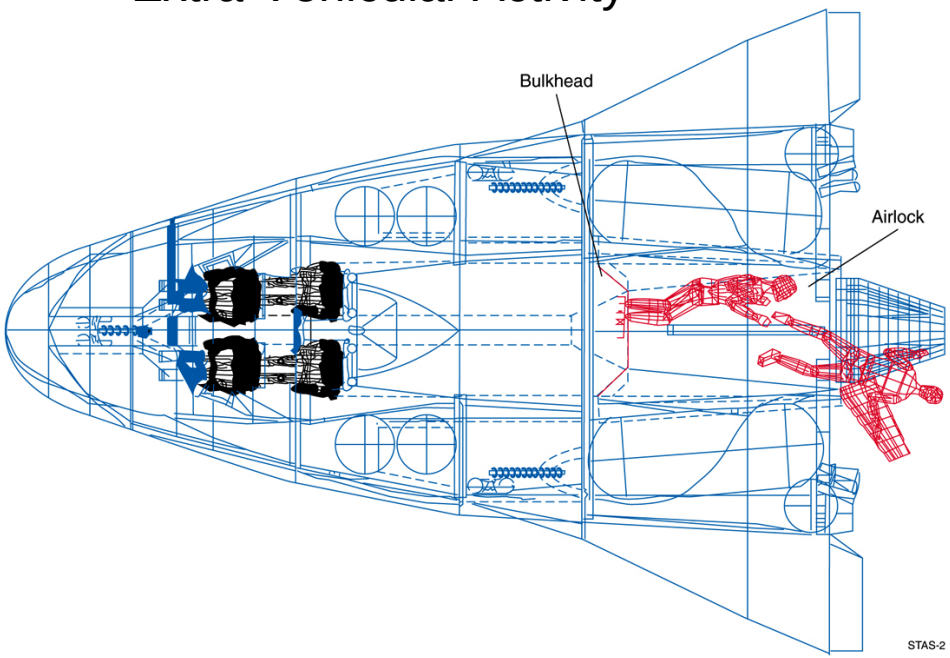
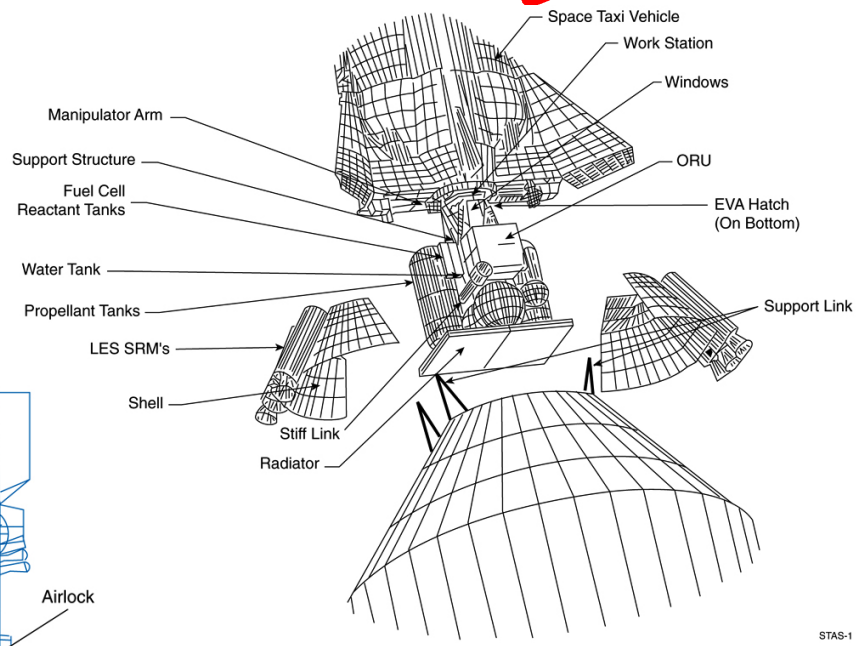
Space Taxi Commercial/Military Market

- Possible Commercial Applications
  - Satellite Servicing/Repair (Including Government)
  - Satellite Re-Boost/Orbit Alteration/Space Transfer (AOTV)
  - Space Debris Disposal
  - Commercial Space Station Servicing
  - Tourism
- Possible Military-Unique Applications (Space Maneuvering Vehicle)
  - Reconnaissance (Sub-Orbital or Orbital)
  - Anti-Satellite
  - Force Projection
- Commercial Applications Too High Risk to Enable Private Investment
- Commercial Applications Might Increase Flight Rates, Thus Lowering Operating/Replacement Costs
- Possibly Enough Military Applications to Justify Joint DoD Funding

Space Taxi Variants

Extra-Vehicular Activity

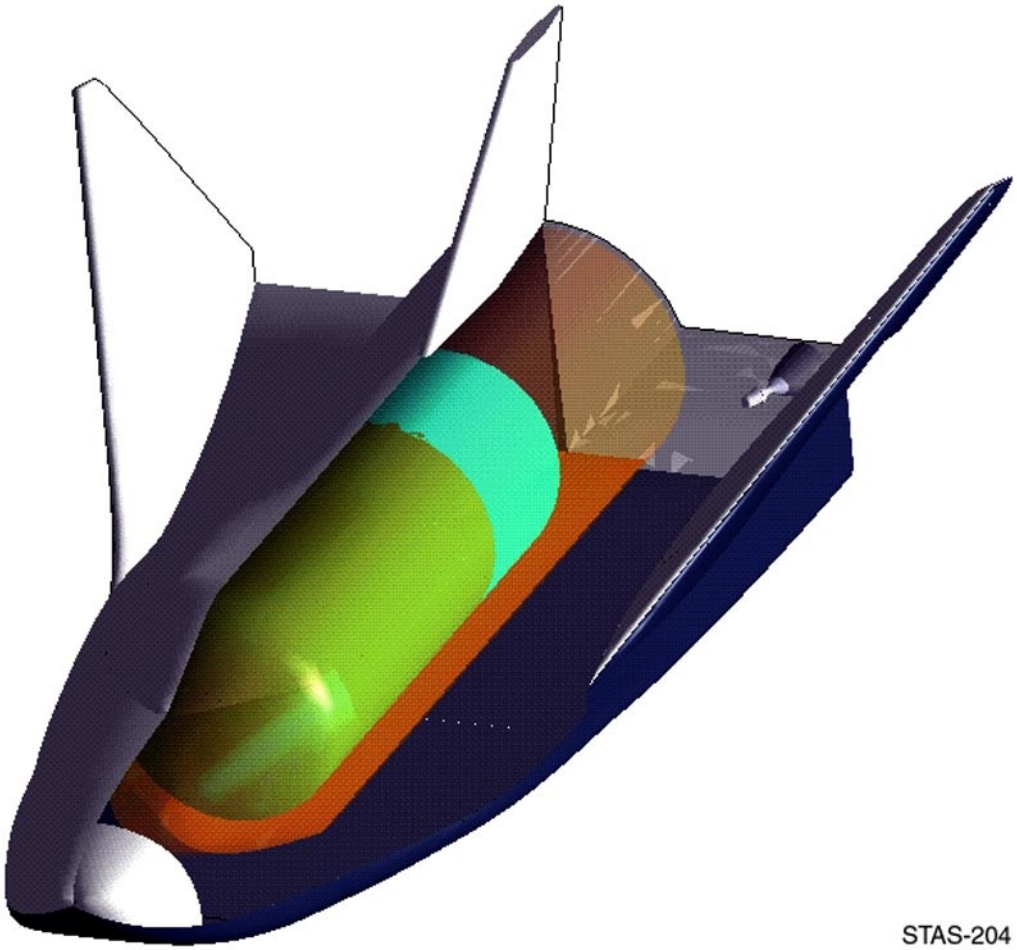




Satellite Servicing

Space Taxi Variants (Cont.)

Orbital Maneuvering



Russian Contingency Option

RS Delivery Vehicle	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Progress-M1 (Number of Flights)	4	4	4	4	4	6	5	6	5	5
Soyuz-TM (Number of Flights)	2	2	3	2	2	2	2	2	2	2
Required Mass to Orbit (kg)	13,346	17,686	18,866	17,822	16,482	21,047	16,955	18,181	21,393	12,238
Crew-Related Resupply (kg)	3,691	4,158	3,970	3,711	3,147	3,950	3,361	3,779	3,836	2,586
Science-Related Resupply (kg)	598	673	644	601	508	641	561	612	619	421
Mass Less Crew Resupply (kg)	9,057	12,855	14,252	13,510	12,827	16,456	13,033	13,790	16,938	9,231
Number of ATV Flights to Accomodate	2	2	2	2	2	3	2	2	3	2

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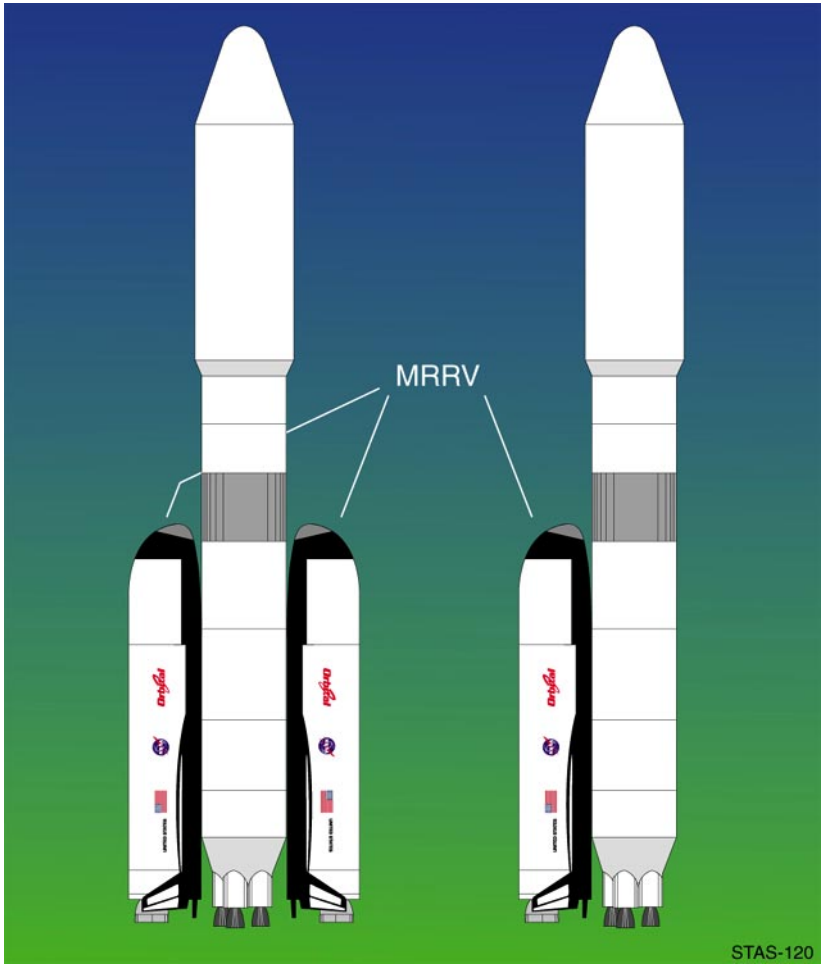
Human Exploration Option



- One or Two MRRVs
- Parallel Burn
- Six SSMEs or RS-68s
- Stretched ET Core
- 150 to 250 Klbs to LEO

Space Taxi/EELV Human Rating Compliance

Requirement	Compliance
General	
1) Design for Human Space Flight	• Complies
2) Aerospace Design Practice	• Partially Complies. The Space Taxi and Related Elements Will Comply, but a More Detailed Review of Delta IV Processes, Specifications, and Standards Are Required. However, Delta IV System May Not Have to Strictly Conform Due to Presence of LES
3) Crew Habitability	• Complies
4) Flight Test	• Complies. Comprehensive Flight Test Program Described in Appendix A
5) Proximity Operations	• Complies
Safety & Reliability	
6) Crew Survival	• Complies. Delta IV Reliability of >.98, Coupled with Space Taxi Probability of Crew Survival in Event of Launch Escape of >.99 Provides Mission Crew Survivability of >.9998. Over 50 Missions Through 2020, This Capability Provides a Program Crew Survivability of >.99
7) Crew Escape	• Complies. LES Provided in All Flight Phases, Exceeding Required Probability
8) Aborts	• Complies. LES Provided in All Flight Phases
9) Flight Termination	• Complies. LES Used to Recover Crew in Event of Delta IV Flight Termination
10) Flight Tolerance	• Complies. Space Taxi and Related Elements Are Dual-Fault Tolerant. Delta IV Is Not Planned to Be Dual-Fault Tolerant, but No Single Failure Will Cause Loss of Crew Due to LES
11) Reliability Verification	• Complies (Appendix A)
12) Software Reliability	• Complies (Appendix A)
Human-In-The-Loop	
13) Crew Role and Insight	• Complies
14) Manual Control	• Complies. Space Taxi Exhibits Required Handling Characteristics and Allows Runway Landing with Direct Pilot Visibility
15) Human/Machine Interface	• Complies
16) Task Analysis	• Complies

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Space Taxi/MRRV Human Rating Compliance

Requirement	Compliance
General	
1) Design for Human Space Flight	• Complies
2) Aerospace Design Practice	• Complies
3) Crew Habitability	• Complies
4) Flight Test	• Complies. Comprehensive Flight Test Program Described in Appendix A
5) Proximity Operations	• Complies
Safety & Reliability	
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7) Crew Escape	• Complies. LES Provided in All Flight Phases, Exceeding Required Probability
8) Aborts	• Complies. LES Provided in All Flight Phases
9) Flight Termination	• Complies. LES Used to Recover Crew in Event of MRRV Flight Termination
10) Flight Tolerance	• Complies
11) Reliability Verification	• Complies (Appendix A)
12) Software Reliability	• Complies (Appendix A)
Human-In-The-Loop	
13) Crew Role and Insight	• Complies
14) Manual Control	• Complies. Space Taxi Exhibits Required Handling Characteristics and Allows Runway Landing with Direct Pilot Visibility
15) Human/Machine Interface	• Complies
16) Task Analysis	• Complies

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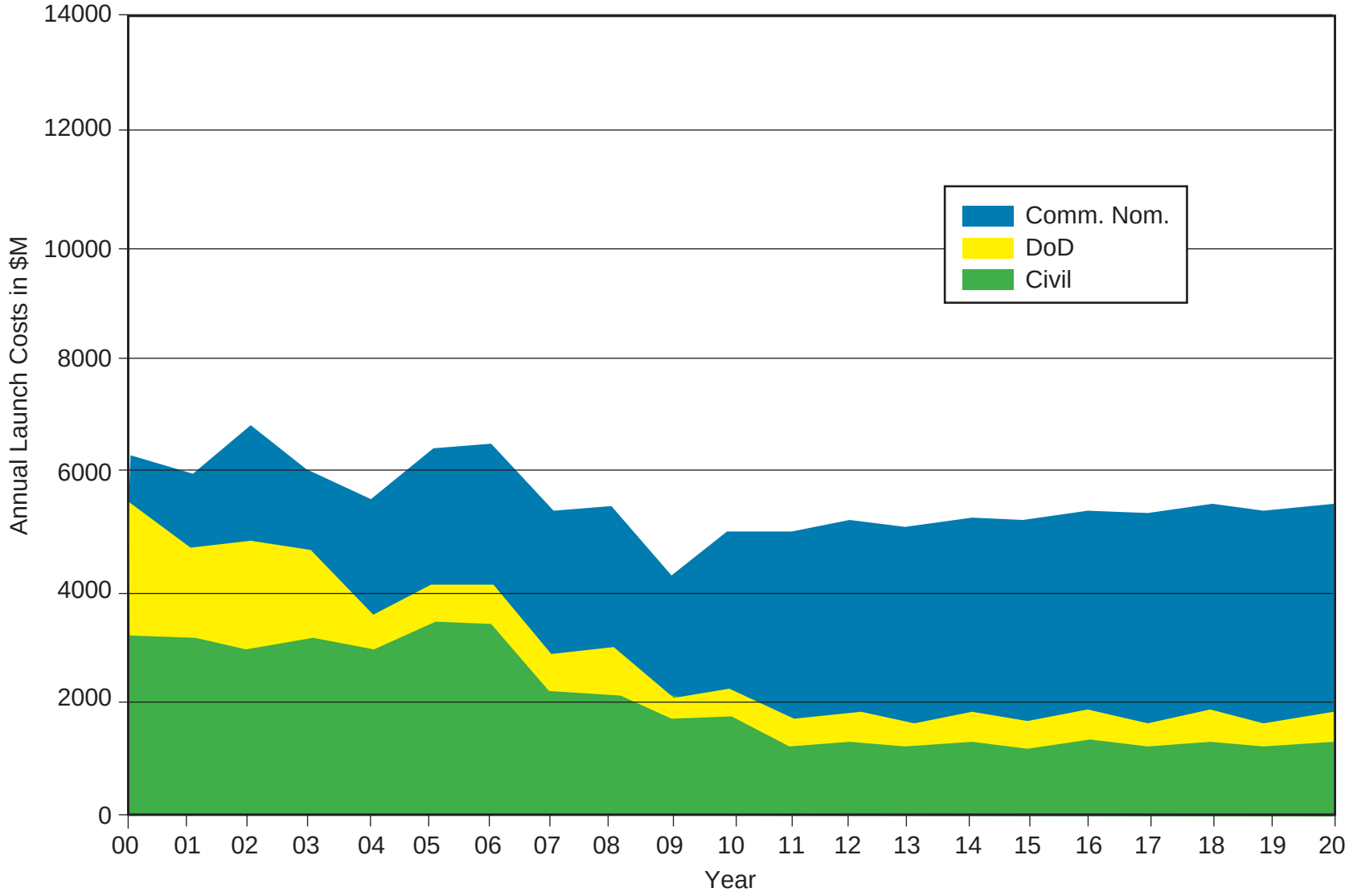
Cost Savings

Cost of Launching Scenario 2 and 3 Mission Model ('00 Dollars)



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Resiliency of Preferred Architecture

- Probability of Failure Reduced by High Reliability of MRRV/Space Taxi
- Cost of Failure Reduced by:
  - Separation of Crew and Cargo
  - High Probability of Crew Survival from LES
- Low Risk Technical Approach with Evolutionary Technologies
  - Reduces Risk of Technology Availability
  - Reduces Cost Risk
  - Reduces Schedule Risk
- Alternate Access by Launching Space Taxi on Multiple Boosters
  - Alternate EELVs
  - Foreign Vehicles
  - Future RLVs
- High Degree of Mission Flexibility/Growth Potential

Industry Role in Preferred Architecture

- MRRV Would Be Industry-Developed, Owned, and Operated
  - Robust MRRV Business Plan
  - Government Financial Incentives Reduce Risk
  - Allows Depreciation of Assets
- Space Taxi Industry-Developed Under Government Contract
  - Insufficient Commercial Market
  - Unique Government Need for Humans in Space and Return Cargo
  - DoD Applications Might Justify Joint NASA/DoD Development
- Space Taxi Industry-Operated
  - Reduces Cost Through Commercial Practices
  - Periodic Competition
- Space Taxi Possibly Industry-Owned
  - Allows Depreciation of Assets
  - Reduces Regulation and Oversight Costs
  - Enables Commercial Space Station

Commercial Convergence of Preferred Architecture

- Maximizes NASA's Use of Commercial Launch Services
- Minimizes Impact of NASA's Unique Needs
  - Space Taxi Used for NASA's Unique Needs
    - Human Transportation
    - Return Cargo
  - Commercial EELV or MRRV Provides Launch Services
- Allows Periodic Competition of Launch Services
- Industry Owned/Operated Space Taxi
  - Enables Commercial Space Station
  - Leads to Convergence of NASA/Industry Needs
- Reduction in ISS Return Cargo Requirements Enables Space Taxi

Competition in Preferred Architecture

- Commercial Competition Possible Throughout Implementation
  - STAS Phase III
  - Space Taxi Detailed Design
  - Space Taxi Development/Production
    - PLV
    - UPLV
    - Adapter/LES
  - Space Taxi Operation
  - EELV Launch Services
  - RLV/MRRV Technology Demonstration
  - RLV/MRRV Launch Services
- Joint NASA/DoD Launch Service Procurement Would Lower Costs
  - EELV Lower Than $135 Million/Flight ($100-120 Million)
  - Lower MRRV Price Structure

National Benefits of Preferred Architecture

- Recaptures Expanded Global Launch Market (Up to 65 Percent)
- Wide Range of Benefits to Other Industries
  - Lower Launch Costs Enable Telecom/Remote Sensing Ventures
  - New Technologies Benefit Other Transportation Sectors
  - Commercial Space Station Enables Space-Based Industries
    - Pharmaceuticals/Biotech
    - Semi-Conductors
- Additional Economic Activity
  - Increases Tax Base/Revenue
  - Creates High-Tech Jobs
  - Increases Exports
- Wide Range of Military Benefits (SMV, SOV, Recon, etc.)
- Wide Range of Commercial Missions (Satellite Servicing, AOTV, etc.)

Finance/Regulatory Analysis

Financing Alternatives

- Goal - Alignment of Government Needs and Commercial Market with Equitable Distribution of Risk and Reward

- Areas to Address
  - Tax Credits *
  - Tax Holidays *
  - Loan Guarantees *
  - Anchor Tenancy *
  - Advance Purchase Agreements *
  - Cooperative Research & Development *
  - Matching Funds *
  - Government Guaranteed Completion Bond
  - Direct Equity Investments
  - Convertible Bonds
  - Termination Liability
  - Government Trust Fund
  - Federal Financing Bank
  - Prizes/Vouchers

*Selected for Further Study

Principles Governing Financial Incentives

- Balance Risk/Reward Between Government and Industry
  - Mitigate Risk Sufficient to “Prime Pump”
  - Avoid Playing With “Other People’s Money”
- Avoid Excessive Government Intervention in Market Decisions Concerning Development of Particular Launch System
- Broad-Based With Qualification Criteria That Are:
  - Clearly Defined
  - Objective
  - Measurable

Tax Credits/Holidays

- Investment Tax Credits to Companies and Individuals
  - Strategic Partners and Individuals Deduct Investments from Taxes
  - Legislation Required (Many Precedents - Including TOS)
  - Mature Companies and Investors Benefit Directly and Immediately
  - Start-ups Benefit Indirectly but Immediately
  - Immediate Effect on Budget
  - Tax Reform Uncertainty

- Tax Holidays to Companies and Individuals
  - Eliminate/Reduce Taxes on Profits of Enterprise
  - Legislation Required (Currently under Draft)
  - All Companies and Investors Benefit in Out Years
  - Very Useful Tool to Attract Investors
  - Effect on Budget in Out Years
  - Tax Reform Uncertainty

Loan Guarantees

- Requires Legislation
- Benefits All Companies
- High Degree of Incentive for Relatively Modest Budget Scoring
  - Reduces Bond Rates from ~14% to ~7%
  - Enables Debt Instruments for Small Companies
  - Scored at 10-20 Percent of Benefit
  - Enables Raising Required Amount of Debt Financing
- Make Loan Guarantees Dependent on Equity Raised
  - Debt Follows Equity
  - Keep Reasonable Debt-to-Equity Ratio
  - Provide “Matching Funds” up to Single Company Cap
  - Let Market Pick Winners and Losers
  - Minimize Collateral Requirements

Anchor Tenancy/Advance Purchase Agreements

- Requires Legislation Under Current Anti-Deficiency Budget Rules
- Pegasus Successful Space Launch Precedent
- Government Market Guarantees Provide Strong Investment Incentives
- Could Use to Stay Within Politically Determined Budget Wedge
- Potentially Benefits All Companies
- Selection Process Must Be Open and Objective
- Could Avoid Selection by Offering:
  - Guaranteed Number of Launches for a Set Price
  - Awards to All Qualifiers
  - Advance Purchase Payments Linked to Milestones
    - Successful Test Launch
    - Successful First Operational Launch

Cooperative Research & Development

- Requires No Legislation Apart from NASA Budget Approval
- NASA Plays Traditional Role of Technology Risk Reduction
- NASA Provides “In-Kind” Contributions
  - Research and Test Facilities
  - Unique Expertise
- Low-Cost Way of Providing Up-Front Assistance to Reduce Risk
- Overwhelming of Limited Resources May Become a Problem
- May Require Some Selection to Allocate Resources
- Selection Process Must Be Open and Objective
- Full Cost Accounting May Make Expensive

Regulatory/Policy Considerations

- Goal - Stable & Predictable Space Policy for the Commercial Launch Service Industry

- Areas to Address
  - Trade Policies & Agreements
  - Government Financial Obligations
  - Allocations of Risk, Indemnification
  - Cost & Access to Government Assets/Services
  - FAA Licensing - Certificates of Airworthiness
  - Access to Launch Facilities
  - Commercial Spaceports
  - Treaty Issues

Foreign Policy/Regulatory Issues

- Export Control Restrictions Have Unintended Consequences
  - Barrier to Cooperative Ventures
  - Restricts Domestic Launches at Foreign Sites
  - Application Process Needs Streamlining
- Strategic Arms Control Treaties Limit Domestic Launch Options
- Commercial RLVs Bring Unique Issues
  - Foreign Overflight or Emergency Landings
  - RLV Sales to Foreign Operators
  - Negotiation of Issues Must Begin Soon
- Keep Industry Involved/Engaged in International Negotiations

Domestic Policy/Regulatory Issues

- Commercial Space Launch Act Has Been Success
  - New Commercial Ventures (Pegasus, Taurus, Sea Launch, Delta 3)
  - Commercially Operated Space Shuttle (USA)
  - Innovative Industry/Government Partnerships (X-33, X-34, EELV)
- FAA/OCST RLV Working Group Provides Useful Forum
  - RLV Licensing
  - RLV Indemnification/Cross-Waivers
- Timely Access to Government Launch Facilities is Major Issue
  - Decrease in Federal Funding for O&M costs
  - Modernization and Upgrades Behind Schedule and Over Budget
  - USAF Not Allowed to Recover Sufficient Amount of Full Cost
  - USAF Liability Issues Drive Up Costs

Concluding Remarks

Scenario 1 Preferred Architecture Summary

- Low Risk Approach Preserves Status Quo
- Meets NASA's Human Space Transportation Needs
- Does Not Meet All Human Rating Requirements
- Phase 3 Upgrades Cost Effective
- Phase 4 Upgrades Cost/Benefit Questionable
- Prevents Development of Commercial Heavy-Lift RLV
- Locks in High Domestic Launch Costs
- Does Not Regain Global Launch Market
- Success of Shuttle "Privatization" Questionable
  - Commercial Operation Has Lowered NASA's Costs
  - Shuttle Costs Still Can't Compete With EELV/Ariane V
  - Subsidies Would Discourage Domestic Launch Ventures
  - Subsidies Might Violate Existing Trade Agreements

Scenario 2 and 3 Preferred Architecture Summary

- Over $15 Billion Net Present Value to NASA ($2 Billion to DoD)
- Two Year Pay Back to NASA After Implementation
- Robust Business Plan
- Order-of-Magnitude Improvement in Human Safety/Reliability
- Meets/Exceeds NASA's Human Rating Requirements
- Low-Risk Evolutionary Approach
- Maximizes Use of Commercial Launch Services
- Preserves Competition Throughout Implementation/Operation
- Flexible, Modular Architecture Approach (Growth Potential)
- Recaptures Global Launch Market