JSC-63724

Exploration Blueprint
Data Book

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Editor

National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas 77058

Released February 2007

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FOREWORD

The material contained in this report was compiled to capture the work performed by the National Aeronautics and Space Administration's (NASA's) Exploration study team in the late 2002 timeframe. The "Exploration Blueprint Data Book" documents the analyses and findings of the 90-day Agency-wide study conducted from September – November 2002.

During the summer of 2002, the NASA Deputy Administrator requested that a study be performed with the following objectives:

- Develop the rationale for exploration beyond low-Earth orbit
- Develop roadmaps for how to accomplish the first steps through humans to Mars
- Develop design reference missions as a basis for the roadmaps
- Make recommendations on what can be done now to effect this future

This planning team, termed the Exploration Blueprint, performed architecture analyses to develop roadmaps for how to accomplish the first steps beyond LEO through the human exploration of Mars. The previous NASA Exploration Team activities laid the foundation and framework for development of NASA's Integrated Space Plan. The reference missions resulting from the analysis performed by the Exploration Blueprint team formed the basis for requirement definition, systems development, technology roadmapping, and risk assessments for future human exploration beyond low-Earth orbit. Emphasis was placed on developing recommendations on what could be done now to effect future exploration activities. The Exploration Blueprint team embraced the "Stepping Stone" approach to exploration where human and robotic activities are conducted through progressive expansion outward beyond low-Earth orbit. Results from this study produced a long-term strategy for exploration with near-term implementation plans, program recommendations, and technology investments. Specific results included the development of a common exploration crew vehicle concept, a unified space nuclear strategy, focused bioastronautics research objectives, and an integrated human and robotic exploration strategy. Recommendations from the Exploration Blueprint included the endorsement of the Nuclear Systems Initiative, augmentation of the bioastronautics research, a focused space transportation program including heavy-lift launch and a common exploration vehicle design for ISS and exploration missions, as well as an integrated human and robotic exploration strategy for Mars.

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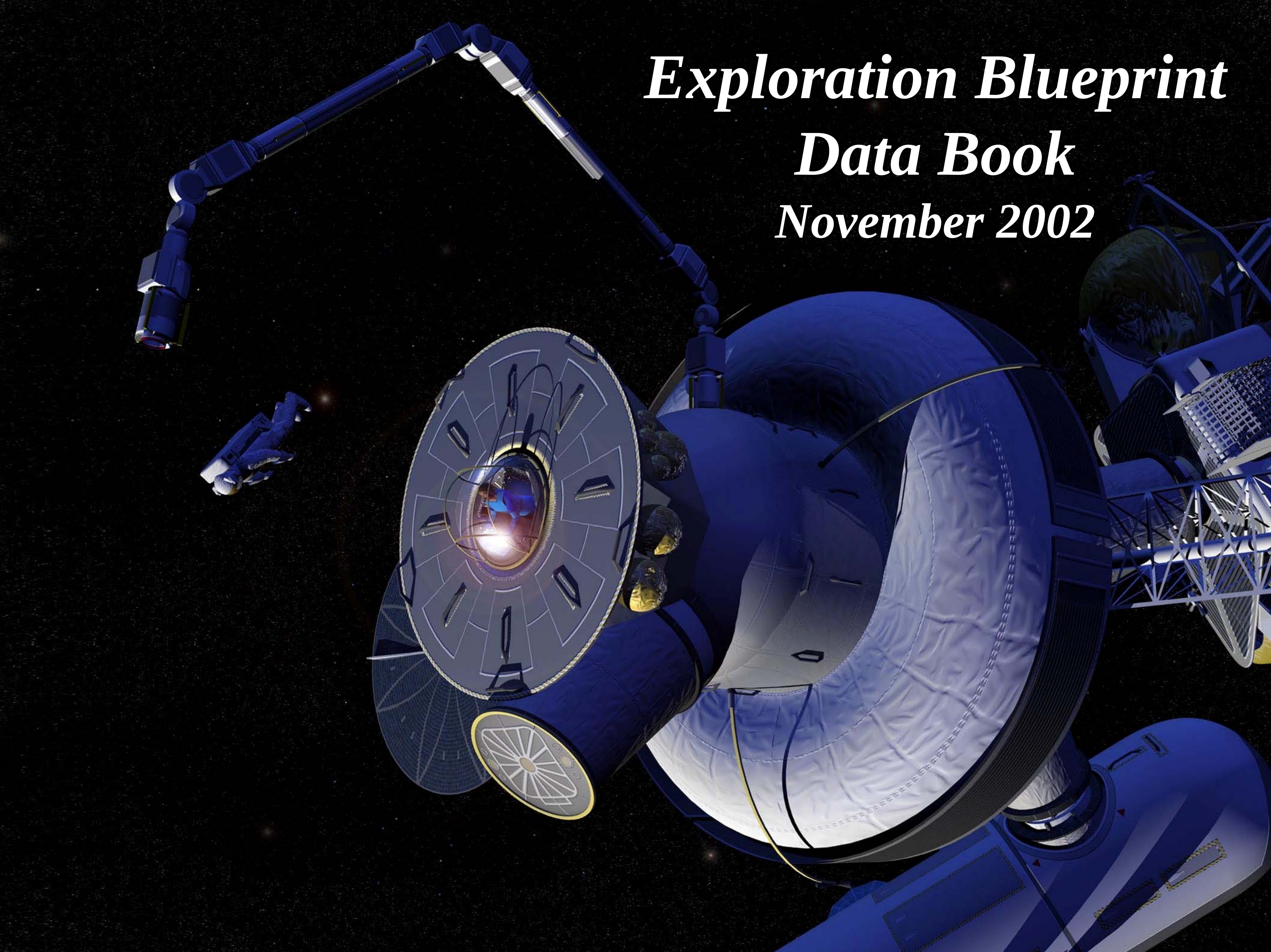
Exploration Blueprint Data Book

November 2002



Exploration Blueprint Input: Integrated Space Plan

Doug Cooke

December 13, 2002

Briefing Objectives

- **Provide initial thinking on Integrated Space Plan content**
- **Present examples of interim products and key architecture drivers**
- **Present preliminary recommendations for consideration**

Gain JSAC's commitment and participation in creating a strategy and executing an implementation plan for conducting an integrated, science-driven space program

Blueprint Assumptions

- Science driven approach for human exploration beyond Low Earth Orbit
- Derived from prior NEXT activities
- Develop roadmaps that accomplish the first steps through humans to Accessible Planetary Surfaces (Mars)
- Develop Design Reference Missions/ concepts as a basis for the roadmaps
- To drive out tall poles, set a time frame
  - TRL 6 by 2006 for Earth's Neighborhood
  - First launch in 2012 time frame
  - Mars launch by 2020
- Recommendations on what can be done now to effect this future

Integrated Space Plan Development Process

Space Act & NASA Strategic Plan

Science: Questions, Pursuits, Activities

Established Enterprise Processes and Priorities

Requirements and Systems Engineering

Architectural Studies & Technology Trades

Technology Roadmaps

Gap analysis

Space Architect Focus

<u>Integrated Space Plan</u>

Long term Strategy
Near term Implementation Plan
Program Recommendations
Technology Investments, New Initiatives

Results from Blueprint Activity

Participants

ACTIVITY LEADS

HQ/Code AD/Gary Martin
JSC/EX/Doug Cooke

TEAMS

Science & Exploration Rationale
Leads: Code S/Harley Thronson
Code S/Marc Allen
Participants: Code S, Code U, Code Y, JSC

Architecture Requirements
Leads: JSC/CB/John Grunsfeld
JSC/DA/Wayne Hale
Participants: JPL, JSC, LPI

Architecture Design and Definition
Leads: JSC/CB/Scott Horowitz
JSC/EX/Bret Drake
Participants: JSC, MSFC

Launch Vehicle Systems
Lead: MSFC/Vance Houston
Participants: MSFC, JSC, KSC

Vehicle Processing and Launch Operations
Lead: KSC/Cristina Guidi
Participants: KSC, MSFC, JSC

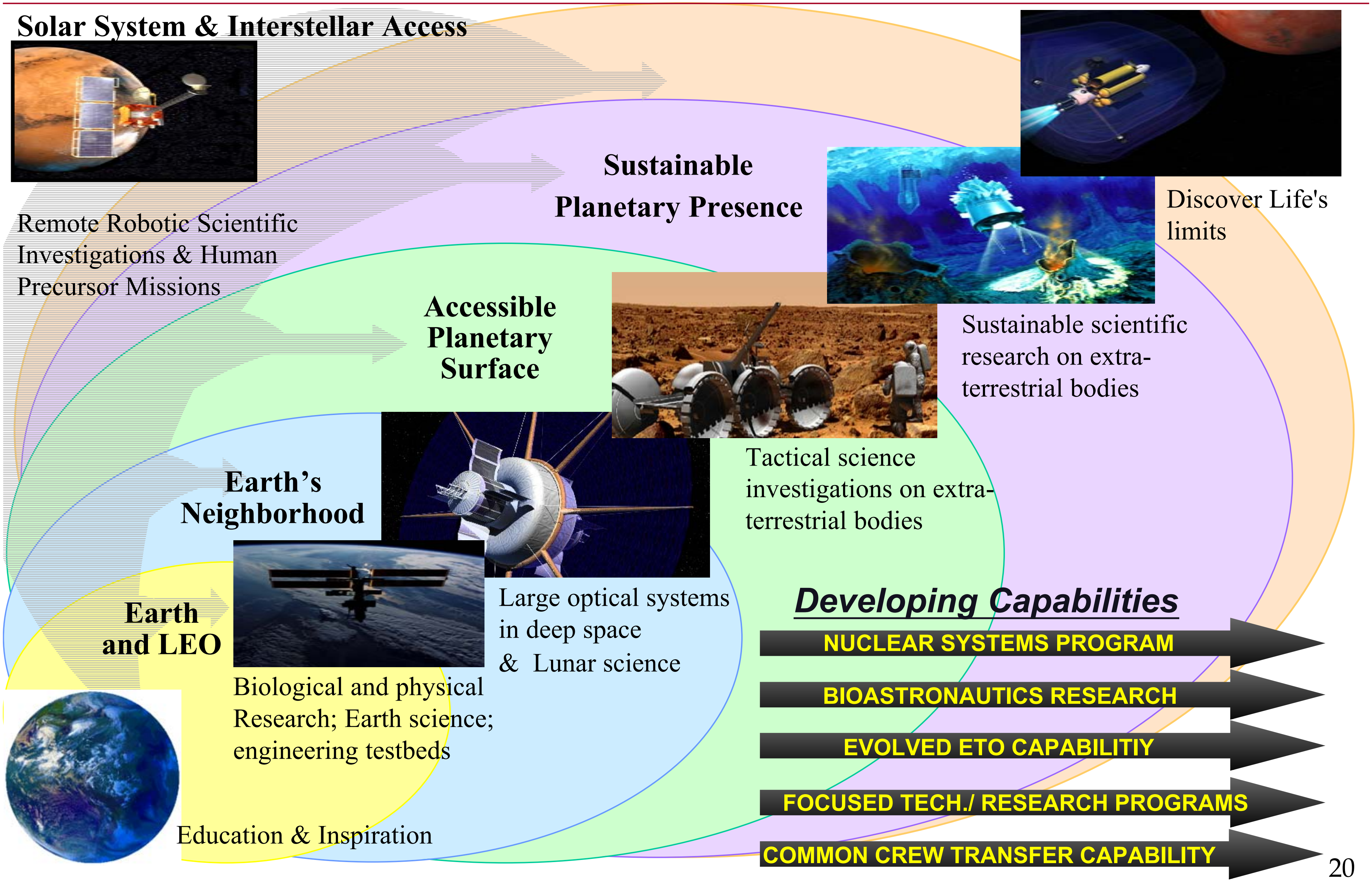
Systems Definition
Lead: JSC/DA/Jeff Hanley
Participants: JSC, MSFC, GSC, LaRC, JPL

Technology Roadmaps
Leads: JSC/MV/Fred Ouellette
JSC/EX/Al Conde
Participants: Code S, Code M, ARC, GRC, JPL, JSC, LaRC, MSFC

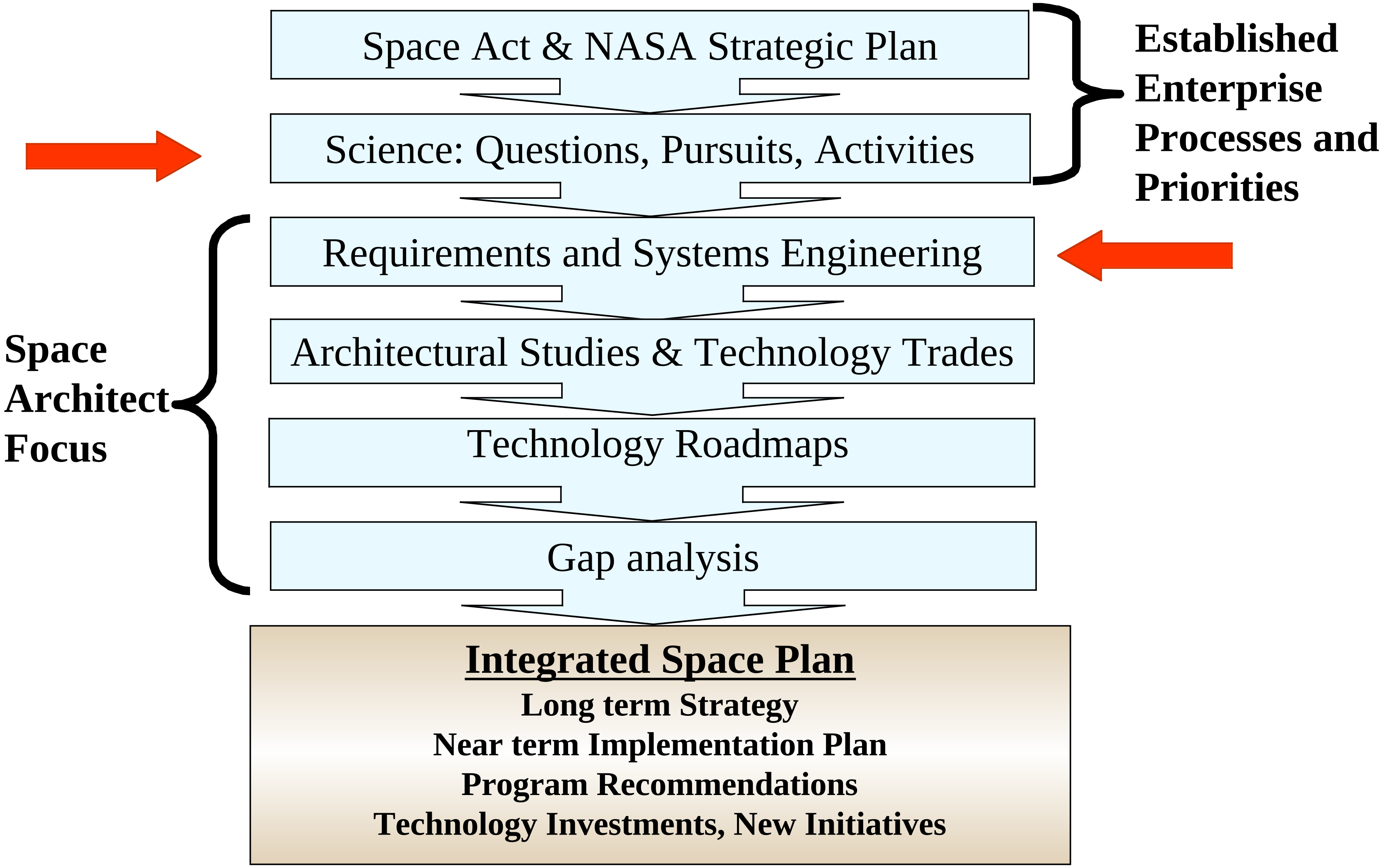
Supportability
Lead: JSC/EX/Kevin Watson
Participants:JSC, KSC, LaRC, GSFC

Risk Assessment
Lead: JSC/NX/Jan Railsback
Participants:JSC

Stepping Stone Science Exploration Strategy

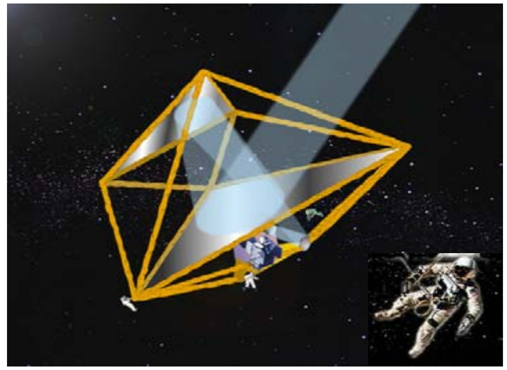


Integrated Space Plan Development Process



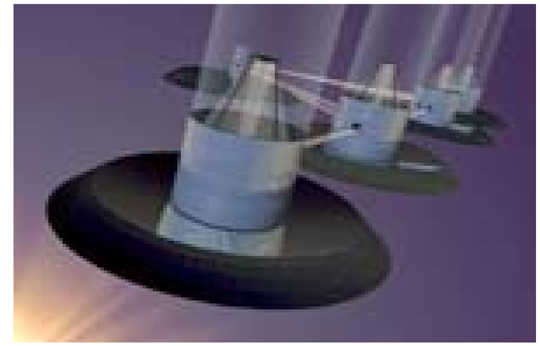
Discovery: Cosmic Origins and Destiny

Geophysical sciences and search or life

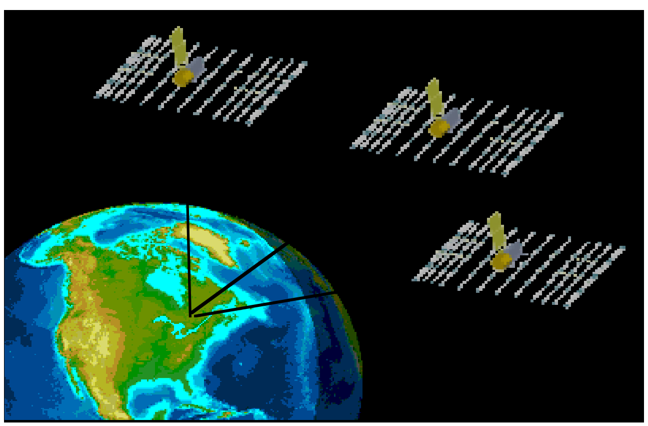


The birth of stars and planets

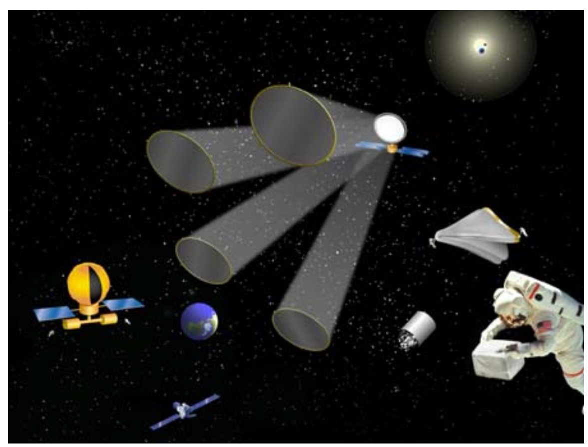
Searching for biomarkers in planetary atmospheres



Detailed environmental monitoring



Studying habitability around neighboring stars



Impact history and evolution of the Moon

Human and Robotic Exploration Strategies

Revolutionize technologies and capabilities to enable discovery and science return and provide the maximum return to the nation:

- **Remote observations and measurements- reach as far into the universe as possible; understand the Earth and its processes**
  - Further the incredible discoveries of Hubble Space Telescope to understand our universe, its, evolution and processes
  - Search for evidence of life on planets outside our solar system
  - Develop a scientific understanding of the Earth system and its responses

- **Robotic missions- maximize the return from remote direct measurements of other planetary bodies**
  - Further automation and virtual presence to increase the return of in-situ measurements
  - Measure the environments and test technologies preparing for follow-on missions and objectives

- **Human exploration- enable cost effective human exploration,**
  - Where human capabilities can enable and increase the rate of return of science and discovery
  - Share the excitement of first hand discoveries through virtual experience

Human/Machine Partnership

- **Humans and robots have collaborated in every NASA mission**
  - Difference between missions is the physical interfaces and proximity of humans
- **Hubble Space Telescope and Apollo demonstrated significant increase in rate of science return through involvement of humans at local science site**
- **Humans and robots represent different tools for accomplishing different jobs**
  - Humans have capabilities not yet attained by robotics
  - Robots more efficient for repetitive tasks and expendable for high risk tasks
- **Understanding benefits and risks of human and robotic capabilities is complex and evolving**
- **Objective is to optimize integration of humans and machines to maximize overall capabilities for effective scientific discovery**

Example Requirements Flow Down from High Level Goals

NASA Vision and Mission:
To improve life here.
To find life beyond.
To understand and protect our home planet.
To explore the universe and search for life.

Fundamental Questions:
How did the universe, galaxies, stars, and planets form and evolve, and what is their destiny?
Does life in any form, however simple or complex, carbon-based or other, exist elsewhere than on Earth?
How can we utilize the latest findings about the Sun, Earth, and other planetary bodies to develop accurate, predictive environmental, weather, climate, natural disaster, and natural resource models to help ensure sustainable development and improve the quality of life on Earth?

Enterprise Strategic Goal (Space Science):
Chart the evolution of the universe, from origins to destiny, and understand its galaxies, stars, planets, and life.

OSS Theme Objectives: [Enterprise Strategic Objectives (Space Science)]
Understand the structure of the universe, from its earliest beginnings to its ultimate fate.
Explore the ultimate limits of gravity and energy in the universe.
Learn how galaxies, stars, and planets form, interact, and evolve.
Understand the formation and evolution of the solar system and the Earth within it.
Probe the evolution of life on Earth, and determine if life exists elsewhere in the solar system.
Understand our changing Sun and its effects throughout the solar system.

Scenarios Need To Be Developed for Code S, Y and U

Example

Potential Scenarios

- **Large Optical Systems**
- **Mars Human Exploration**
- **Near-Earth Object (NEO) Sample Return**
- **Humans to Asteroids – Field Exploration Beyond LEO**
- **Mars Sample Return**
- **Many Additional Scenarios- TBD**

Science-driven architectures and requirements are derived from a variety of potential mission scenarios

Example: Large Space Telescope
(Post JWST Gossamer concept)

NASA Vision and Mission:
To explore the universe and search for life.

Fundamental Question:
How did the universe, galaxies, stars, and planets form and evolve, and what is their destiny?

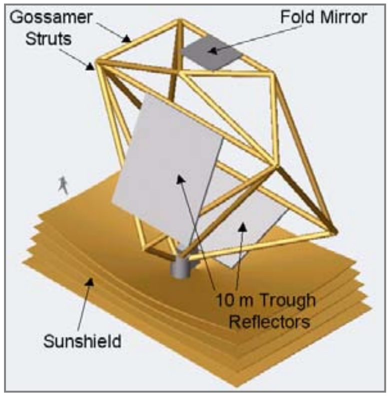
Enterprise Strategic Goal (Space Science):
Chart the evolution of the universe, from origins to destiny, and understand its galaxies, stars, planets, and life.

Theme Objectives: [Enterprise Strategic Objectives (Space Science)]
Understand the structure of the universe, from its earliest beginnings to its ultimate fate.
Explore the ultimate limits of gravity and energy in the universe.
Learn how galaxies, stars, and planets form, interact, and evolve.

Objective:
Study interstellar gas and dust over a wide redshift range.

- What lies at the cores of star- and planet-forming regions?
- What properties do Kuiper Belt objects have?
- What is the principal power source for IR-bright galaxies?

Implementation:
Assemble a 10 m telescope in Earth's Neighborhood and operate it at Sun-Earth L2.



Derived Architecture Requirements:
- High spatial and spectral resolution imaging in the 40-500 μm range.
- Membrane reflectors, actively cooled detectors, V-groove sunshade.
- EVAs over ~weeks to assemble and deploy truss.
- Infrastructure: crew transfer vehicles, robotic aids, EVA technology.

Rationale: Science objectives can be achieved only by a large-aperture, far-infrared and sub-millimeter, post-James Webb Space Telescope. Because of the size of the large reflectors, it would be impractical to launch it fully assembled.

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Space Architect Focus

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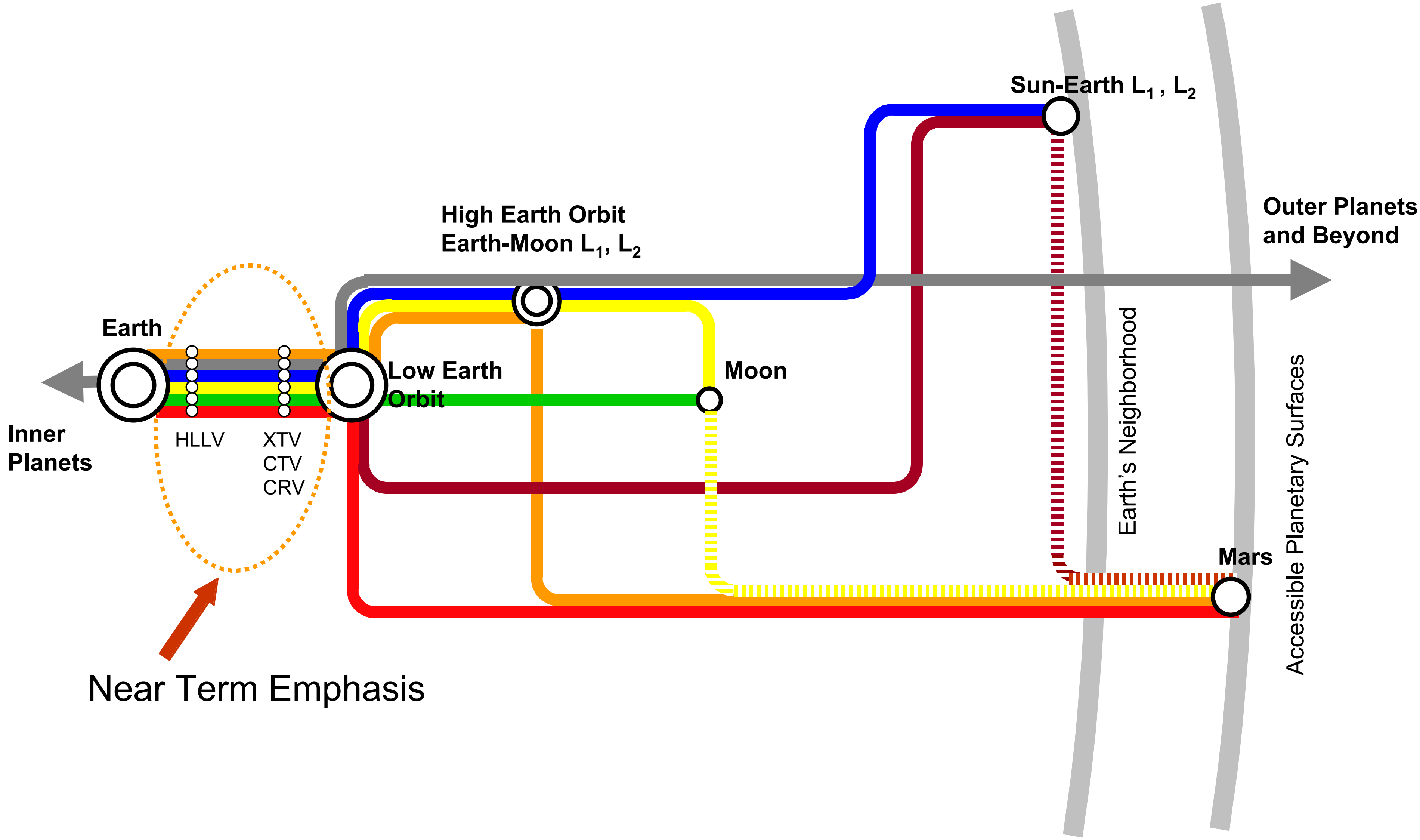
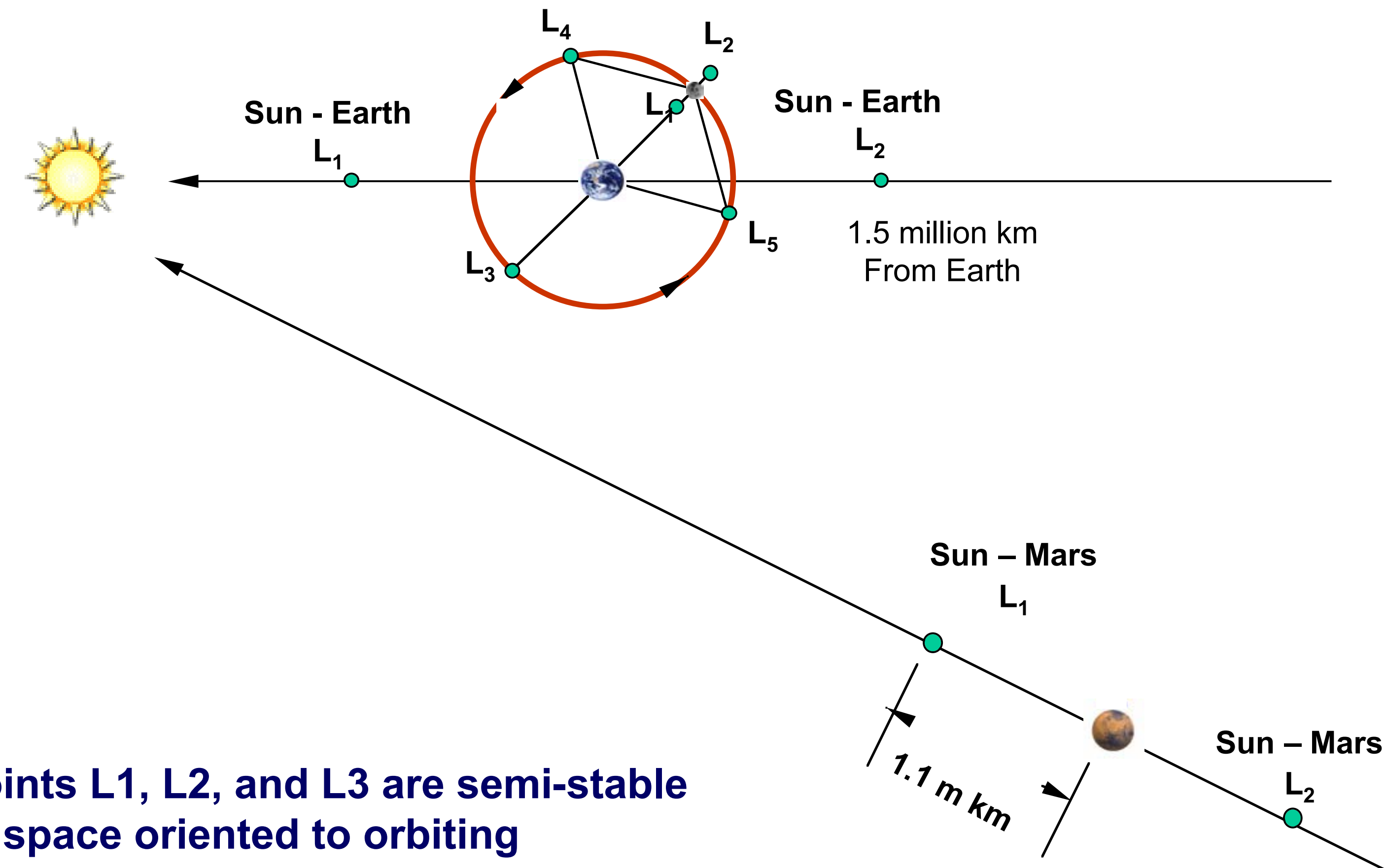
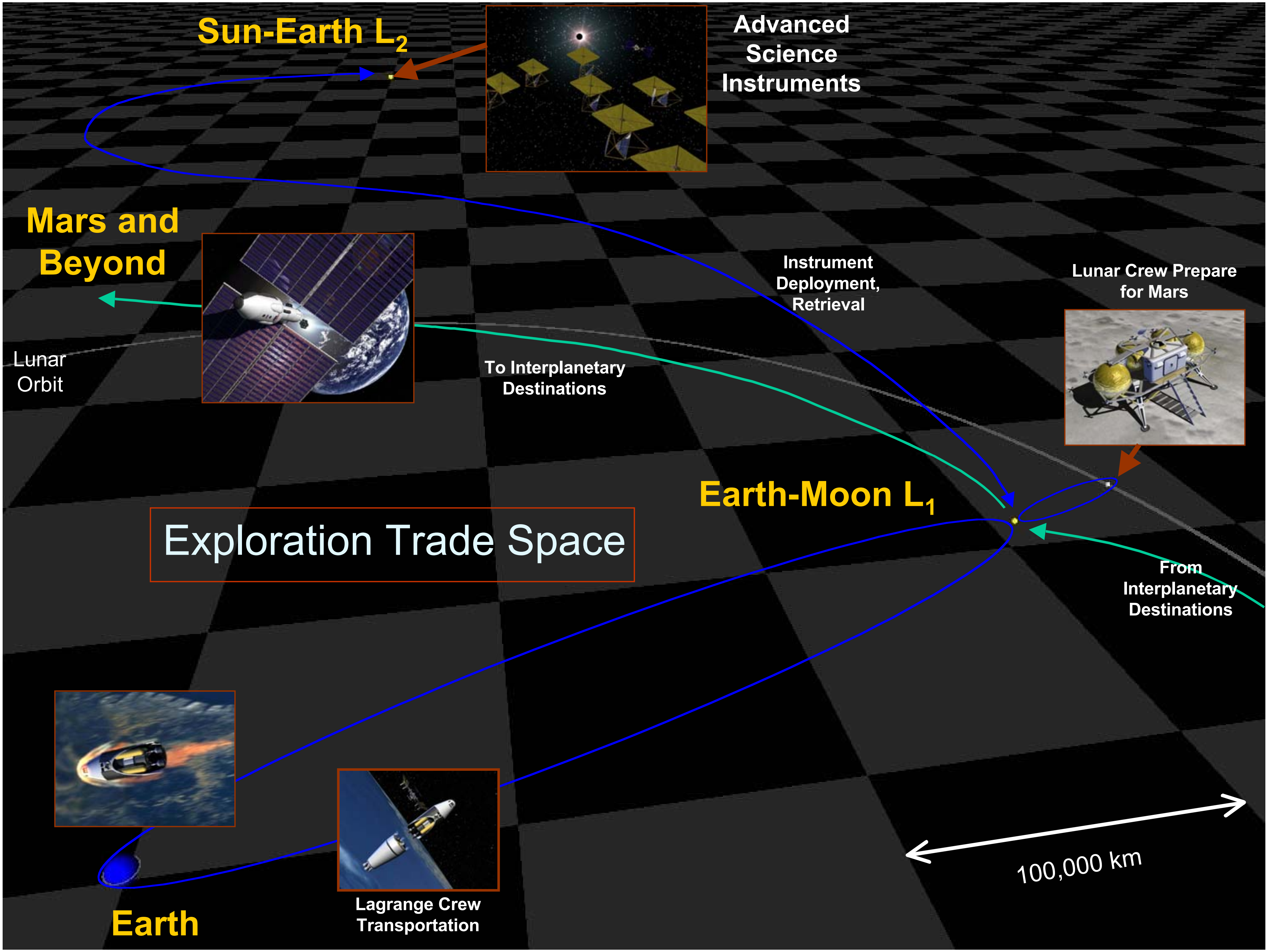
Progression in Capability Development



Libration Points

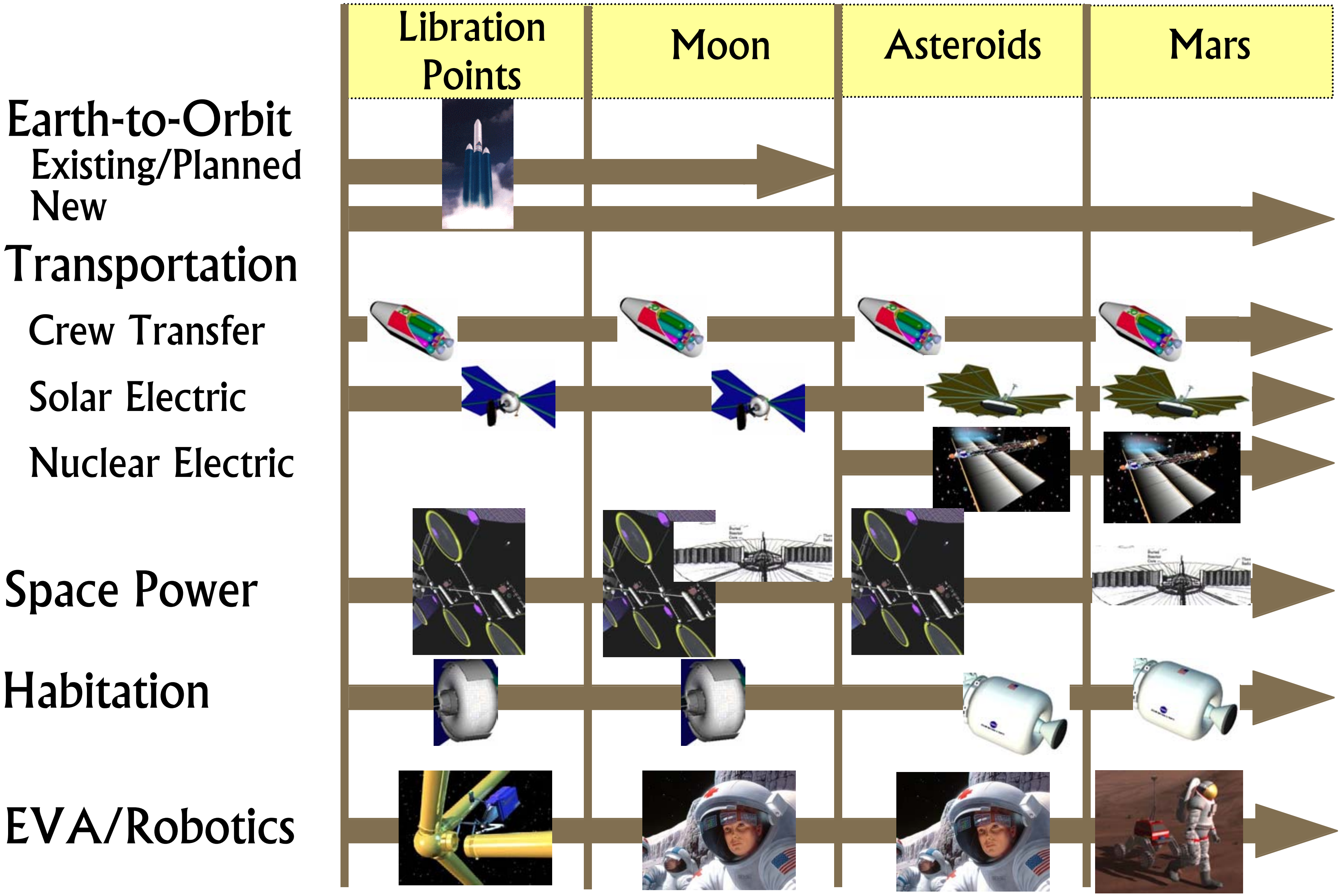


- **Libration Points L1, L2, and L3 are semi-stable locations in space oriented to orbiting planetary bodies**
- **Access to all locations on moon and Mars is equivalent**
- **Very low energy transfers between libration points are possible**



Sun-Earth L_2
Advanced Science Instruments
Mars and Beyond
Instrument Deployment, Retrieval
Lunar Crew Prepare for Mars
Lunar Orbit
To Interplanetary Destinations
Earth-Moon L_1
Exploration Trade Space
From Interplanetary Destinations
100,000 km
Earth
Lagrange Crew Transportation

Stepping Stone Concepts

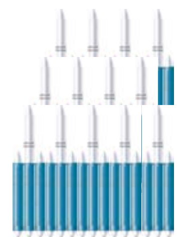
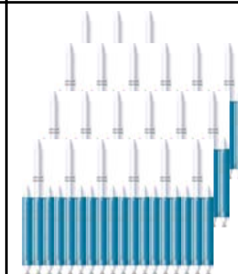
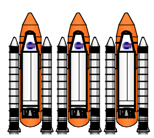
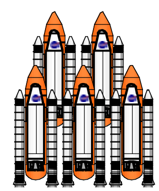
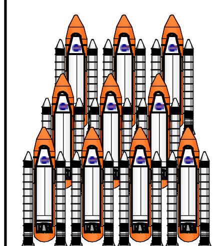
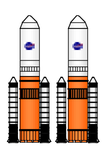
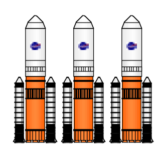
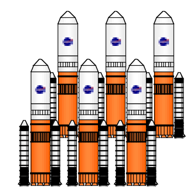


Architectural Drivers

- Launch Capability
- Crew Transfer Vehicle design
- Value of Applied Technology
- Artificial Gravity/ Nuclear Electric Concepts

Exploration Launch Comparison

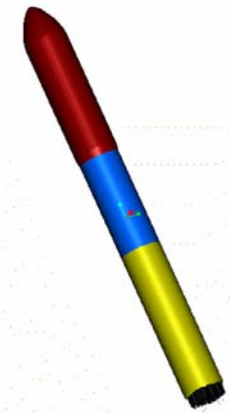
* Note: A launch mass packaging efficiency of 75% is assumed for on-orbit assembly

	Telescope Assembly **IMLEO = 150 mt ***	**Lunar Expedition** **IMLEO = 240 mt ***	**Mars Mission** **IMLEO = 450 mt ***
EELV-H **Payload to LEO = 23 mt** **Probability of Launch Failure = 1/40**	 9 Launches 80% Probability of Launch Success	 13 Launches 72% Probability of Launch Success	 27 Launches 50% Probability of Launch Success
Shuttle-Class **Payload to LEO (small shroud) = 71 mt** **Payload to LEO (large shroud) = 60 mt** **[Assumes 4-segment SRMs]** **Probability of Launch Failure = 1/400**	 3 Launches 99% Probability of Launch Success	 5 Launches 99% Probability of Launch Success	 10 Launches 97% Probability of Launch Success
In-Line HLLV **Payload to LEO = 100 mt** **Probability of Launch Failure = 1/400**	 2 Launches 99% Probability of Launch Success	 3 Launches 99% Probability of Launch Success	 6 Launches 98% Probability of Launch Success

Telescope Assembly mission includes launches for infrastructure buildup

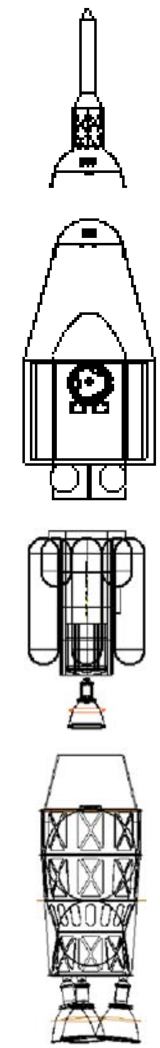
Lunar Expedition includes launches for infrastructure buildup

Preliminary Concepts for Exploration Blueprint Launch Vehicle

	Shuttle Class	Shuttle Class- Evolved	In-line HLLV	2 Stage In-line
Concept Configuration				
Concept Description	• 1.5 Stage Vehicle • Side mount Payload Carrier - 4.6m x 25m Pld envelope • ET - LOX/LH2 Core • 3 SSME Boat tail on Carrier • 2 - Four Segment SRBs	• 1.5 Stage Vehicle • Side mount Payload Carrier - 7.6m x 27.4m Pld envelope • ET LOX/LH2 Core - 5 ft. stretch LH2 tank • 3 SSME Engines on Carrier • 2 - Five Segment SRBs	• 2.5 Stage Vehicle • Inline Payload Shroud - 9.4m x 27.4m Pld for Mars - 7.3m x 27.4m Pld for Near Earth • ET Derived, LOX/LH2 Core • 3 RS-68 Engines • 2 - Five Segment SRBs • Large LOX/LH2 Upper Stage - 2 J-2S Engines or - 1 SSME	• 2 Stage Vehicle • Inline Payload Shroud - 9.4m x 27.4m Pld for Mars - 7.3m x 27.4m Pld for Near Earth • LOX/RP First Stage • 8 RD-180 Engines • LOX/LH2 Second Stage - 4 J-2S Engines or - 2 SSME
GLOW	2041mt	2449 mt	2871 mt w/ J2S(2) 2876 mt w/ SSME(1)	2223 mt w/ J2S(4) 1991 mt w/ SSME(2)
Performance (Destination)	88.6 mt (30 x 150 nmi Ellipse.. @28.5°)	93.5 mt (30 x 150 nmi Ellipse.. @28.5°)	108.5 mt w/ J2S(2) 113.5 mt w/ SSME(1) (30 x 150 nmi Ellipse.. @28.5°)	102.0 mt w/ J2S(4) 102.0 mt w/ SSME(2) (30 x 150 nmi Ellipse.. @28.5°)

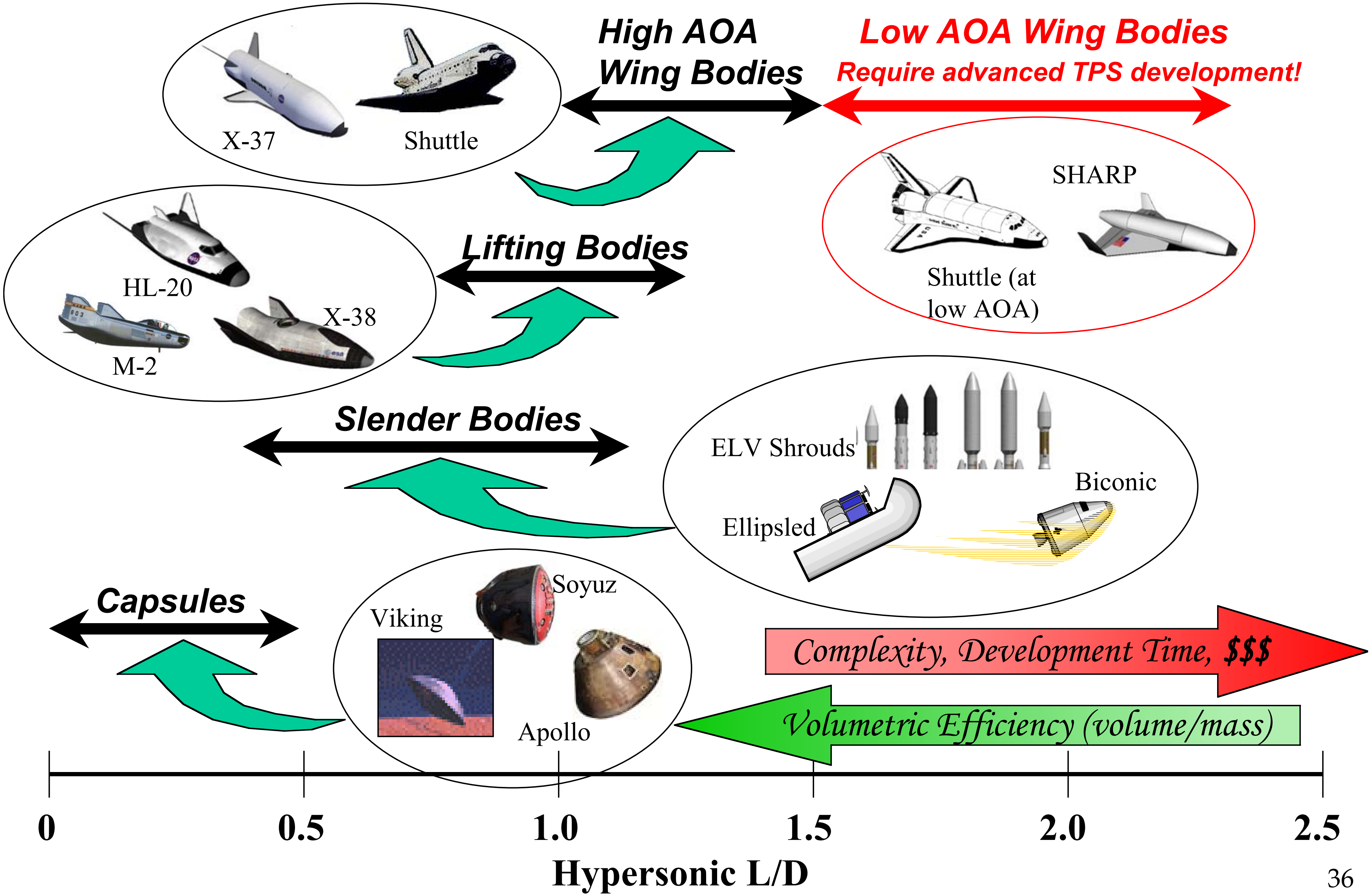
Example Trade Study-
XTV Vehicle Design Status

- **XTV was reexamined**
  - **Larger launch vehicle capability**
  - **Sort functionality between XTV/CTV/CRV**
- **Work completed or in progress:**
  - **XTV vehicle high-level requirements identified**
  - **Initial vehicle mass estimation completed**
  - **XTV requirements comparison with previous XTV, CRV and CTV requirements**
- **Splinter team assessed slender body vehicle compared to other vehicle shapes**
  - **Aerocapture into LEO, direct entry from L1, direct entry from ISS, and direct entry from Mars.**
  - **Vehicle stability and aerodynamics**
  - **Deceleration strategy**

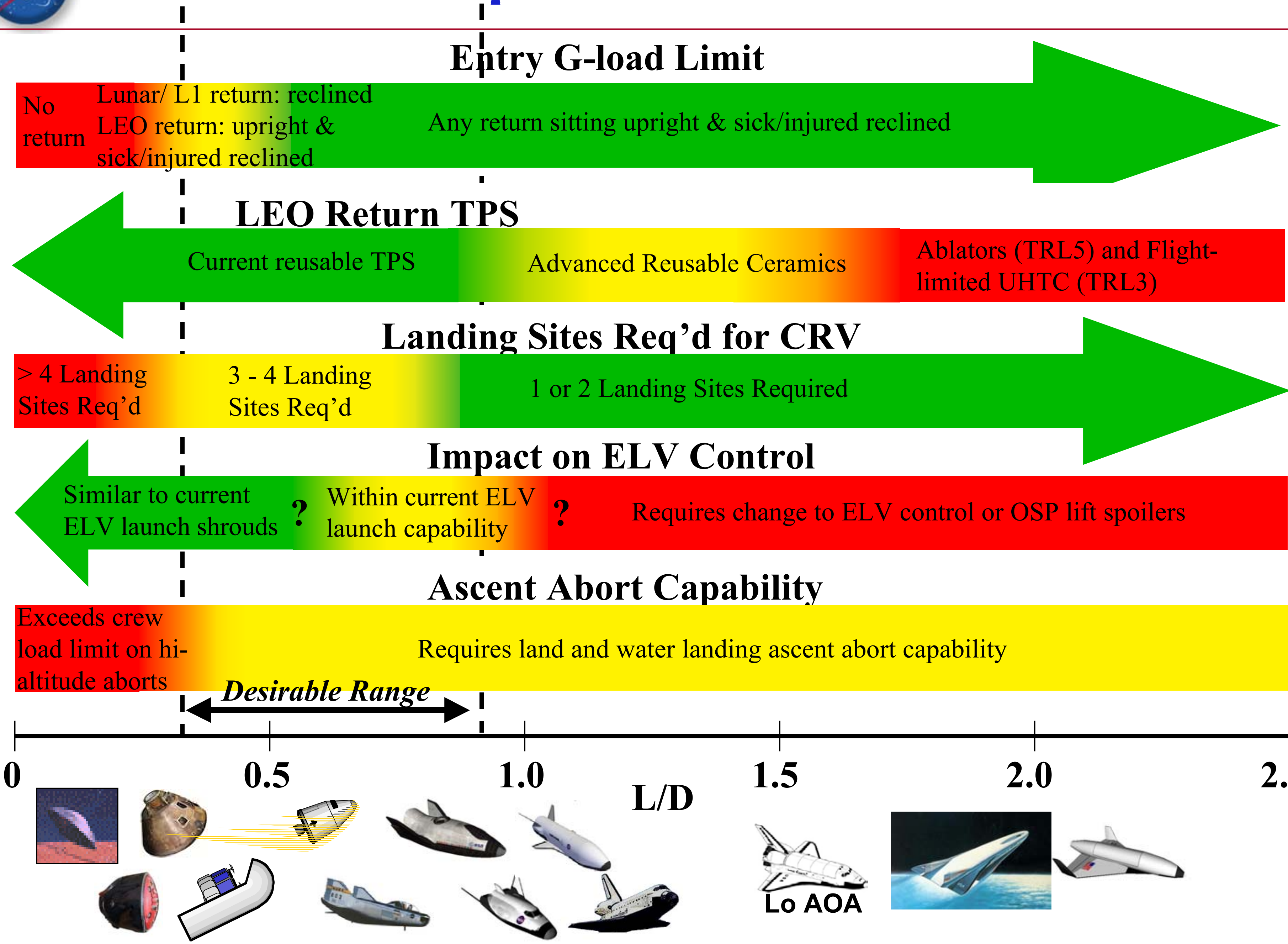


Vehicle Shapes' Lift-to-Drag (L/D) Characteristics

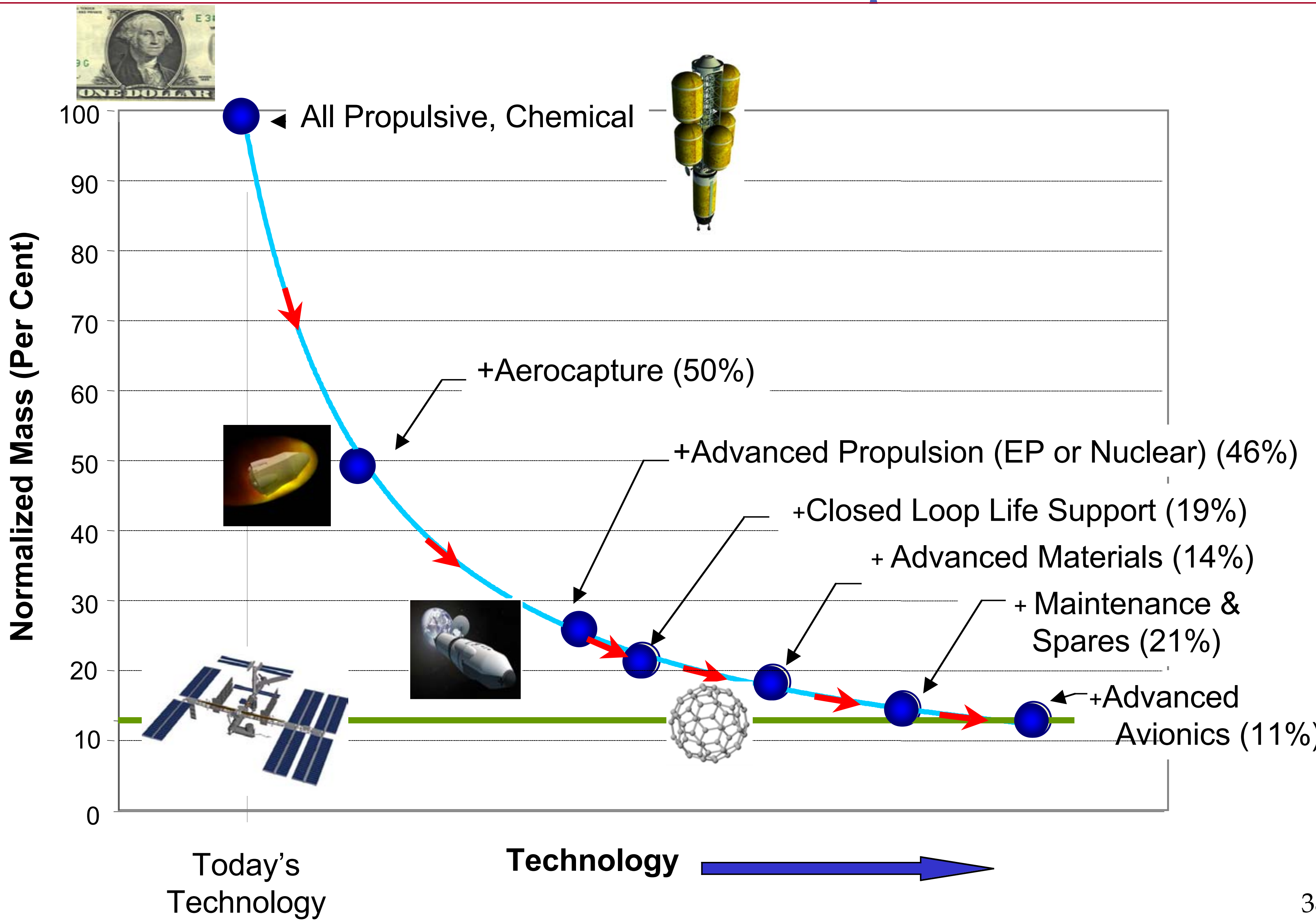
AOA ~ Angle of attack



Shape Sensitivities



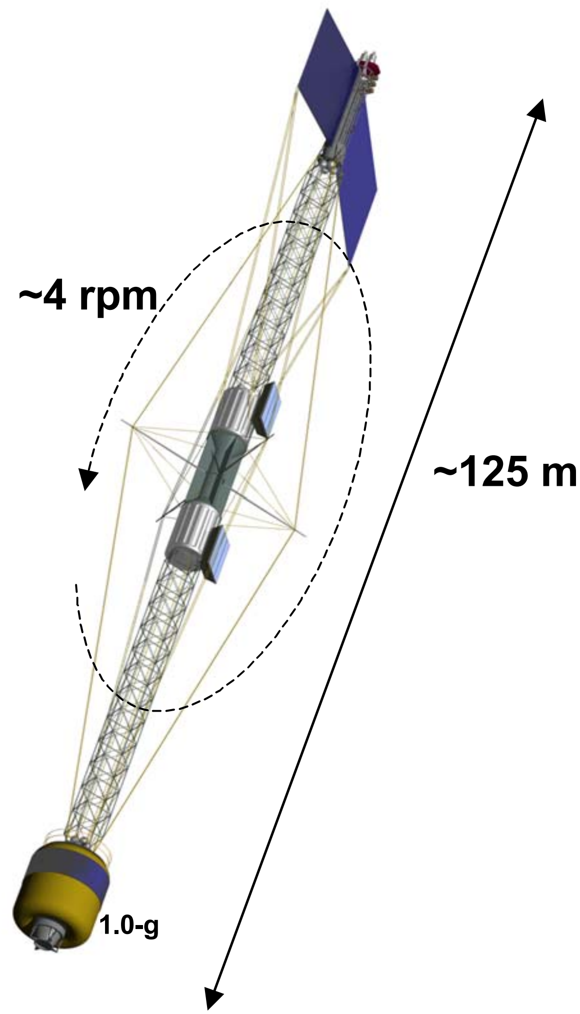
The Value of Technology Investments
- Mars Mission Example -



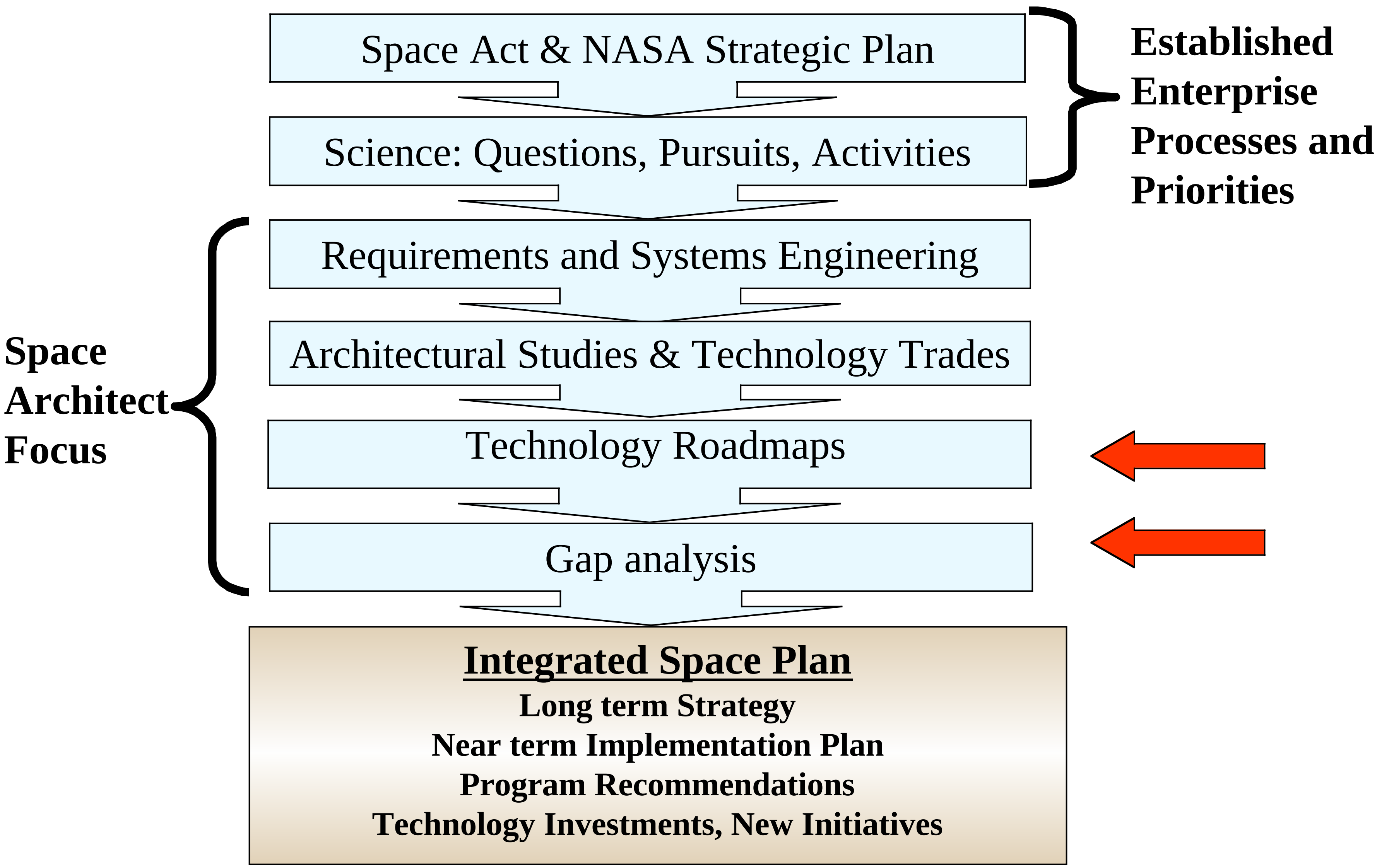
Long-Duration Human Missions

Artificial Gravity/Nuclear Electric Option for Long Duration Missions

- Alternative to micro gravity crew countermeasures
  - 1-g @ 4 rpm
- May simplify qualification of some spacecraft systems operating at 1g
- Synergism between Artificial Gravity (AG) requirements and Nuclear Electric Propulsion vehicle design
  - Booms to separate crew from reactor/ AG moment arm
  - "Nuclear Power module" as counterweight
- Impacts currently under study
- Human exploration nuclear power requirements ready to submit to Nuclear Space Initiative

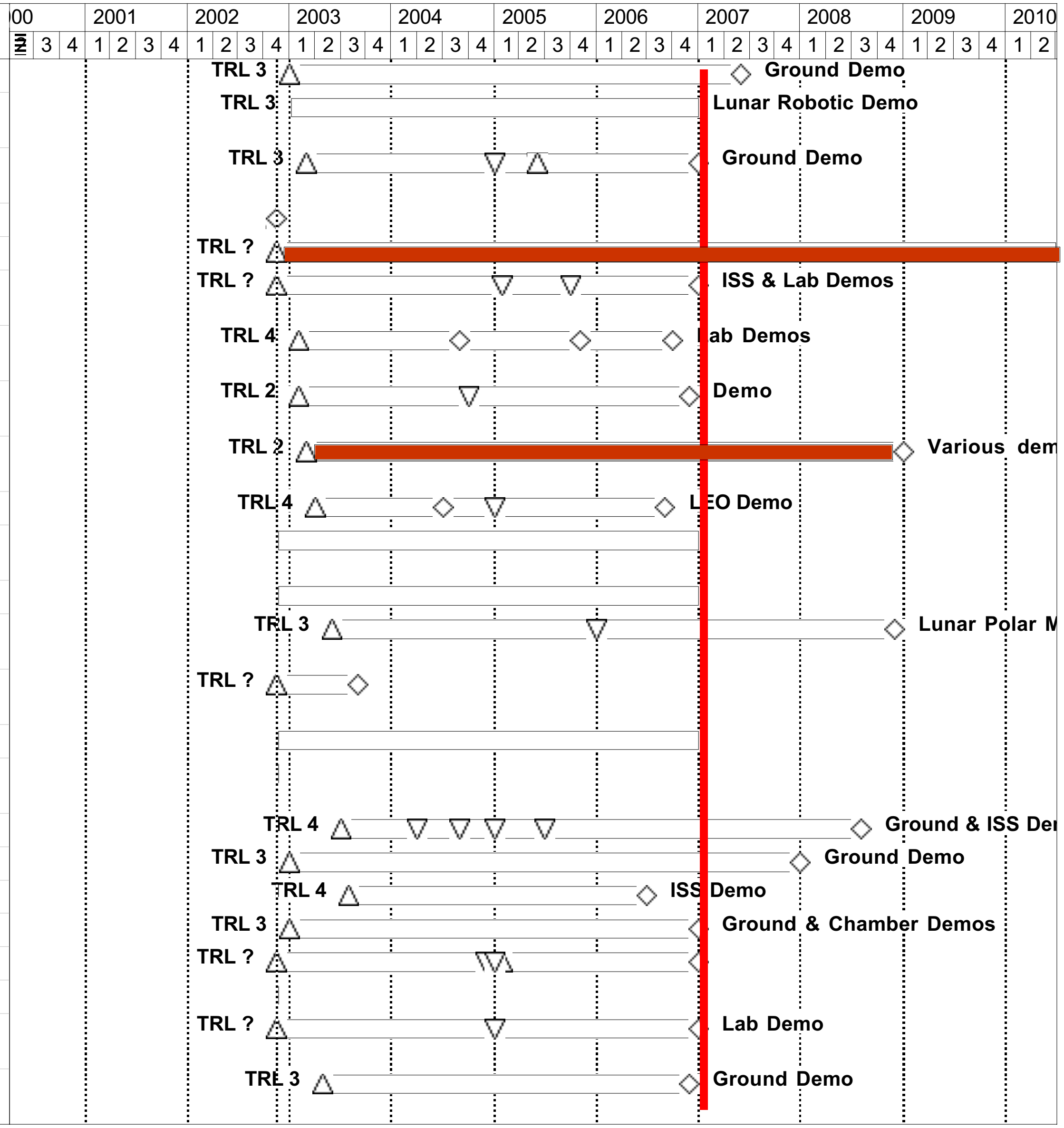


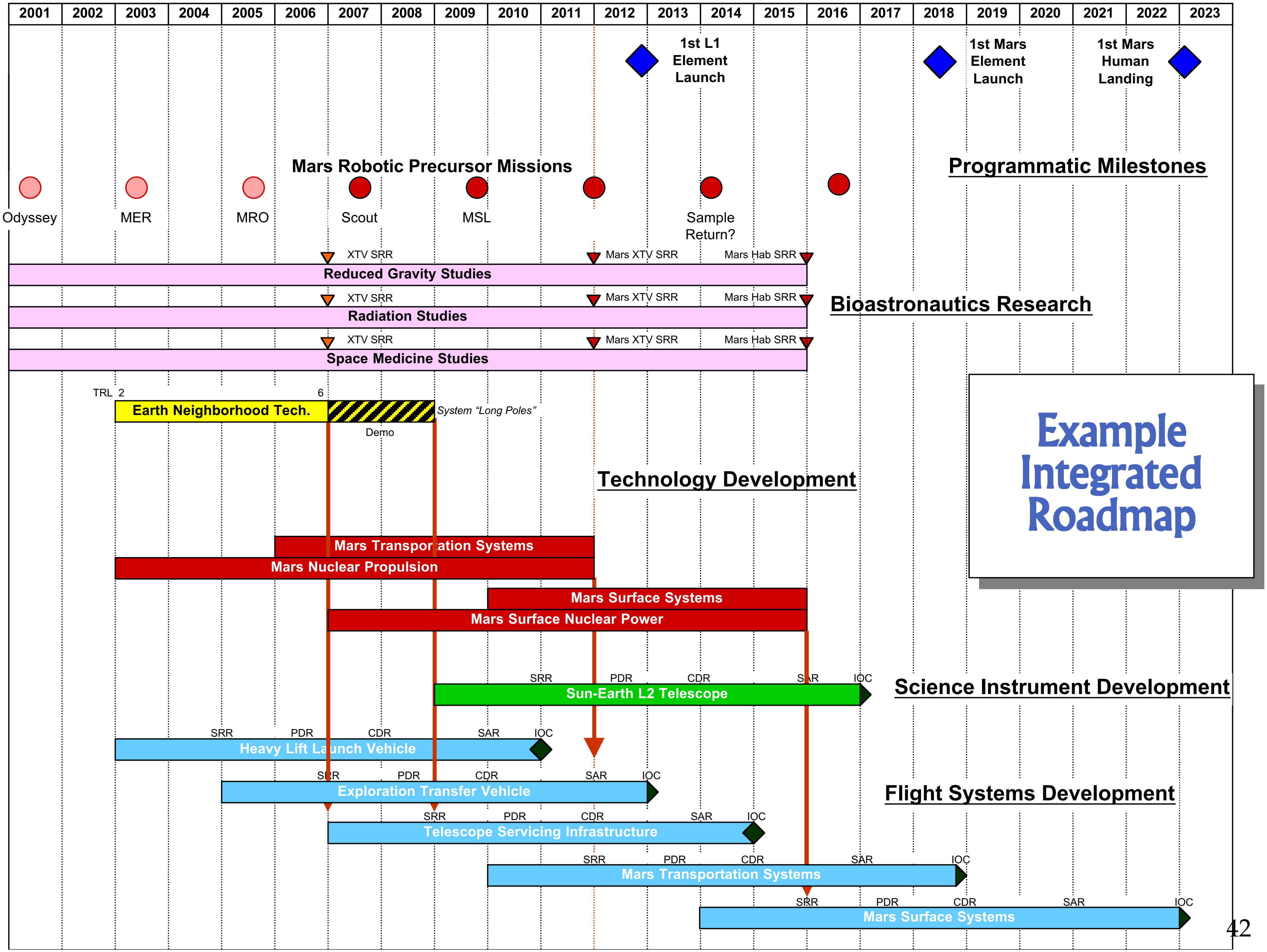
Integrated Space Plan Development Process



Earth's Neighborhood Tech Roadmaps
Draft-Top Level

D	Task Name	Element	Funding
1	(AL) Airlock	GW-LL-Hab	$0
5	(ALH&A) Automated Landi	LL-Hab	$0
6	(AR&M) Automated Rendezvous & Mating	GW-XTV-LL	$0
34	(AVI) Avionics		-
36	(BIO) Bioastronautics	ALL	$
39	(CSS) Crew Support Systems	ALL	$0
55	(ECLSS) Environmental Control & Life Support	GW-Hab	$
68	(EDL) Entry Descent Landing	XTV	$
75	(EVA) Extra-Vehicular Activity	ALL	$0
85	Inflatable Habitat	GW-Hab	$0
89	Information Technology A		-
90	IVHM (?)	All	-
91	(ISRU) In-Situ Resource Utilization	LL	$0
104	Maintenance Information Management		-
108	Medical Technology		-
109	MEMS Wireless Applicatio		-
110	(PWR) Power	ALL	$
131	(PROP) Propulsion	ALL	$
137	(ROB) Robotics	GW	$0
140	(STRUC) Structures	All	$
145	(SUP) Supportability	All	$0
194	Surface Mobility	LL-Hab	$0
195	(SHA) System Health Assessment	ALL	-
209	(TCS) Thermal Control System	All	$0 - $



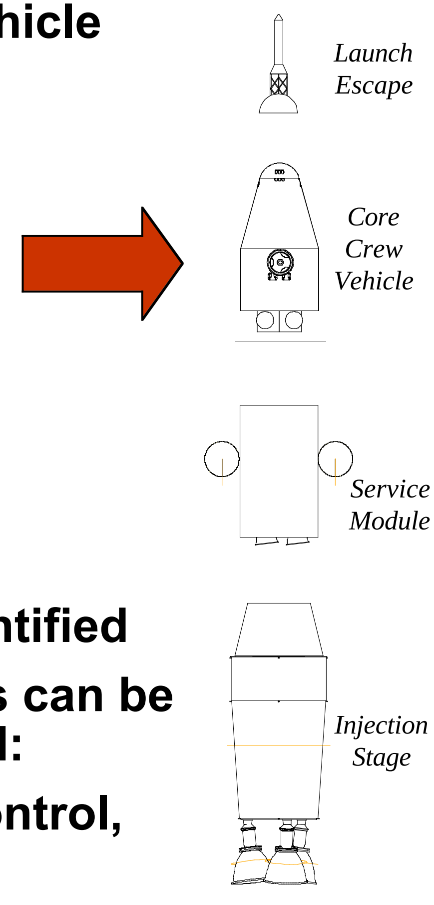

2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023
1st L1 Element Launch
1st Mars Element Launch
1st Mars Human Landing
Programmatic Milestones
Mars Robotic Precursor Missions
Odyssey
MER
MRO
Scout
MSL
Sample Return?
XTV SRR
Mars XTV SRR
Mars Hab SRR
Reduced Gravity Studies
Radiation Studies
Space Medicine Studies
Bioastronautics Research
TRL 2
6
Earth Neighborhood Tech.
System "Long Poles"
Demo
Technology Development
Mars Transportation Systems
Mars Nuclear Propulsion
Mars Surface Systems
Mars Surface Nuclear Power
SRR PDR CDR SAR IOC
Sun-Earth L2 Telescope
Science Instrument Development
Heavy Lift Launch Vehicle
Exploration Transfer Vehicle
Telescope Servicing Infrastructure
Mars Transportation Systems
Mars Surface Systems
Flight Systems Development
Example Integrated Roadmap

Opportunities to Augment or Align NASA Programs to the Exploration Strategy

- Crew Transfer Vehicle
- Space Nuclear Program
- Bioastronautics
- Research on ISS
- Mars Program (robotic)

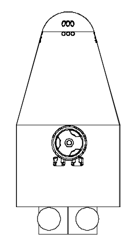
Common Core Crew Vehicle Requirements

- **Objective:**
  - **Establish the requirements for a common core crew vehicle which satisfies multiple, long-term, needs.**
- **Approach:**
  - **Initiate a process to develop common requirements**
  - **Crew vehicle requirements should include needs for:**
    - **CRV- ISS Crew Return Vehicle- Priority 1**
    - **CTV- Crew Transfer Vehicle- Priority 2**
    - **XTV- Exploration Transfer Vehicles- Priority 3**
- **Status:**
  - **Initial set of common core requirements have been identified**
  - **Capabilities beyond the scope of the core requirements can be met with additional systems to be developed as needed:**
    - **Service module for consumables, power, thermal control, extended duration**
    - **Injection stage for larger propulsive maneuvers**
  - **Process should be continued to further refine through OSP**



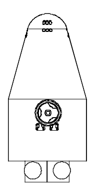
Common Crew Vehicle Design Concept

Core Crew Vehicle



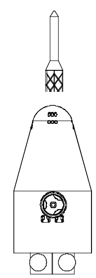
- Common crew element satisfying multiple mission capabilities
- Key Design Requirements :
  - Configurable for 4-7 crew
  - Independent one day mission duration
  - Autonomous / manual operations
  - Propulsive orbital maneuvering
  - Return the crew safely to Earth

ISS Crew Return



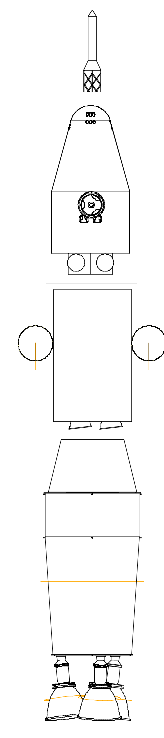
- Provides safe and expeditious recovery of astronauts from low-Earth orbit
- Core Vehicle Configuration Changes:
  - Configured for 4 deconditioned crew (7 highly desirable)
  - Medical emergency provisions
  - Emergency undock capability
  - ISS interfaces and six-month to two-year on-orbit stay
- Key Issues:
  - EELV launch compatibility including automated delivery to ISS
  - Degree of vehicle reusability

LEO Crew Transfer



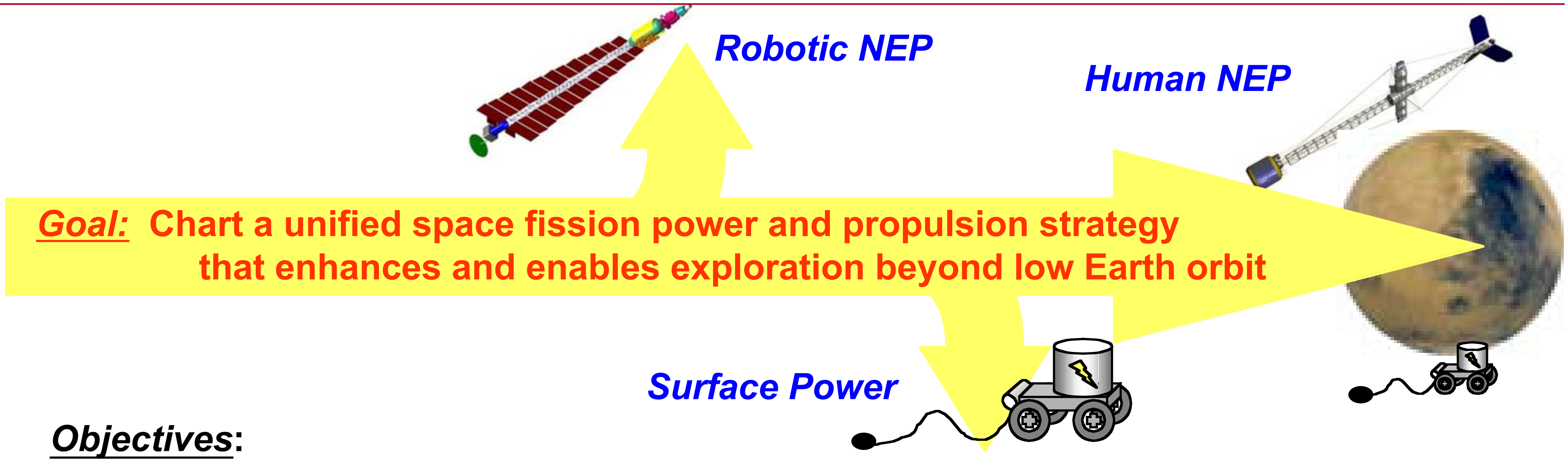
- Crew transfer to low-Earth orbit and return
- Core Vehicle Configuration Changes:
  - Crew escape for aborts
  - Configured for 5 crew (3 ISS transfer)
  - 12 day mission duration for ISS support
  - Resources for extended mission duration (propellant, power, thermal control, life support consumables)
- Additional Systems:
  - EVA systems for on-orbit satellite servicing and repair
- Key Issues:
  - EELV launch compatibility and human rating
  - Degree of vehicle reusability

Near-Earth Transfer



- Transport crew to lunar vicinity and return to Earth
- Core Vehicle Configuration Changes:
  - Configured for 4-6 crew (mission dependent)
  - Crew escape for aborts
  - 12 (active) + 8 (dormant) day mission
  - Deep-space environmental protection
  - Resources for extended mission duration (propellant, power, thermal control, life support consumables)
- Additional Systems:
  - EVA systems for servicing and repair as required
  - Injection stage for trans-lunar injection
- Key Issues:
  - Lunar return velocities
  - Large launch vehicle
  - Degree of vehicle reusability

A Unified Space Nuclear Strategy…
…Lays the Foundation for Sustained Exploration



Objectives:

- **Strategy should address projected robotic and human needs of the agency**
- **Identify desired system requirements and concepts**
  - **Robotic: Recent NSI studies**
  - **Human: NEXT Human Exploration Requirements for Future Nuclear Systems**
- **Assess multi-applicable technologies and infrastructure options**
- **Develop a roadmap linking technology and infrastructure developments**

Endorsement: **Nuclear Systems Initiative (NSI) is to Implement a Unified and Coordinated Development Program Leading to Nuclear Electric Propulsion and Nuclear Surface Power Capabilities for Human and Robotic Exploration**

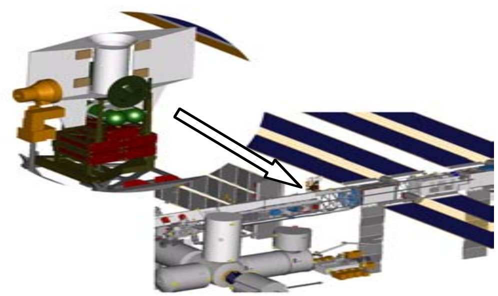
Bioastronautics

- Objective: Humans will enable, not limit, exploration.
- Issues for long-duration human missions
  - Risks and critical questions have been identified and prioritized
    - Risk reduction on-going through 2010 and beyond
    - Incremental risk reduction progressively reduces mission risks
  - Radiation concerns limit deep-space exposure
  - Micro gravity exposure can effect crew performance and health
  - Medical response plan is determined by risk level to be accepted
- ISS Program issues
  - More crew time needed for bioastronautics research
  - Larger “n” required for biomedical studies
    - Larger crew size on ISS
    - More frequent crewmember turn-over
  - The ISS centrifuge is required for artificial gravity research

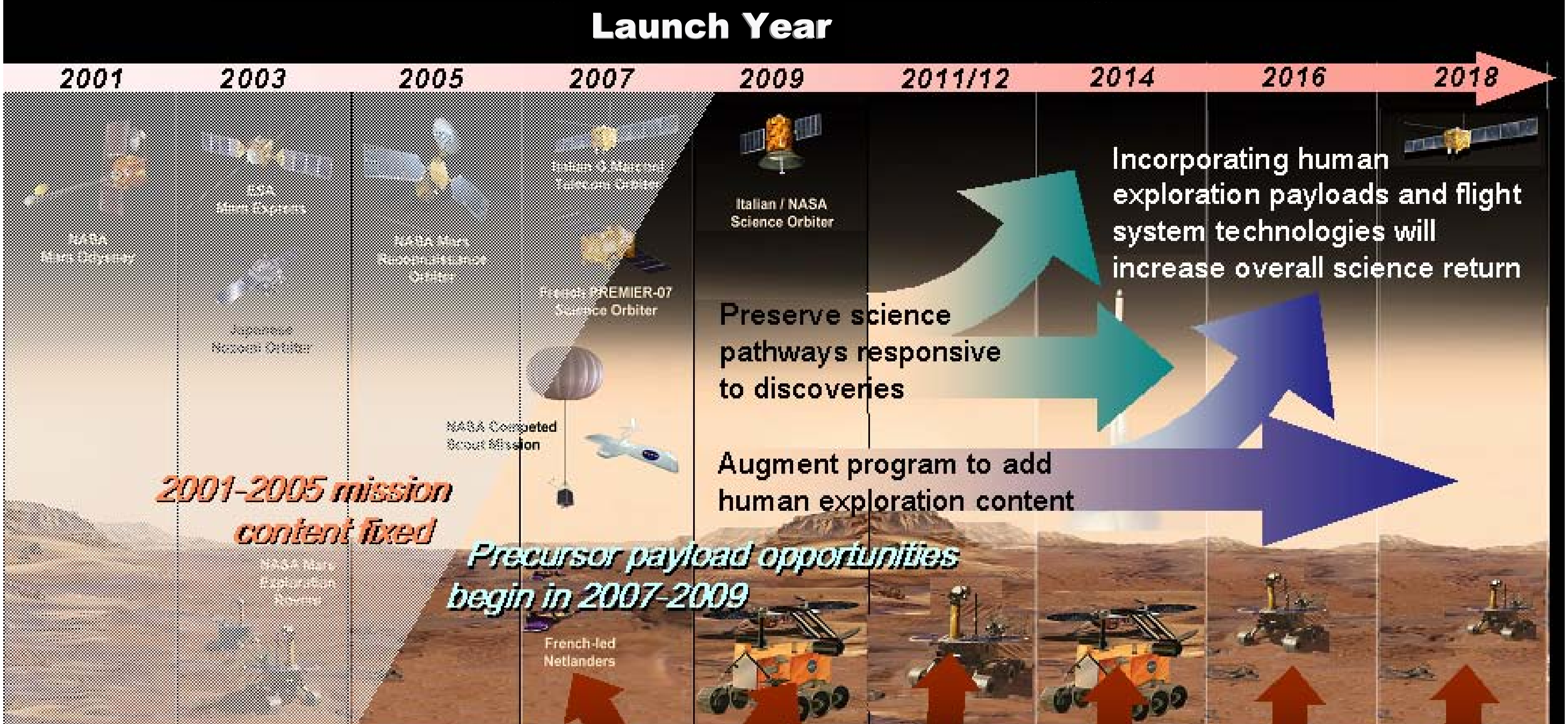
Critical Research Needs- International Space Station Opportunities

Research benefits ISS as well as future programs:

- Critical need for Bioastronautics research
  - Micro gravity
  - Radiation
  - Human performance on long missions
  - Behavioral Health
- Improve performance / crew productivity and safety
  - Proper automation of systems
  - Advanced crew interfaces
  - Reduce time required for biomedical countermeasures
  - Fire Safety Research
- Reduce resupply
  - Closed loop life support minimizes consumables
  - Miniature sensors, processors and wireless technologies
  - Plasma engine could perform reboost with waste H2
  - Advanced fabrication and repair technologies
- Operational experience and systems exposure to space environment
  - Contributes to long term reliability
  - Evolution to simpler designs and better performance



Potential Augmentation



	2007 / 2009		2011/12	2014	2016	2018
Mission Opportunities:	• 2007 Scouts • Dedicated 2007/9 Mission	• 2009 MSL	• Site Survey Mission	• Mars Sample Return	•Site Survey Mission	•Site Survey Mission •Comsat
Potential Human Exploration Content :	• Hazard avoidance and precision landing • Measure Cr VI, Ph and buffer capacity • Measure organic carbon • Measure surface radiation • Measure mechanical and adhesive properties of soil and dust		• Advanced entry shapes (mid L/D) • High Mach parachute • Deep drilling	• Sample return (required if organic carbon found by in-situ measurement)	• Landing site characteri-zation • ISPP, ISCP • Water recovery	• Comm. and navigation infrastructure

Summary Recommendations

- **Endorse Nuclear Systems Initiative**- Develop technologies and capabilities that address near term robotic missions and evolve towards future human missions
  - Nuclear Electric Propulsion
  - Nuclear Power Reactors for surface applications
- **Endorse and augment Bioastronautics research-** Accelerate capability on ISS to obtain needed data for long term missions
- **Focus Integrated Space Transportation Program**
  - Provide low-cost / High Payload Earth-to-Orbit Transportation
    - Payload: 100 mt class
  - Pursue process to provide synergy in Crew Transportation
    - CRV for ISS
    - CTV for alternate access
    - XTV for lunar missions

    Common Core Vehicle
- **Endorse and augment Augment Mars Program to increase science and address precursor needs**
  - Increased science return and further interest in exploration
  - Environmental data for science, site certification, and engineering design
  - Demonstration of key technologies
  - Miniaturization of sensors
  - Accelerate Mars Sample Return Mission

Summary Recommendations

- **Coordinate roadmaps between Exploration architecture and science programs and plans**
  - Office of Space Science
  - Office of Earth Science
  - Office of Biological and Physical Research
- **Invest in critical key technologies**
  - Pursue process to identify critical technologies and gaps
  - Implement technology development plan through re-focused existing programs/projects and new initiatives
- **Develop an integrated analysis capability to evaluate options and understand synergies for NASA in space programs and research**

Space Architecture Team - FY03 Objectives

- **Develop integrated space plan**
  - Develop rationale
  - Develop architecture concepts/approaches
  - Document level 0/1 requirements (collect science, generate technical and programmatic)
  - Update technology roadmaps and gap analyses
- **Recommend technology realignments and initiatives**
  - Long-term evolving strategy with near-term implementation requirements
- **Seed investments in specific concepts and technologies**
- **Coordinate development of decision support tools**
- **Develop and implement external engagement plan**

Space Architecture Team – Products Schedule

Milestone/Event	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
Integrated Space Plan						Initial Plan					Annual Update
Rationale				Initial Concepts							Annual Update
Architecture concepts				Initial Concepts							Annual Update
Level 0/1 requirements				Initial Set							Annual Update
Technology Roadmaps				Initial Set							Annual Update
Investment Recommendations							Support FY03 POP				
Annual Report											
IPAO Annual Assessment											

Space Architecture Team - FY03 Products

Title	HQ Lead	$M
Integrated Space Plan	Space Arch	
Rationale Development of a clear and compelling set of justifications to support the pursuit of robust space exploration goals	SA & Chief Sci	0.5
Architectures, Concepts, Requirements and System Analysis Definition of a diverse set of human/robotic architectures based on innovative concepts to identify common technological needs and challenges. Capturing of associated upper and lower level requirements	Space Arch	5
Space Transportation Architecture Requirements Integration of a comprehensive set of requirements and traffic models consistent with both near and long term exploration needs	Space Arch	3
Technology Roadmaps, Gap Analyses and Priorities Develop technology roadmaps and conduct gap analysis to guide strategic decision making	Code R	2
Engagement Strategy Development and implementation of a plan for communicating NASA strategy and results while also providing opportunities for internal and external inputs	L, I, P & N	1

Total (this page) = 11.5M

Space Architecture Team - FY03 Studies and Analyses
(Initial Efforts)

Internal NASA Use Only

Task Title	$K
Mass Reduction (Materials) Assessment of means to reduce vehicle launch mass and operational complexity through lightweight structural materials, wireless systems that replace vehicle cabling and cold plates, etc	350
Precision Landing and Hazard Avoidance Studies that improve the ability to safely land robotic and human missions near valuable science sites (e.g. Mars)	500
Radiation Shielding Studies Analysis of active and passive shielding technologies that support definition of reference architectures	572
Space Assembly, Maintenance and Servicing Development of concepts and technologies for robotics, EVA, autonomous systems and intelligent operations	2100
Observational platform concepts (Space & Earth Science), Auton Reconfig Constellations (Earth Science) Studies of concepts for revolutionary capabilities that address important scientific goals using new technologies and operational methods (e.g. pure automation and combined human/robotic)	1500
Earth Analogs Definition of requirements for a ground based facility that can validate new technologies and reduce future implementation unknowns/risks	1000
Development of space Identify opportunities to leverage industry investments for scientific exploration	350
Decision Support Tools Complete ongoing updates of THREADS technology roadmaps for continued development by Space Architecture team. Further development of model of top level architecture and technology metrics to aid strategic assessments	1150
Human/Robotic Enabled Science NRA Studies to identify and develop concepts for human enabled science on planetary surfaces and in space	2000
Mars Precursor Studies Soil and dust characterization based on “Safe on Mars” report from NRC	200

Total (this page) = 9.72M (1M-U, 0.5M-Y, 3.9M-S, 3.32M-M, 1M-R)

Space Architecture Team
FY03 Products, Studies, & Analyses Leadership

Space Architect
Technical Lead

- •Rationale
- •Architecture Concepts, Requirements & Sys Analysis
- •Space Transportation Architecture Requirements

Code M | Code R | Code S | Code U | Code Y | Codes LIPN | Center Reps

FY03 Products and Studies Leadership Assignment

Code M
- •Space Assembly and Maintenance
  - EVA
  - Intell Ops
  - Robotics
- •Development of Space
- •Radiation Shielding Effects
- •Decision Support Tools

Code R
- •Technology Roadmaps & Gap Analyses

Code S
- Observational Platforms
- Precision Landing/Hazard Avoidance
- Space Assembly and Maintenance
  - Robotics
  - Auton Sys
- Human/Robotic Enabled Science NRA

Code U
- •Earth Analogs - Integrity
- •Mass Reduction Materials
- •Mars Precursor Studies

Code Y
- Observational Platforms
- Autonomous/ Reconfigurable Constellations

Codes LIPN
- Engagement Strategy

Center Reps
- Ames
- Dryden
- Glenn
- Goddard
- Johnson
- JPL
- Kennedy
- Langley
- Marshall
- Stennis

Next Steps

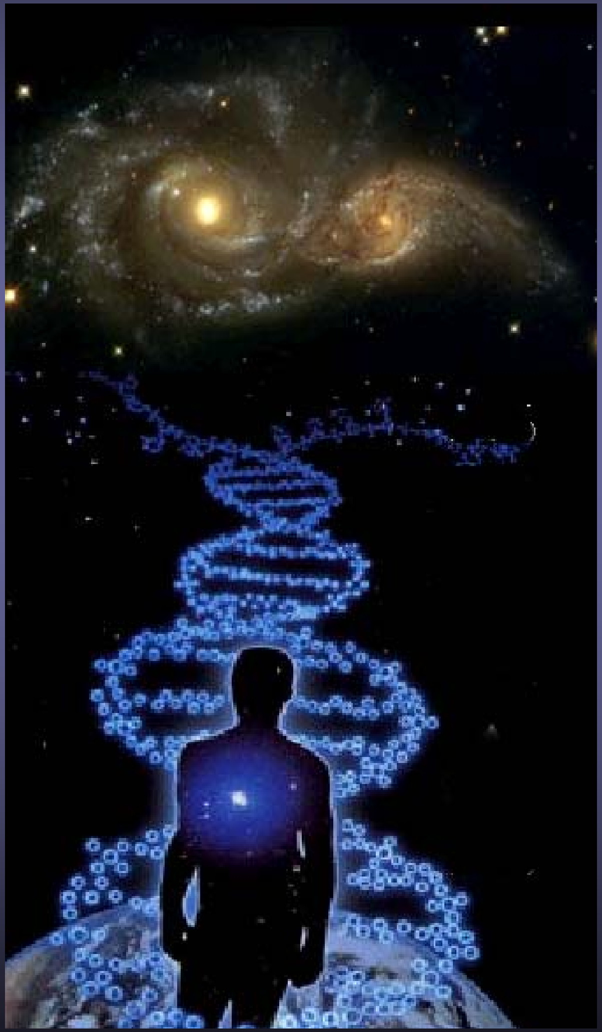
- **Develop Integrated Space Plan**
- **Request current goals, objectives and themes from each Enterprise**
  - Develop rationale for each (as needed)
  - Integrate holistic set to support science driven exploration
- **Through agency decisions, align and focus existing programs to fulfill portions of the Integrated Space Plan**
- **Identify and pursue new initiatives to fill gaps in technologies and capabilities**
- **Issues**
  - FY03 funding and R&PM support
  - FY04 funding

The Exploration of Life in the Universe

To improve life here

To extend life to there

To find life beyond



… and sharing the adventure of discovery with all humanity

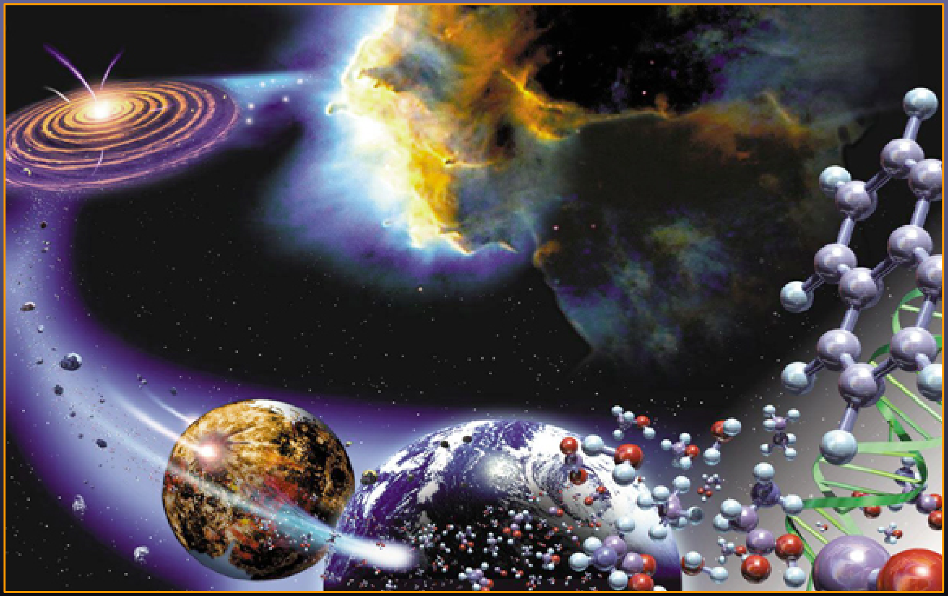
Why exploration of space?

Why, indeed, did we trouble to look beyond the frontier?

Our prime obligation to ourselves is to make the unknown known.

We are on a journey to keep an appointment with what whatever we are.

--- Gene Roddenberry



Exploring the grand cycle of life in the cosmos

Only NASA can lead life's exploration of space

Space provides a unique perspective on our planet, other worlds, the Universe . . . and, especially, ourselves.

As the last century closed, the United States led the world in *discovering* new scientific evidence and new processes that *revealed* our place in the Universe, by *exploring* new places and phenomena, *leading* outward beyond the vicinity of the Earth, to *enhance* the quality of life and share the *adventure* of discovery with all humanity.

At the start of a new century, we build upon past success, modern skills, and a shared vision of the future.

Only NASA can lead and manage the missions and technologies for the nation that will expand human presence in the cosmos, increase fundamental knowledge, and inspire future generations of explorers and discoverers.

NASA’s unique place within the nation, in history, in science and exploration, is embodied within the Space Act and Strategic Plans.

Of all the nation’s institutions, *only* NASA can

Explore Life in the Universe . . .

To improve life here

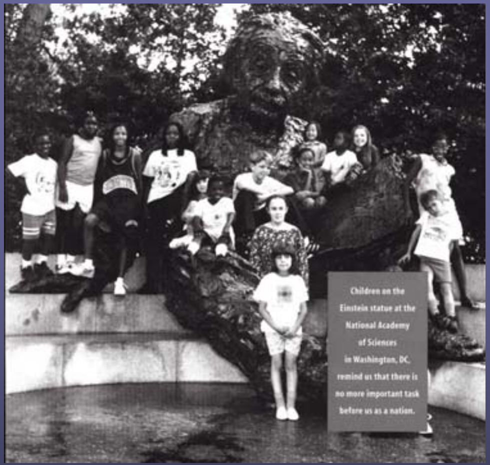
To extend life to there

To find life beyond

To improve life here

Space exploration has historically inspired young people to undertake the challenging tasks required for advanced education, where all citizens have the opportunity to be literate in science and technology no matter what their goals may be.

In a competitive world at the dawn of the 21st Century, only NASA will set challenges in exploration sufficiently exciting to motivate the nation’s best students.



“Every child in America deserves to be challenged by high expectations and supported by a commitment to excellence.”

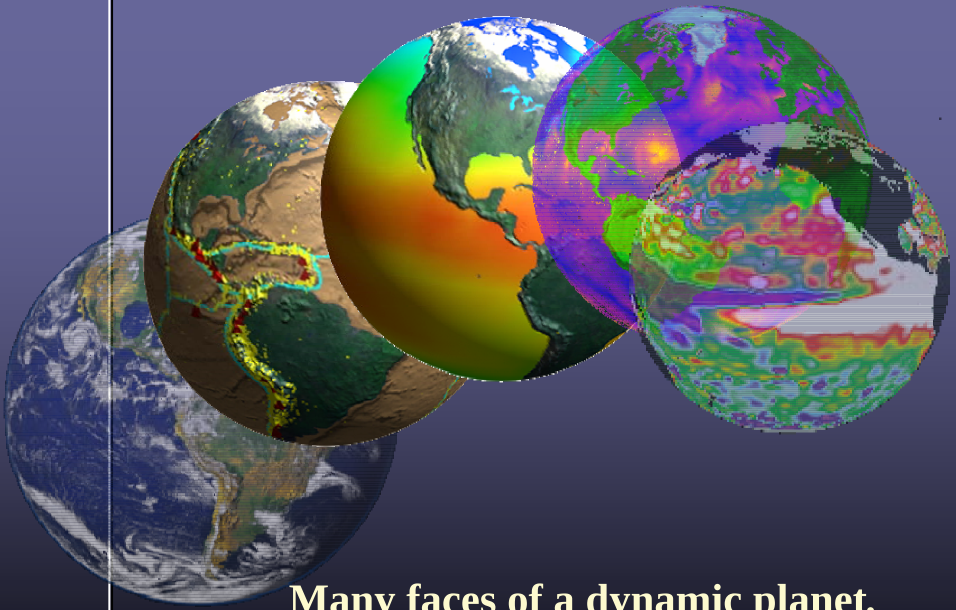
--- George W. Bush

To improve life here

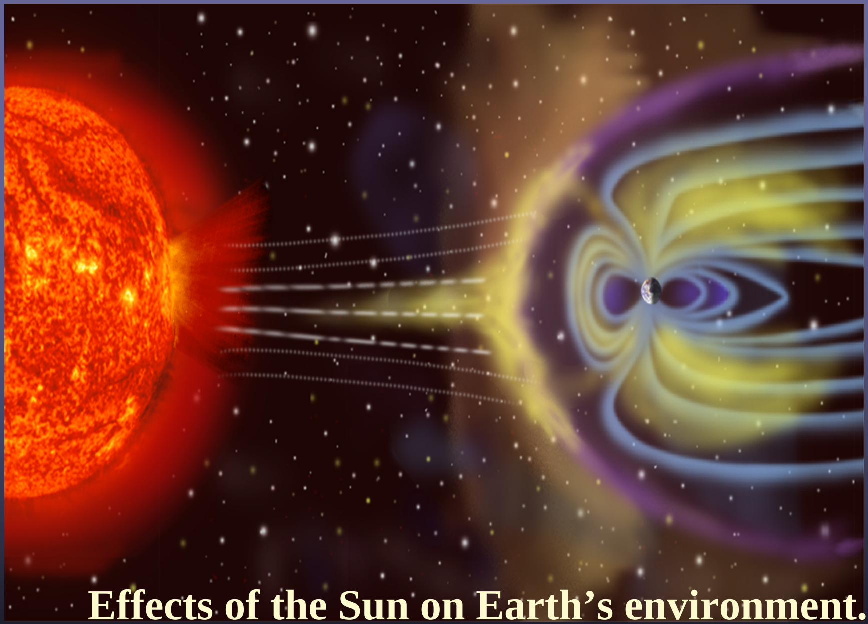
Only from space, enabled by NASA, has our civilization learned to appreciate the complex interplay among the biosphere, the Earth, and the Sun.

Today our observations in low Earth orbit are limited in time and in perspective. Tomorrow, with a vista from beyond low Earth orbit, our perspective will become global in time and space, as we investigate, understand . . . and one day *predict* . . . the effects of our environment upon ourselves.

NASA explores the effects of life on the environment . . . . and of the environment on life.



Many faces of a dynamic planet.



Effects of the Sun on Earth's environment.

To improve life here

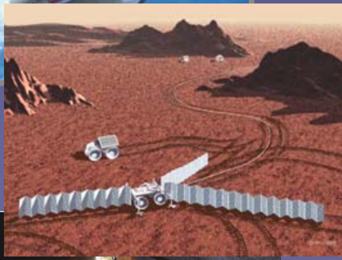
NASA technology investment makes possible the scientific discovery today and opening the frontier for human exploration tomorrow.

The Challenges

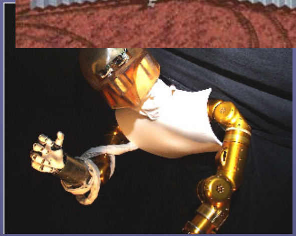
- **Space Transportation**
  - Safe, fast, and efficient
- **Affordable, Abundant Power**
  - Solar and nuclear
- **Optimized Robotic and Human Operations**
  - Dramatically higher productivity; on-site intelligence
- **Crew Health and Safety**
  - Countermeasures and medical autonomy
- **Space Systems Performance**
  - Advanced materials, low-mass, self-healing, self-assembly, self-sufficiency…

Investing in Solutions

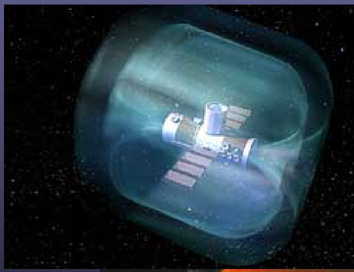
- Reusable Launch Vehicles



- Surface Power on Mars
- Telerobotics and Autonomy



- Active Shielding (M2P2)

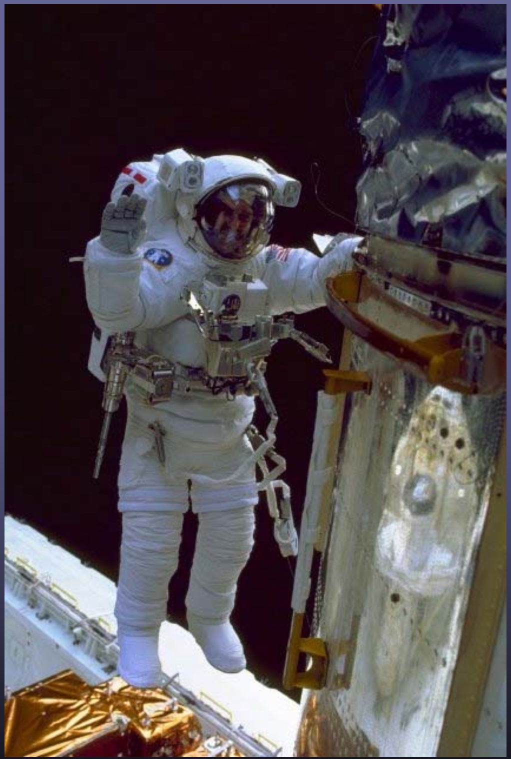


- **Intelligent Spacecraft Systems**

To extend life to there

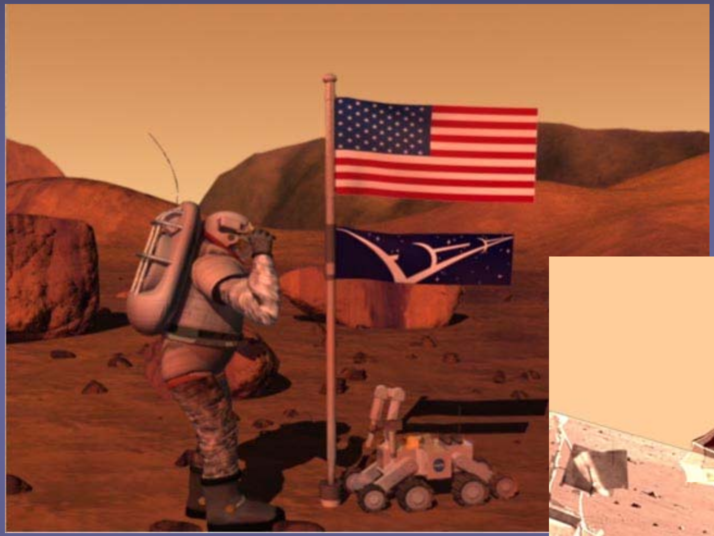
Those nations that have ceased exploring remain in the backwaters of history and are consigned to follow where others will lead.

Only NASA is developing the capabilities . . . and has the mandate . . . to use humans in space to make possible scientific exploration, discovery, and to inspire a nation.

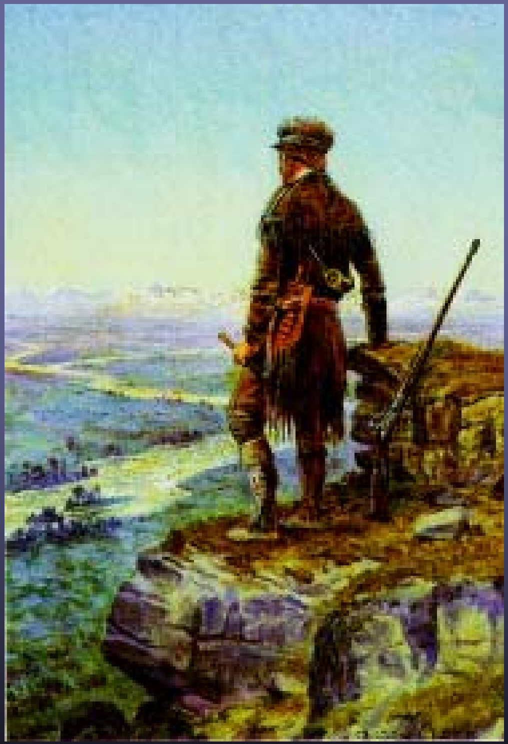


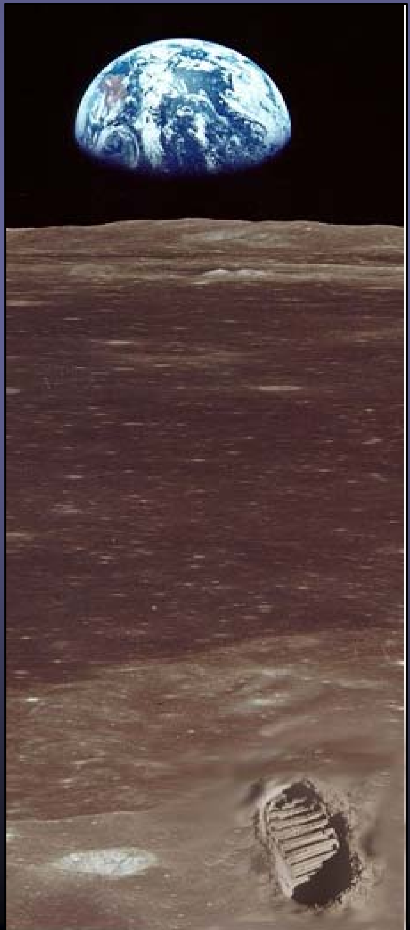
To extend life to there

Robotic pathfinders are leading humanity's exploration beyond low Earth orbit, preparing the way for humanity . . .



To extend life to there





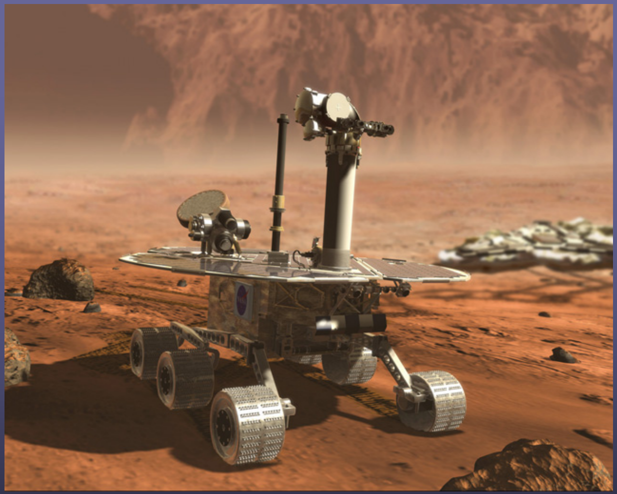
To extend life to there

To seek life beyond

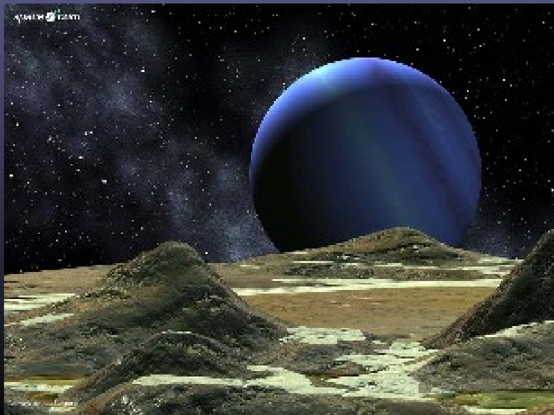
Life's place on the cosmic stage will only be understood when we search for its other homes, in the Solar System . . . and beyond.

Only NASA can search for all life's origins . . .

From extremes on Earth . . . .



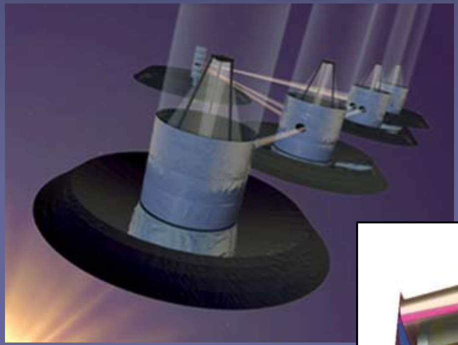
. . . to the deserts of Mars . . .



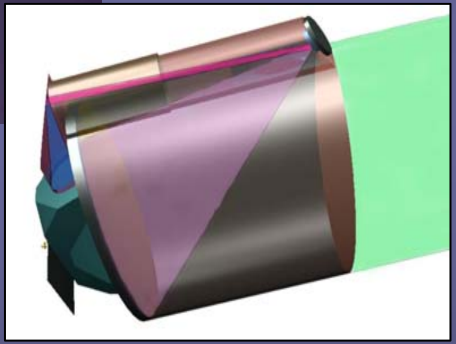
. . . and beyond.

To seek life beyond

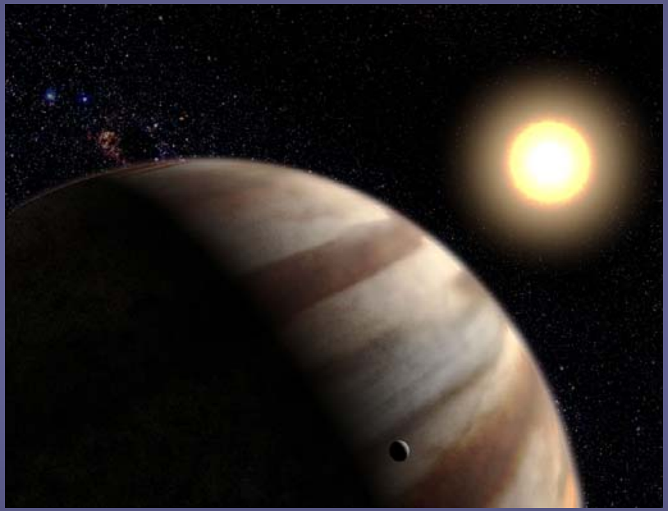
And only NASA can carry humanity's search deep into the Universe . . .



IR Separated Spacecraft Interferometer Concept

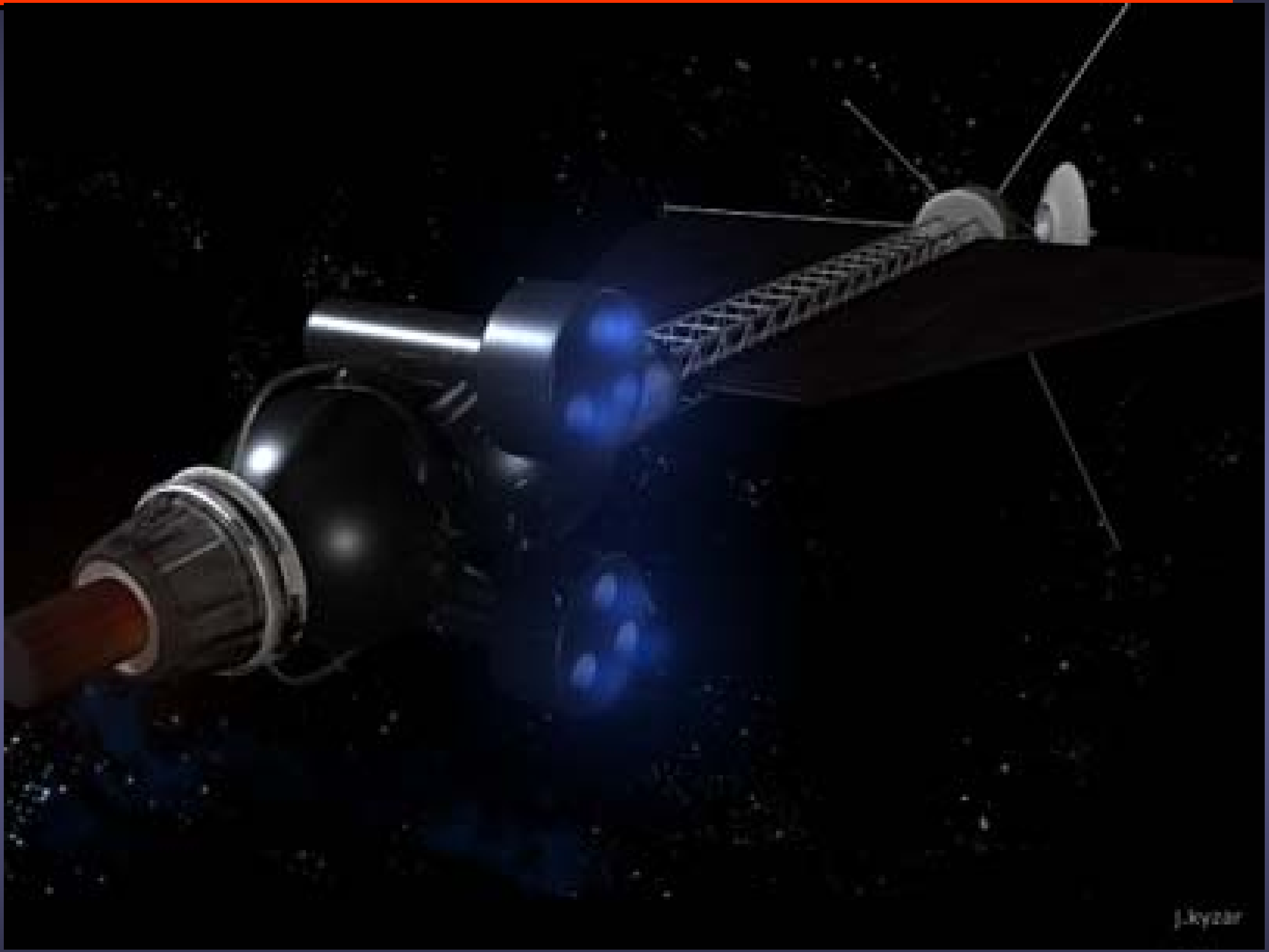


Visible Coronagraph Concept



Advanced optical systems . . . **seeking life's abodes among the stars.**

Exploration of Life in the Universe



"Let us create vessels and sails adjusted to the heavenly ether and there will be plenty of people unafraid of the empty wastes. In the meantime, let us prepare for the brave sky-travelers . . ."

-- Johannes Kepler to Galileo Galilei

Advanced Concept Analysis in Support of the Integrated Space Plan

Section 2.2

Opportunities

November 2002

Structure of the NASA Strategic Plan for Science

NASA Goals

	Strategic Goals
Understand and protect our home planet	1. Understand the Earth system and apply Earth system science to improve prediction of climate, weather, and natural hazards. 2. Enable a safer, more secure, efficient, and environmentally friendly air transportation system. 3. Create a more secure world and improve the quality of life by investing in technologies and collaborating with other agencies, industry, and academia.
Explore the Universe and search for life	4. Explore the fundamental principles of physics, chemistry, and biology through research in the unique natural laboratory of space. 5. Explore the solar system and the universe beyond, understand the origin and evolution of life, and search for evidence of life elsewhere.
Inspire the next generation of explorers	6. Inspire students to pursue careers in science, math, and engineering. 7. Engage the public in shaping and sharing the experience of exploration and discovery.
	Enabling Goals
	8. Improve the provision of access to space for the nation by making it increasingly safe, reliable, and affordable. 9. Demonstrate the feasibility and develop the capabilities required to enable human space exploration beyond low Earth orbit. 10. Enable revolutionary capabilities through new technology.

Themes

- Solar System Exploration
- Mars Exploration
- Astronomical Search for Origins
- Structure and Evolution of the Universe
- Critical Aeronautics Solutions
- Space Launch Innovation
- Pioneering Technology
- Commercial Technology Partnerships
- Earth System Science
- Earth Science Applications
- Biological Sciences Research
- Physical Sciences Research
- Commercial Research & Flight Support
- Education Programs
- Space Station
- Space Shuttle
- Space and Flight Support

Challenges to NASA

- Increase the shared experience of space exploration (“being there”)
- Enables *new* science goals—can’t do without humans *on site*
- Increase the pace of science returns ➔ rapid “in-the-field” discoveries rarely possible today
- Reduce the loss of mission returns by rescue/repair/replanning
- Inspire new generations because “they can go!” & vicarious exploration
- Demonstrate leadership : Human/robots “on site” at tangible frontiers evokes world-class science/technological prowess
- Extend life to there while Searching for Life’s records in the Universe (let humans uncover the fossil records!…)

Human Advantage :
Benefit to America / Benefit to NASA

Benefit to America

- Encourages pride in our nation and its citizens
- Provides genuine heroes
- Inspires achievement
- Source of wonder, hope, adventure, drama
- Enables vicarious space travel

Benefit to NASA

- Adaptability and responsiveness
- On-site decision making
- Enables complex operations not otherwise possible
- Human insight and intuition
- Recovery of otherwise-lost missions

Spaceflight is intensely human

Human Advantage: *Planetary Surfaces*

- Results:
  - Humans “on site” enable technology to go and collect unique data (***Greenland ice cores, Lake Vostok access***)
    - Demonstrated here on Earth and on Moon with Apollo
  - Adaptability to real, potentially dynamic, field conditions with real-time adjustment of science activities (dynamic response)
  - Sampling: getting the ‘right stuff’ to make discoveries (humans intelligently narrow the huge sample collection trade-space most rapidly and effectively)
  - Gaining new vantage points, nimbly, and rapidly, with highest potential for breakthrough results
  - Human(in-situ)/Human (extended) interaction offers NEW approaches to challenging field problems
  - Humans naturally “extend life to there” while adaptively “seeking life in the Universe” in best places

Human Advantage: *In Space Servicing*

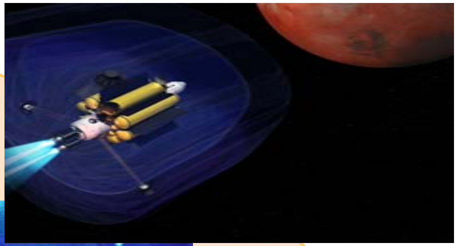
- Humans in space enable new technology to be inserted into existing systems
  - Extension of science capabilities and operational lifetimes
- Adaptability to real, potentially dynamic, conditions with real-time adjustment of activities (dynamic response)
- Erecting: setting up the complex robotic systems to do the science work (i.e, unfurling new apertures, etc.)
- Gaining new vantage points, nimbly, and rapidly, with highest potential for repair, rescue, and innovative servicing
- Human(in-situ)/Human (extended) interaction offers NEW approaches to challenging in space servicing problems
- Humans naturally “extend life to there” while adaptively “seeking life in the Universe” in best places

Technology: Stepping Stones in the Exploration Strategy

Solar System & Interstellar Access

Remote Robotic Scientific Investigations & Human Precursor Missions

Go anywhere, anytime



Discover Life's limits

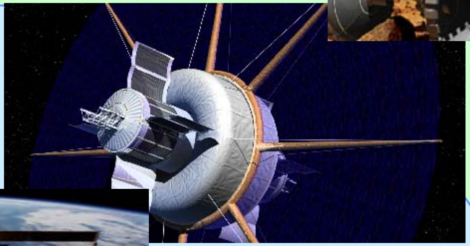
Sustainable Planetary Presence

Sustainable scientific research on extra-terrestrial bodies

Accessible Planetary Surface

Tactical science investigations on extra-terrestrial bodies

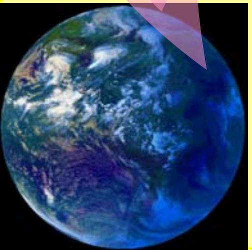
Earth's Neighborhood



Large optical systems in deep space & Lunar science

Earth and LEO

Earth and Space science investigations & Testing of human/robotic systems



- **Science-Driven**
- **Technology Enabled**
- **Stepping Stones**
- **Sequence: Robots, humans, new markets**
- **Leveraging Partnerships**

Technology: Priority Areas for Investment

"Earth Neighborhood" Mission Driven	Accessible Planetary Mission Driven	Sustained Planetary Presence Driven
Solar Power (High Power)	**Regenerative Life Support Systems**	**Advanced Habitation Systems**
Space Assembly, Maintenance & Servicing (Robotic, EVA)	**Surface Science & Mobility**	**Nuclear Power**
Cryogenic Propellant Depots	**Materials and Structures** (Manufacturing Validation)	In Situ Resource Utilization
Biological Risk (Radiation)	Space Medicine and Health Care	In Situ Manufacturing
Aero- Assist/Entry and Landing	Earth-to-Orbit Transportation	Flying Systems
Electric/Electromagnetic Propulsion (High Power)	In-Space Chemical Propulsion	
Adaptation and Countermeasures (Gravity)	Nuclear Propulsion	
Communications and Control		
Human Factors and Habitability		

Current "Top-10"

- √ **Advanced Power (Solar, Nuclear Power)**
- √ **Biological Risk (Radiation)**
- √ **Space Assembly, Maintenance & Servicing (Robotic, EVA)**
- √ **Aero- Braking/Assist/Entry**
- √ **Regenerative Life Support / Habitation Systems**
- √ **Surface Science & Mobility Systems**
- √ **Materials and Structures (Mfg)**
- √ **Cryogenic Propellant Depots**

PLUS…

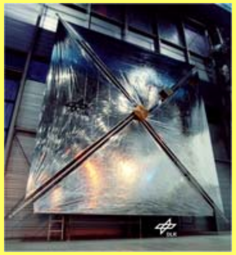
- √ **Systems Studies, Advanced Concepts, etc.**
- √ **Technology Flight Demos**

Technology: Achievements

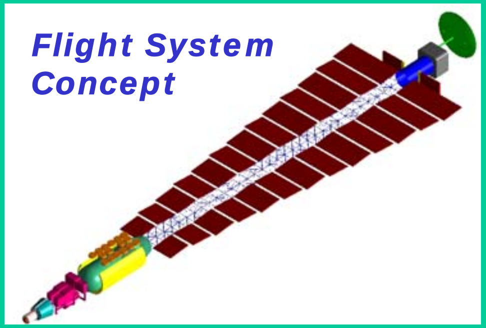
- In-Space Propulsion
  - Aerocapture
  - Solar Sails
  - Solar Electric Propulsion
  - Nuclear Electric Propulsion

Aeroassist

Solar Sails



- Nuclear Systems
  - <u>Energy</u> for science, mobility, playback
  - <u>Time</u> for surface reconnaissance and discovery
  - <u>Accessibility</u> to planets (latitude & terrain)
  - <u>Resiliency</u> and adaptability



Flight System Concept

- Space Radiation Initiative
  - Interaction of radiation with materials and living tissues
  - Critical experiments on ISS, Mars, free flyers
  - Optimized shielding and operations
  - Pharmacological and biological intervention

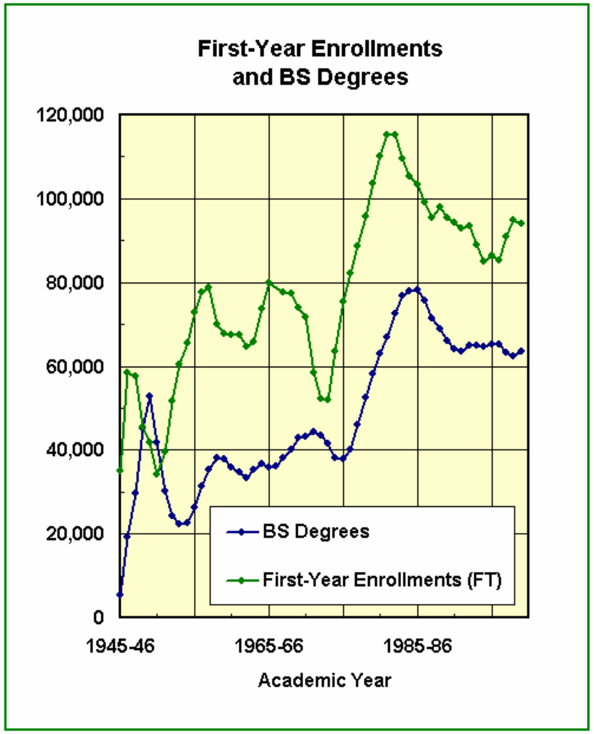
Radiation Absorbing Materials

National Education Challenge

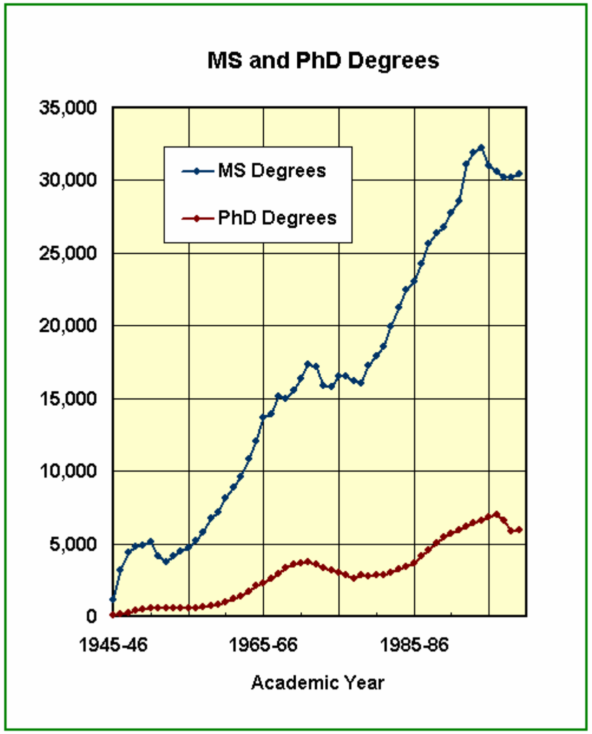
The U.S. Engineering and Physical Sciences *People* "Crises"

•Walker Aerospace Commission Report: 2002
•Rudman Report: 2000
•National Science Foundation "Indicators": 1995-2002
•National Academy of Engineering Reports: on-going
•Space Policy Institute Report on Origins of Scientists and Engineers: 1989

Engineering Degrees 1945-2001



- 33 % Retention Loss between Freshman and Senior years.
- At Same time University enrollment is increasing, engineering enrollment decreasing.
- Minority Enrollment decreased by 9% since 1992
- 2001: 7.4 % of Undergraduate are foreign nationals, but 42.8% of M.S. and 45% of PhDs are FN
- Taiwan: 35% of undergraduates are engineering students
- China: 46% of undergraduates are engineering students
- US demographics show a shrinking pool of possible engineers without the entry of minorities and women



NASA OPPORTUNITY

Catalyst for Excellence K-12

Creating the pipeline for scientists and engineers

- Instructional materials to meet state and local curriculum standards
- Professional development programs for educators
- Educator involvement in research and development
- Inspiration and motivation

The Enablers:

Universities

The ***people*** *part of technology and science*

- Research Support for Engineering /Physical Sciences Departments
- Undergraduate and Graduate Student Support
- Improved support for institutional capabilities
- Developing Engineering Faculty Pipeline

•NASA needs the output of the K-16+ student pipeline to execute the national Space Exploration vision and mission.

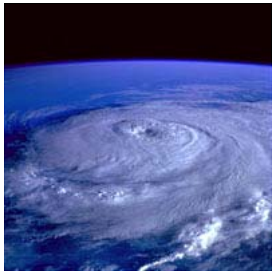
•NASA has in the past, and can in the future, inspire entry into the education pipeline and retain participation in that pipeline for benefit of the entire nation

Best Documented Solution: *Hands On* Experiential Involvement

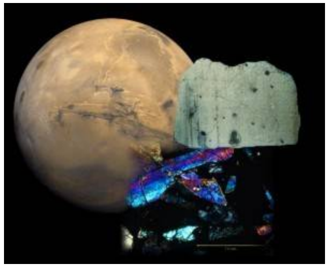
Many NASA Programs have proven successes----but many more opportunities exist

K-12

• EarthKam: Since 1996 Middle School Students throughout the US have taken pictures of the earth via Camera on Space Shuttle and ISS: Started by Dr. Sally Ride and UCSD.



•High School Aerospace Scholars: Pilot Project in Texas funded by Texas Legislature and Hosted by JSC. Over 400 students from throughout the state, representing a large diversity, have designed missions to Mars during a week at JSC while learning science and engineering concepts.



•Sponsorship of FIRST RoboticTeams

•New Concept: schools throughout the US issued Exploration Licenses, e.g. one square mile of Mars—a real place to study and generate excitement with real time Web linkage to rover video.

UNIVERSITIES

•KC-135 Undergraduate Project Teams

•Undergraduate Balloon Teams

•Undergraduate Engineering Design Projects

•HEDS-UP (Human Exploration and Development of Space-University Partners Design Teams)

•Intelligent Synthetic Environments (ISE) Linked Universities

•New Research Initiatives to Engineering, Physics and Chemistry Departments for faculty and graduate students: Competitive NASA Research Announcements (NRA's)

•More Fully Utilize the 52 Space Grant University Consortia, EPSCoR, and the University Space Research Association (USRA)

Advanced Concept Analysis in Support of the Integrated Space Plan

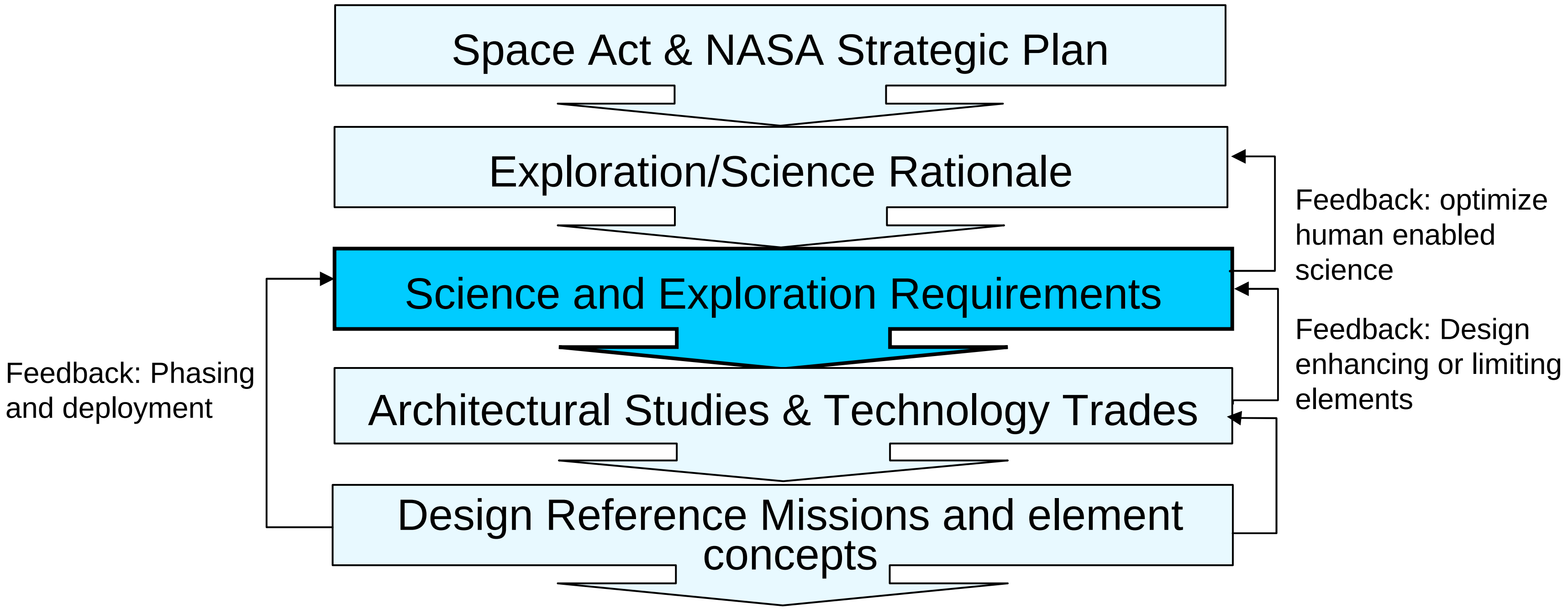
Section 3.0

Requirements

November 2002

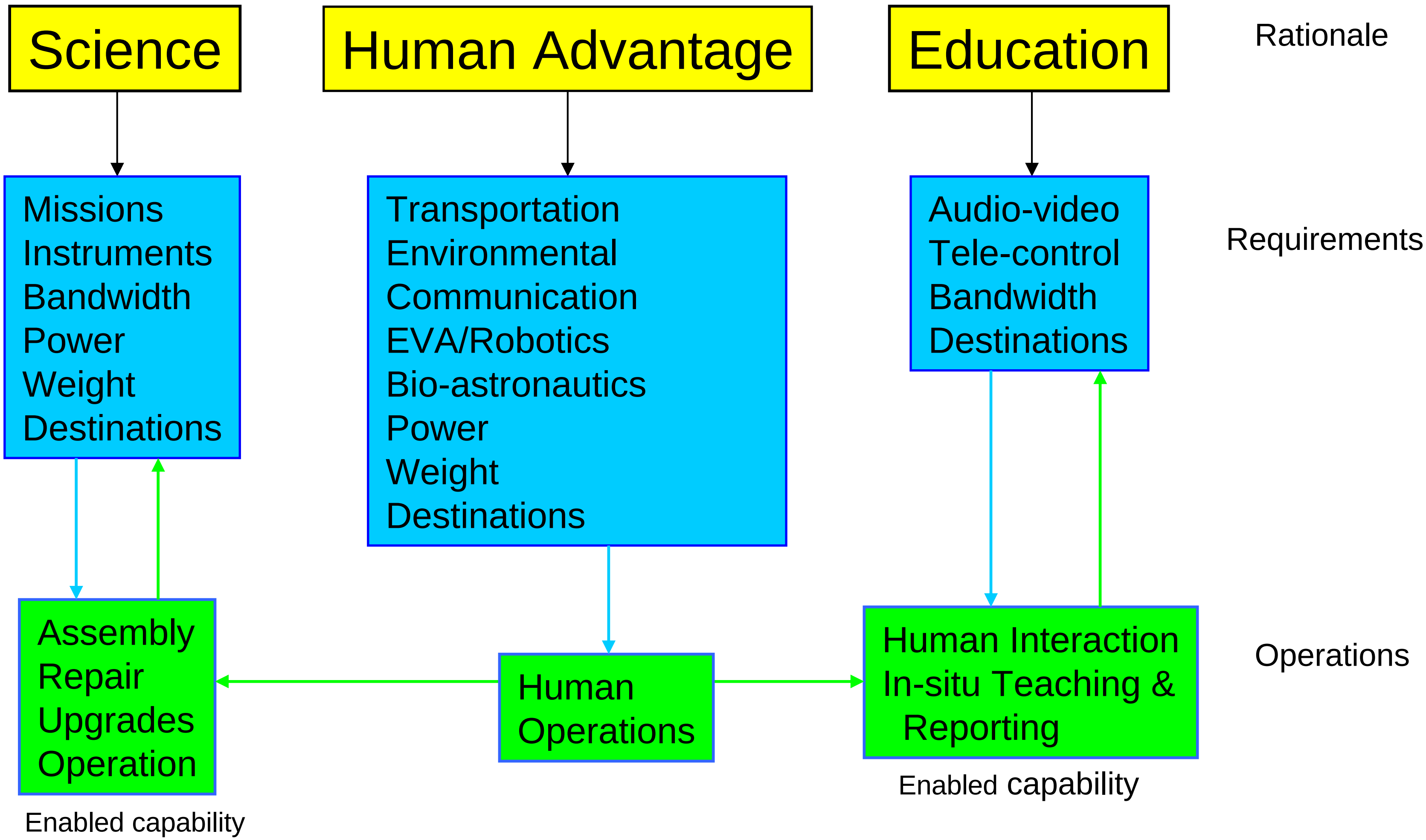
Requirements

Requirements Flow-down from Rationale and Feedback from Design Process

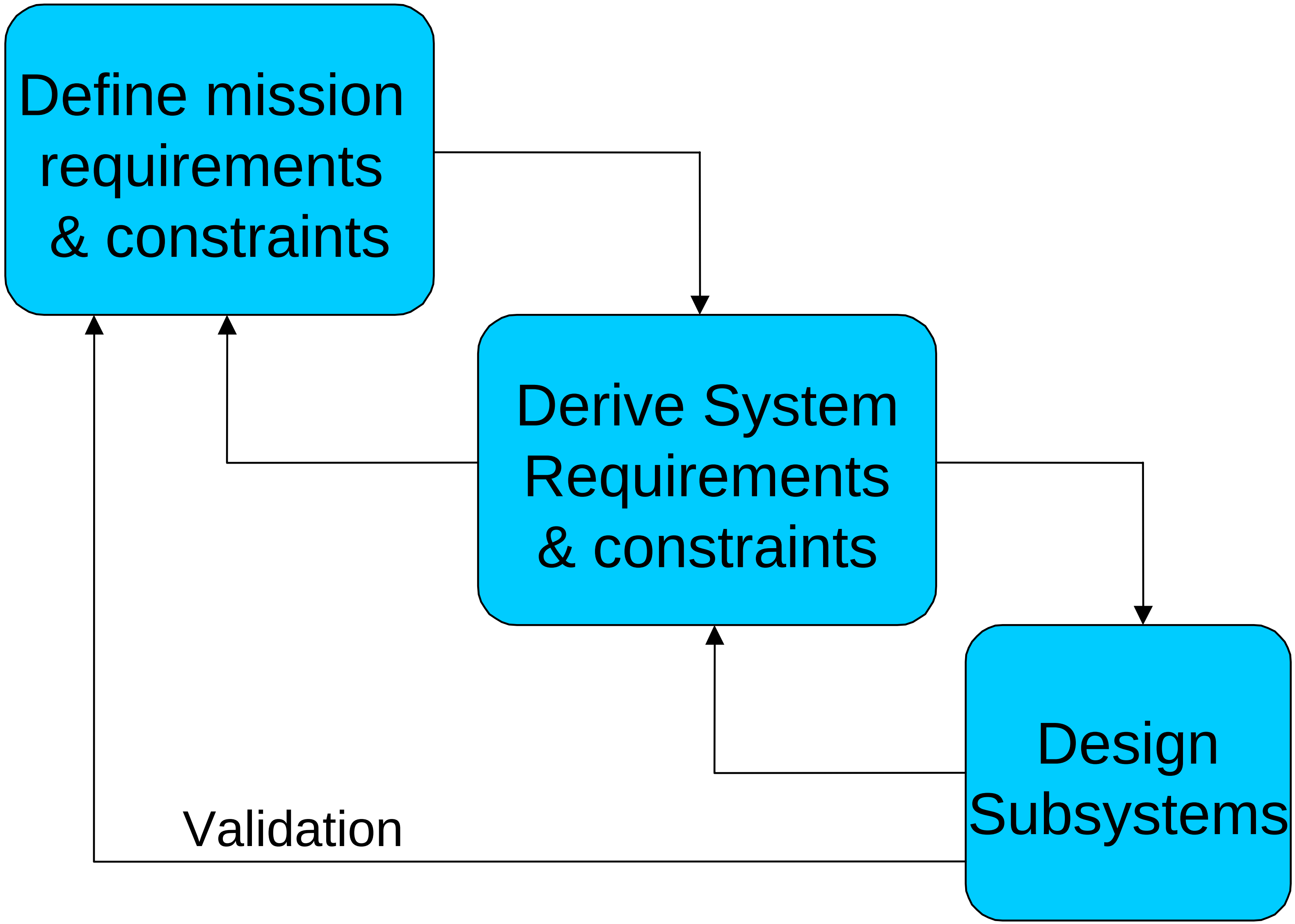


Requirements

Feedback: Optimize Human Enabled Science and Education



Requirement Definition Process



Requirement Definitions

Level	**Description**	**Source**
Level 0	**Space Policy**	**NASA Administrator**
	Example: Humans shall explore space, including the LEO, HEO, Libration points, Moon, Mars and beyond.	
Level 1	**Guiding Principles/Goals**	**Space Architect**
	Example: Spacecraft shall protect the crew from radiation hazards	
	Example: Return vehicle shall safely return the crew to Earth	
Level 2	**Design Requirements**	**Design Team**
	Example: Transfer vehicle shall support 4-6 crew to ISS	
	Example: To support telescope servicing, the vehicle shall support 6 EVAs	

Requirements

Architecture: Level 1

Education: Level 1

Science: Level 1

- An optimal mix of human and robotic elements shall be employed to maximize the mission scientific return and the safety of the astronauts.
- Scientists shall be involved in every stage of exploration planning from conception to execution to ensure that quality science is accomplished.
- Astronauts with a high level of relevant scientific knowledge and experience shall be included in the missions and mission planning.
- Crew training and exploration planning shall be designed to take advantage of the human initiative, flexibility, adaptability, and inductive and deductive reasoning abilities.
- Space science missions shall be located at optimal destination for science return, consistent with taking advantage of the human enabled leverage.

(NRC/CHEX 1993)

Requirements

Science: Level 1

Education: Level 1

Architecture: Level 1

- The Architecture shall support multiple science-driven destinations beyond Low Earth Orbit.
- The Architecture shall employ an evolutionary approach to fulfill scientific objectives.
- The Architecture shall support sustainable human presence beyond Low Earth Orbit.
- The Architecture shall provide for the crew arriving at the destination in optimal physical condition.
- Architecture systems and technologies shall be chosen for strategic, architecture-level goals.
- The Architecture shall employ the ISS as a test bed for human factors, life sciences, and critical technologies research

(JSC/EX)

Requirements

Science: Level 1

Education: Level 1

Architecture: Level 1

- The architecture shall provide the capability to enable crewed support of science payloads located at Lagrange points.
- The architecture shall provide the capability to support L1 science missions and servicing.
- The architecture shall provide the capability to enable crewed science missions to the lunar surface.
- The architecture shall provide global lunar landing capability.
- The architecture shall provide the capability to return the crew from Lunar surface at anytime.

(JSC/EX)

Requirements

Science: Level 1

Education: Level 1

Architecture: Level 1

- The Earth's Neighborhood elements shall support future exploration beyond Earth's Neighborhood..
- The architecture shall comply with NASA "Human Rating Document" (Latest revision)

(JSC/EX)

Requirements

Architecture: Level 1

Science: Level 1

Education: Level 1

To be supplied by Code N

Science Mission Examples

Mission concepts to be supplied or reviewed by NASA HQ

Science Missions: (list in development)

<u>Deep Space L1/L2 and beyond</u>

- •Large Space Telescope
- •Earth Observing Platform
- •Cosmic Background Radiation Polarimeter
- •Near Earth Object-Asteroid Exploration

<u>Lunar</u>

- •Lunar Astrobiology Laboratory
- •Low Frequency Radio Telescope
- •Lunar Planetary-Science Exploration
- •Solar System Volatiles Search
- •South Pole Aikten Basin Exploration

<u>Mars</u>

- •Search for extant or fossil biospheres
- •Search for Martian water

Example Science Missions: Flow-Down of Common Requirements

(subset of NASA Vision and Mission, Fundamental Questions, and Enterprise Strategic Goals and Objectives, for selected example missions)

NASA Vision and Mission:

To improve life here.
To find life beyond.
To understand and protect our home planet.
To explore the universe and search for life.

Fundamental Questions:

How did the universe, galaxies, stars, and planets form and evolve, and what is their destiny?
Does life in any form, however simple or complex, carbon-based or other, exist elsewhere than on Earth?
How can we utilize the latest findings about the Sun, Earth, and other planetary bodies to develop accurate, predictive environmental, weather, climate, natural disaster, and natural resource models to help ensure sustainable development and improve the quality of life on Earth?

Enterprise Strategic Goal: [Space Science]

Chart the evolution of the universe, from origins to destiny, and understand its galaxies, stars, planets, and life.

Theme Objectives: [Enterprise Strategic Objectives (Space Science)]

Understand the structure of the universe, from its earliest beginnings to its ultimate fate.
Explore the ultimate limits of gravity and energy in the universe.
Learn how galaxies, stars, and planets form, interact, and evolve.
Understand the formation and evolution of the solar system and the Earth within it.
Probe the evolution of life on Earth, and determine if life exists elsewhere in the solar system.
Understand our changing Sun and its effects throughout the solar system.

Large Far Infrared Space Telescope – Concept A

Large Far Infrared Space Telescope – Concept B

Cosmic Microwave Back-ground (CMB) Polarimeter

Near-Earth Object (NEO) Sample Return

Humans to Asteroids: Field Exploration Beyond LEO

Lunar South Pole-Aitken Basin Sample Return

Mars Precursor Lander

Mars Sample Return

Earth Science Missions

⋮

Example Space Science Mission: Large Far Infrared Space Telescope – Concept A

NASA Vision and Mission:
To explore the universe and search for life.

Fundamental Question:
How did the universe, galaxies, stars, and planets form and evolve, and what is their destiny?

Enterprise Strategic Goal (Space Science):
Chart the evolution of the universe, from origins to destiny, and understand its galaxies, stars, planets, and life.

Theme Objectives: [Enterprise Strategic Objectives (Space Science)]
Understand the structure of the universe, from its earliest beginnings to its ultimate fate.
Explore the ultimate limits of gravity and energy in the universe.
Learn how galaxies, stars, and planets form, interact, and evolve.

Mission Objective:
Study interstellar gas and dust over a wide redshift range.

- What lies at the cores of star- and planet-forming regions?
- What properties do Kuiper Belt objects have?
- What is the principal power source for IR-bright galaxies?

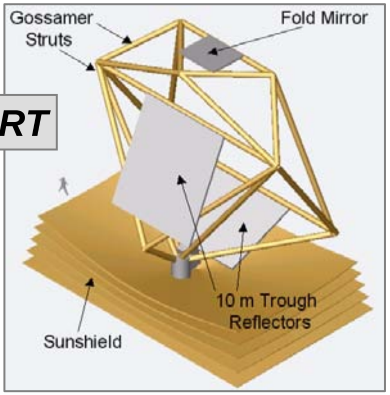
Mission Implementation:
Assemble a 10 m telescope at Lunar L1, and operate it at Sun-Earth L2.

Mission-Derived Architecture Requirements:

- High spatial and spectral resolution imaging in the 40-500 μm range.
- Membrane reflectors, actively cooled detectors, V-groove sunshade.
- EVAs over ~weeks to assemble and deploy truss at Earth-Moon L1.
- Infrastructure: crew transfer vehicles, robotic aids, EVA technology.

Rationale: FAIR-DART science objectives can be achieved only by a large-aperture, far-infrared and sub-millimeter, post-James Webb Space Telescope. Due to the size of the large reflectors, it would be impractical to launch it fully assembled.

FAIR-DART



FAIR = Filled Aperture InfraRed Telescope
DART = Dual Anamorphic Reflecting Telescope

Example Space Science Mission: Large Far Infrared Space Telescope – Concept B

NASA Vision and Mission:
To explore the universe and search for life.

Fundamental Question:
How did the universe, galaxies, stars, and planets form and evolve, and what is their destiny?

Enterprise Strategic Goal (Space Science):
Chart the evolution of the universe, from origins to destiny, and understand its galaxies, stars, planets, and life.

Theme Objectives: [Enterprise Strategic Objectives (Space Science)]
Understand the structure of the universe, from its earliest beginnings to its ultimate fate.
Explore the ultimate limits of gravity and energy in the universe.
Learn how galaxies, stars, and planets form, interact, and evolve.

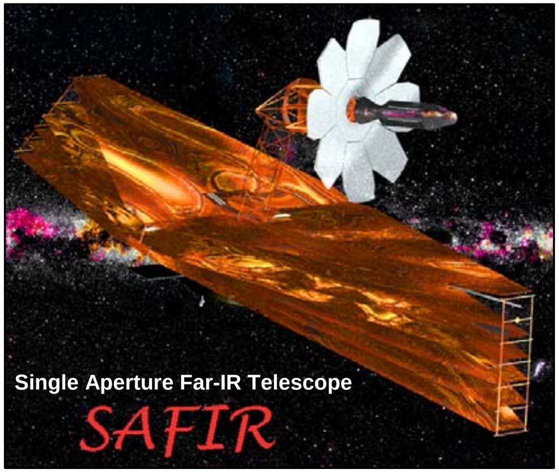
Mission Objective:
Take the next step to explore the far IR part of the sky.

- What is the history of star formation and element production?
- What prebiotic material is in the planet-forming environment?
- How do black holes and their host galaxies interact?

Mission Implementation:
Deploy an 8-10 m, cooled, far IR telescope at Sun-Earth L2.

Mission-Derived Architecture Requirements:
- Filled 8-10 m aperture, Sun-Earth L2, 0.1 K heterodyne detectors.
- Passive cooling to 4 K with V-groove radiators. Alternate concepts: membrane reflectors (FAIR-DART), and multiple fixed baselines.

Rationale: Dust efficiently reprocesses radiation into the IR and submillimeter parts of the spectrum. The young distant universe is redshifted there from the visible and near IR. Large prebiotic molecules have strong, unique spectral features in this spectral region. Half the luminosity in the universe is observed to be in the far IR.



Example Space Science Mission:
Cosmic Microwave Background (CMB) Polarimeter

NASA Vision and Mission:
To explore the universe and search for life.

Fundamental Question:
How did the universe, galaxies, stars, and planets form and evolve, and what is their destiny?

Enterprise Strategic Goal (Space Science):
Chart the evolution of the universe, from origins to destiny, and understand its galaxies, stars, planets, and life.

Theme Objectives: [Enterprise Strategic Objectives (Space Science)]
Understand the structure of the universe, from its earliest beginnings to its ultimate fate.
Explore the ultimate limits of gravity and energy in the universe.
Learn how galaxies, stars, and planets form, interact, and evolve.

Mission Objective:
Reveal the large-scale structure of the universe.

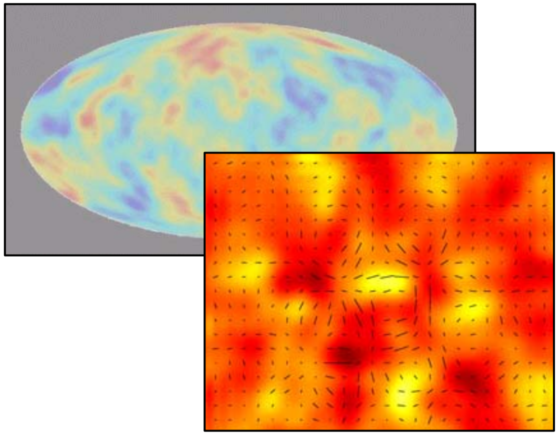
- What do CMB polarization measurements reveal about the Big Bang, and about the physics of processes that occurred in the early universe at energies far above those accessible to Earth-bound accelerators?
- Is the current paradigm of inflationary cosmology correct?

Mission Implementation:
Deploy an ~6 m cooled long-wavelength telescope at Sun-Earth L2.

Mission-Derived Architecture Requirements:

- CMB polarization signals are about 10 times smaller than temperature anisotropy signals. To observe the entire sky at the same rate as current experiments would take 500,000 years.

Rationale: Minute fluctuations in the CMB are the seeds of all the structure we see today. Detailed CMB observations are fundamentally important to both astronomy and physics. MAP and Planck measure CMB temperature anisotropy.



Example Space Science Mission: Near-Earth Object (NEO) Sample Return

NASA Vision and Mission:
To understand and protect our home planet. To explore the universe and search for life.

Fundamental Questions:
How did the universe, galaxies, stars, and planets form and evolve, and what is their destiny?
How can we utilize the latest findings about the Sun, Earth, and other planetary bodies to develop accurate, predictive environmental, weather, climate, natural disaster, and natural resource models to help ensure sustainable development and improve the quality of life on Earth?

Enterprise Strategic Goal (Space Science): [Mission also flows from HEDS strategic goals / objectives]
Chart the evolution of the universe, from origins to destiny, and understand its galaxies, stars, planets, and life.

Theme Objective: [Enterprise Strategic Objective (Space Science)]
Understand the formation and evolution of the solar system and the Earth within it.

Mission Objective:
Understand our origins and ensure our future.

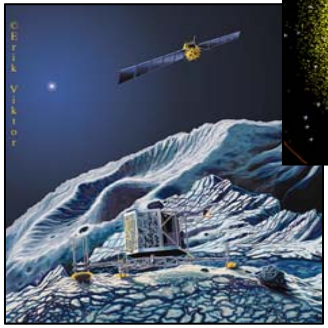
- To what extent did NEOs deliver carbon-based molecules and water?
- What is the composition and structure of solar system building blocks?
- How will we deal with a class of objects that threatens civilization?

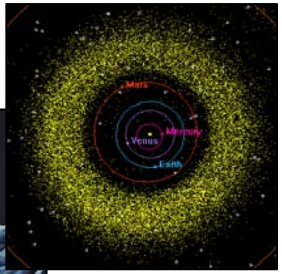
Mission Implementation:
Intensively study a NEO from orbit and in situ, and return samples.

Mission-Derived Architecture Requirements:

- Study structure: imaging, radar, spectroscopy, gravity, seismology.
- Investigate anchoring methods: thrusters, solar sails, mass drivers.
- Precisely track the NEO with transponders, make fuel out of ice.

Rationale: Before technologies are developed to deflect NEOs, we need to understand them better. NEOs contain mineral, water, and fuel resources. NEOs are logical stepping stones to human Mars missions: Practice exploration techniques.





Example Space Science Mission:
Humans to Asteroids: Field Exploration Beyond LEO

NASA Vision and Mission:
To understand and protect our home planet. To explore the universe and search for life.

Fundamental Questions:
How did the universe, galaxies, stars, and planets form and evolve, and what is their destiny?
How can we utilize the latest findings about the Sun, Earth, and other planetary bodies to develop accurate, predictive environmental, weather, climate, natural disaster, and natural resource models to help ensure sustainable development and improve the quality of life on Earth?

Enterprise Strategic Goal (Space Science): [Mission also flows from HEDS strategic goals and objectives]
Chart the evolution of the universe, from origins to destiny, and understand its galaxies, stars, planets, and life.

Theme Objective: [Enterprise Strategic Objective (Space Science)]
Understand the formation and evolution of the solar system and the Earth within it.

Mission Objective:
Lead the way for human exploration beyond LEO.

- What will NEOs reveal about the early solar system?
- How will NEOs help reduce the cost of future space exploration?
- What will we learn to help guard against the Earth impact threat?

Mission Implementation:
Send humans to NEOs (Near-Earth Objects), explore, return samples.

Mission-Derived Architecture Requirements:
- Milli-g fieldwork, surface EVAs, anchoring systems, dust challenge.
- Expand existing NEO search programs and precursor missions.
- Research on space hazards, NEO resources, propulsion technology.

Rationale: NEOs are easy to access, offer a rich store of knowledge about the early solar system, and have resources to reduce the cost of future exploration. NEO missions are a practical hedge against an impact threat, and serve as steps toward Mars.

Example Space Science Mission: Lunar Astrobiology Laboratory

NASA Vision and Mission:
To find life beyond. To explore the universe and search for life.

Fundamental Question:
Does life in any form, however simple or complex, carbon-based or other, exist elsewhere than on Earth?

Enterprise Strategic Goal (Space Science):
Chart the evolution of the universe, from origins to destiny, and understand its galaxies, stars, planets, and life.

Theme Objective: [Enterprise Strategic Objective (Space Science)]
Probe the evolution of life on Earth, and determine if life exists elsewhere in the solar system.

Mission Objective:
Characterize an abiological environment.

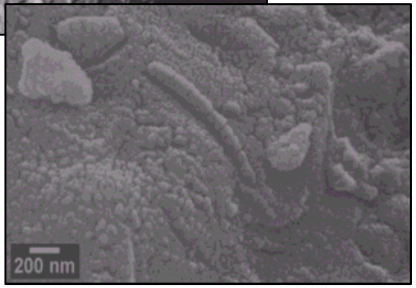
- How do we interpret samples from life detection missions to destinations such as Mars if our instruments have never been tested on pristine materials?

Mission Implementation:
Establish a lunar astrobiology research station.

Mission-Derived Architecture Requirements:

- Short-range remote sensing: reflectance spectroscopy, fluorescence imaging/spectroscopy, gas chromatography/electronic nose.
- Contact instruments: Raman/IR spectroscopy, LIBS (laser induced breakdown spectroscopy), micro-CT (computed tomography).
- Analytical instruments: mass spectrometers, wet chemical probes.

Rationale: The Moon is an ideal negative control for in situ life detection, and is also an excellent environment for curating samples from Mars and elsewhere. Studying water ice will enhance the contrast of potential biosignatures against an abiological background, due to the chemical simplicity of ice compared to lithologic sediment.



Example Space Science Mission:
Lunar Low Frequency Radio Telescope

NASA Vision and Mission:
To improve life here. To understand and protect our home planet. To explore the universe and search for life.

Fundamental Questions:
How did the universe, galaxies, stars, and planets form and evolve, and what is their destiny?
How can we utilize the latest findings about the Sun, Earth, and other planetary bodies to develop accurate, predictive environmental, weather, climate, natural disaster, and natural resource models to help ensure sustainable development and improve the quality of life on Earth?

Enterprise Strategic Goal (Space Science):
Chart the evolution of the universe, from origins to destiny, and understand its galaxies, stars, planets, and life.

Theme Objectives: [Enterprise Strategic Objectives (Space Science)]
Understand the structure of the universe, from its earliest beginnings to its ultimate fate.
Understand the formation and evolution of the solar system and the Earth within it.
Understand our changing Sun and its effects throughout the solar system.

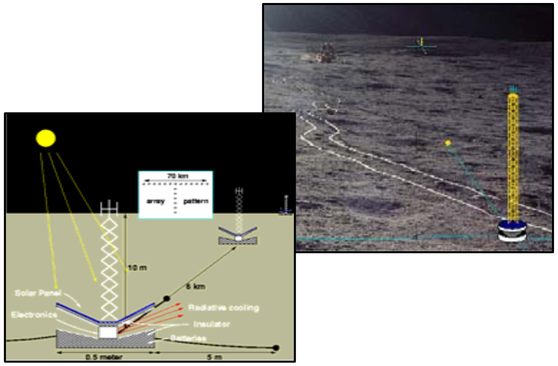
Mission Objective:
Open a new electromagnetic window on the universe.

- What radio emitters await discovery (e.g., extrasolar planets)?
- How can we complement current magnetospheric imagers?
- How do we predict space weather, enhancing astronaut safety?

Mission Implementation:
Deploy a low frequency radio telescope array on the lunar surface.

Mission-Derived Architecture Requirements:
- 19 easily deployed 20-kg stations, 6 km spacing, 150 kHz - 3 MHz.
- Incremental deployment, part of a larger program.

Rationale: Observe galaxies, stars, pulsars, interstellar medium, and magnetospheric radio (300-700 kHz) emissions. Resolve density profiles of coronal mass ejections.



Example Space Science Mission:
Lunar South Pole-Aitken Basin Sample Return

NASA Vision and Mission:
To understand and protect our home planet. To explore the universe and search for life.

Fundamental Question:
How did the universe, galaxies, stars, and planets form and evolve, and what is their destiny?

Enterprise Strategic Goal (Space Science):
Chart the evolution of the universe, from origins to destiny, and understand its galaxies, stars, planets, and life.

Theme Objective: [Enterprise Strategic Objective (Space Science)]
Understand the formation and evolution of the solar system and the Earth within it.

Mission Objective:
Address the first billion years of solar system history.

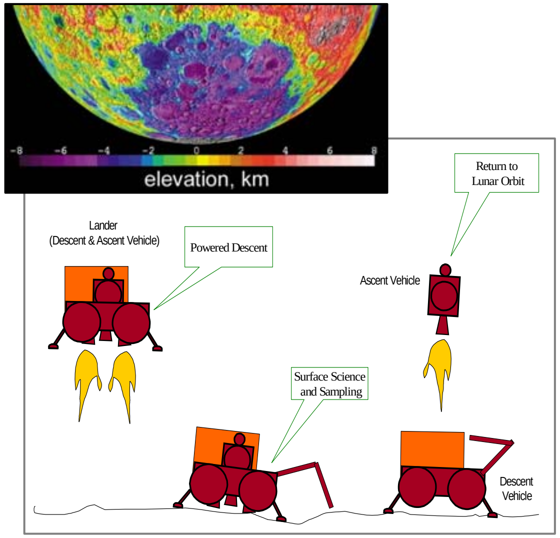
- What processes marked the initial stages of planet formation?
- How did the impactor flux decay in the solar system's youth?
- How did this influence the emergence of life (on Earth, Mars)?

Mission Implementation:
Return samples from one of the solar system's deepest basins.

Mission-Derived Architecture Requirements:

- Put a spacecraft in an area exposing lower crust and mantle rocks.
- Sample the surface rocks, and return them to Earth for analysis.
- Sieve to obtain rocks < 1 cm in size, enhancing sample diversity.

Rationale: The South Pole-Aitken Basin is the oldest and largest well-preserved basin on the Moon, and represents a key event during early heavy bombardment of the inner solar system. It exposes lower crust and possibly some upper mantle. A sample return mission will constrain the nature of the Moon's crust and mantle, and the early impact history of the inner solar system, and will develop sample acquisition, handling, and return technologies applicable to Mars and other destinations.



Example HEDS Mission in Support of Space Science: Mars Precursor Lander

NASA Vision and Mission: [Mission flows from HEDS as well as Space Science strategic goals and objectives]
To extend life to there. To explore the universe and search for life.

Fundamental Question:
What is the fundamental role of gravity and cosmic radiation in vital biological, physical, and chemical systems in space, on other planetary bodies, and on Earth, and how do we apply this fundamental knowledge to foster a permanent human presence in space and to improve life on Earth?

Enterprise Strategic Goal (Space Science):
Use robotic science missions as forerunners to human exploration beyond Low-Earth Orbit..

Theme Objective: [Enterprise Strategic Objective (Space Science)]
Investigate the composition, evolution, and resources of Mars, the Moon, and small bodies..

Mission Objective:
Pave the way for safe future human Mars exploration.

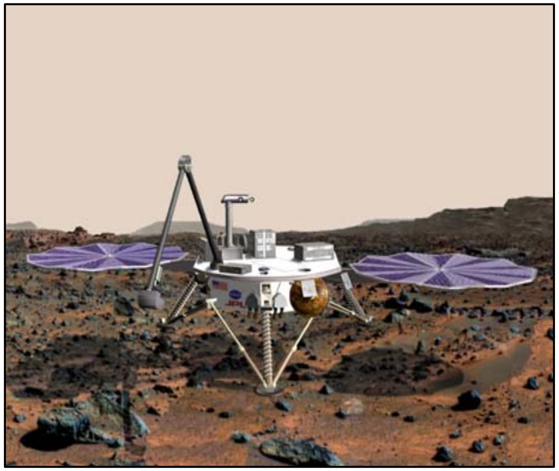
- What data sets will reduce the risks to future human explorers?
- What technologies need to be demonstrated before being used for human missions?

Mission Implementation:
Collect Mars environmental data, and demonstrate key technologies.

Mission-Derived Architecture Requirements:

- Manifest instruments on Mars robotic missions.
- Utilize and test future human technologies on Mars robotic missions.
- Use a dedicated landed mission if the baseline Mars robotic program missions are oversubscribed, lack capability, or will not generate results by needed dates.

Rationale: The existing Mars robotic program should be augmented whenever possible to acquire data sets and demonstrate future human mission technologies. If that is not feasible, a dedicated human precursor lander can carry all instruments and technology demonstration payloads.



Example Space Science Mission: Mars Sample Return

NASA Vision and Mission:
To find life beyond. To explore the universe and search for life.

Fundamental Question:
Does life in any form, however simple or complex, carbon-based or other, exist elsewhere than on Earth?

Enterprise Strategic Goal (Space Science):
Chart the evolution of the universe, from origins to destiny, and understand its galaxies, stars, planets, and life.

Theme Objective: [Enterprise Strategic Objective (Space Science)]
Probe the evolution of life on Earth, and determine if life exists elsewhere in the solar system.

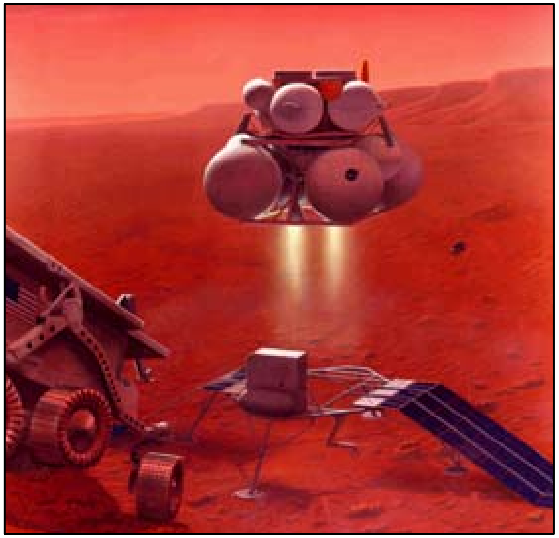
Mission Objective:
Determine whether Mars harbors fossil or extant life.

- Does Mars harbor extant or extinct life?
- How has the climate of Mars changed over time?
- What are the geological processes that have shaped the planet?

Mission Implementation:
Return samples from a well-characterized site, ideally near liquid water.

Mission-Derived Architecture Requirements:
- Return Martian soil, rock and atmospheric samples from a pre-selected landing site
- Protect the samples from forward contamination from Earth
- Protect the Earth from backward contamination from Mars

Rationale: The first returned samples from Mars will greatly increase our knowledge of Martian history, climate, geological processes, and astrobiology. The acquisition of rocks, in addition to soil and atmosphere samples, is considered scientifically essential. Planetary protection, both forward and backward, is critical for purity of the samples and protection of the Earth.



Example Space Science Mission: Template

NASA Vision and Mission:

Fundamental Question:

Enterprise Strategic Goal (Space Science):

Theme Objective: [Enterprise Strategic Objective]

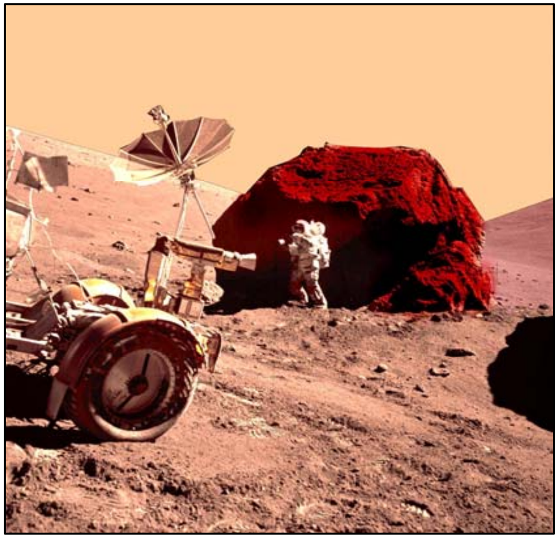
Mission Objective:

Mission Implementation:

Mission-Derived Architecture Requirements:

Rationale:

Reference:



Requirements Development/Capture

- NASA HQ Codes and NASA Stakeholders shall provide high level (Level 0 and Level 1) requirements
- NASA HQ Codes shall provide science mission examples/prototypes to drive Level 2 and higher architecture requirements
- Requirements will be collected and captured in a database referencing origin, heritage, and rationale
- Standard Form shall be provided to facilitate entry of requirements

Advanced Concept Analysis in Support of the Integrated Space Plan

Section 4.1

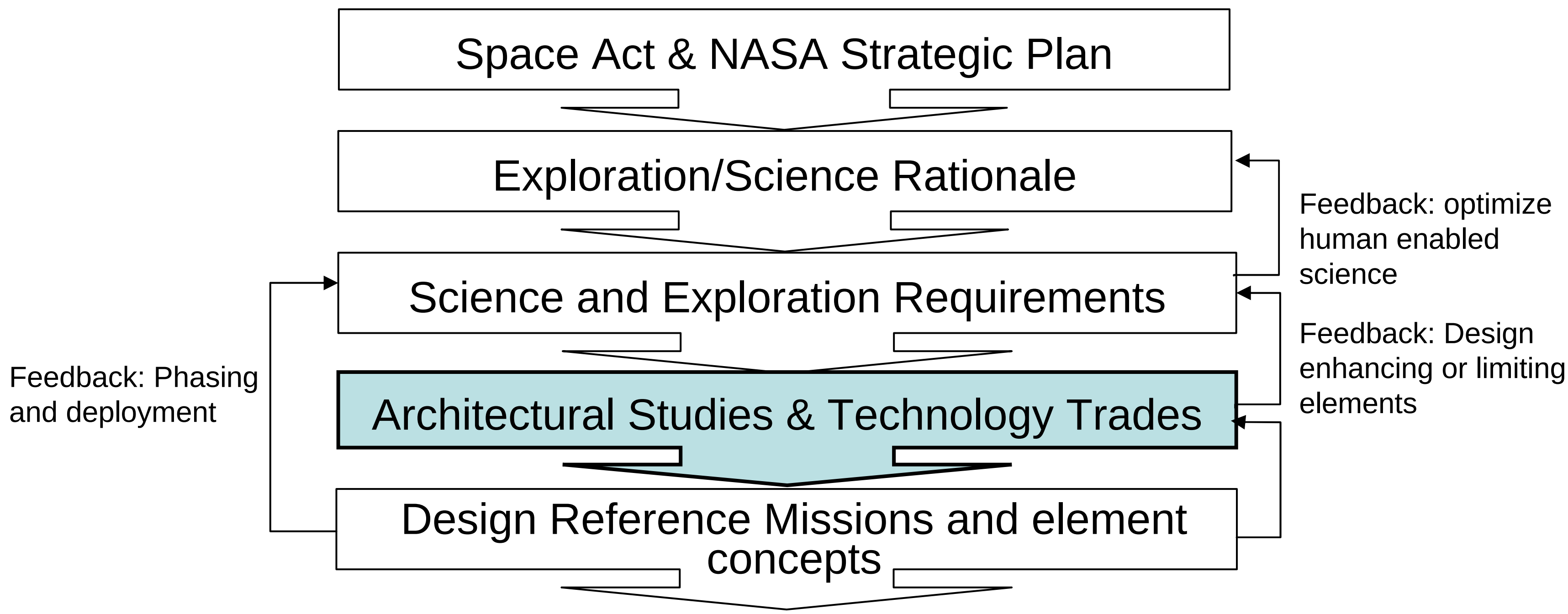
Exploration Architecture Analysis
Introduction

November 2002

Outline

- **Introduction & Architecture Considerations**
  - Trade Space & Decision Tree
- **Earth's Neighborhood**
  - Requirements
  - Mission Modes
    - Mission Staging Points
    - Earth Entry Descent & Landing Mode
    - Utility of ISS
  - General Architecture Concept
  - Architecture Analysis
    - Architectures A & B
    - Element Design
- **Mars**
- **Summary & Conclusions to Date**

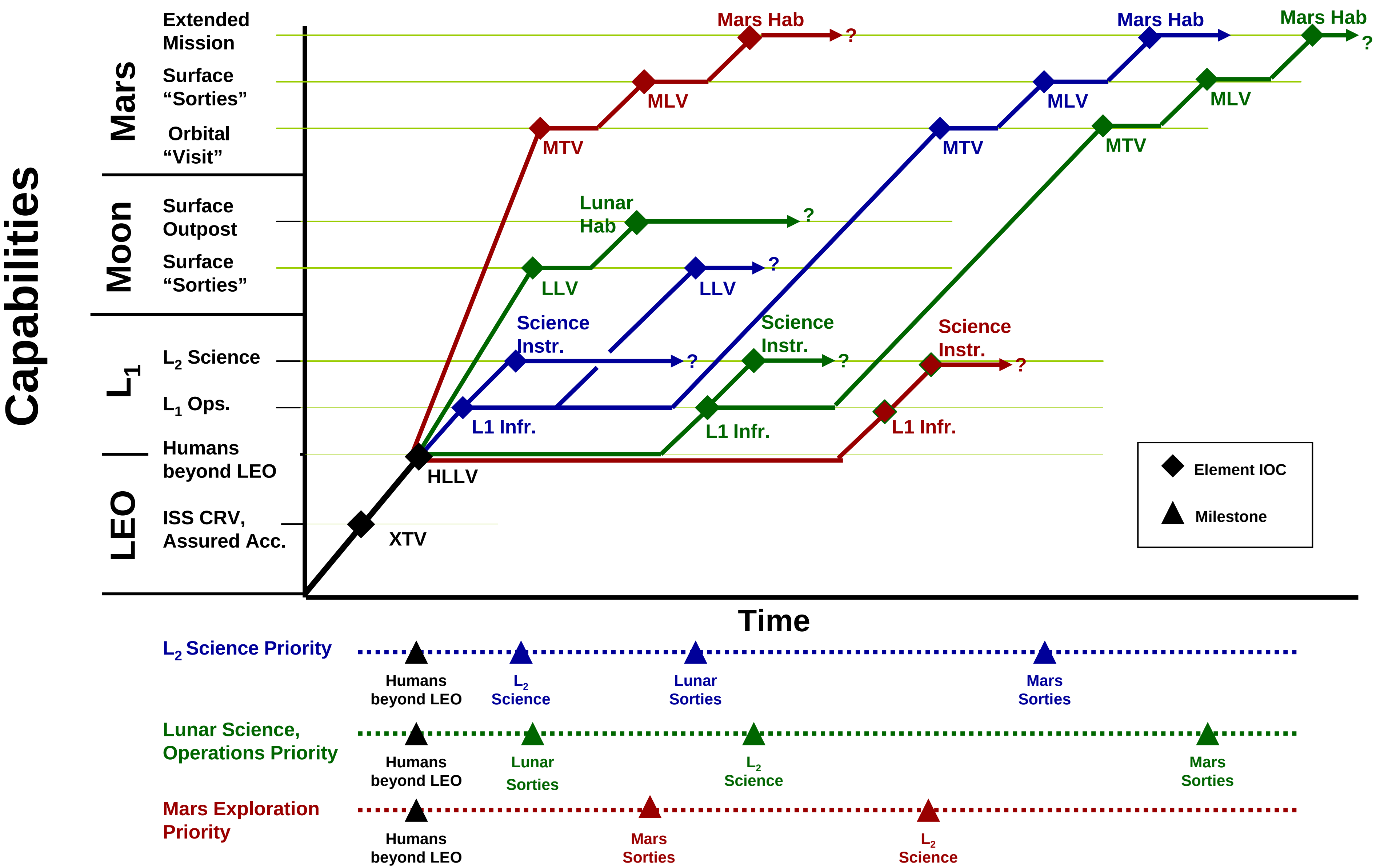
Requirements Flow-down from Rationale and Feedback from Design Process



Architecture Trade Space

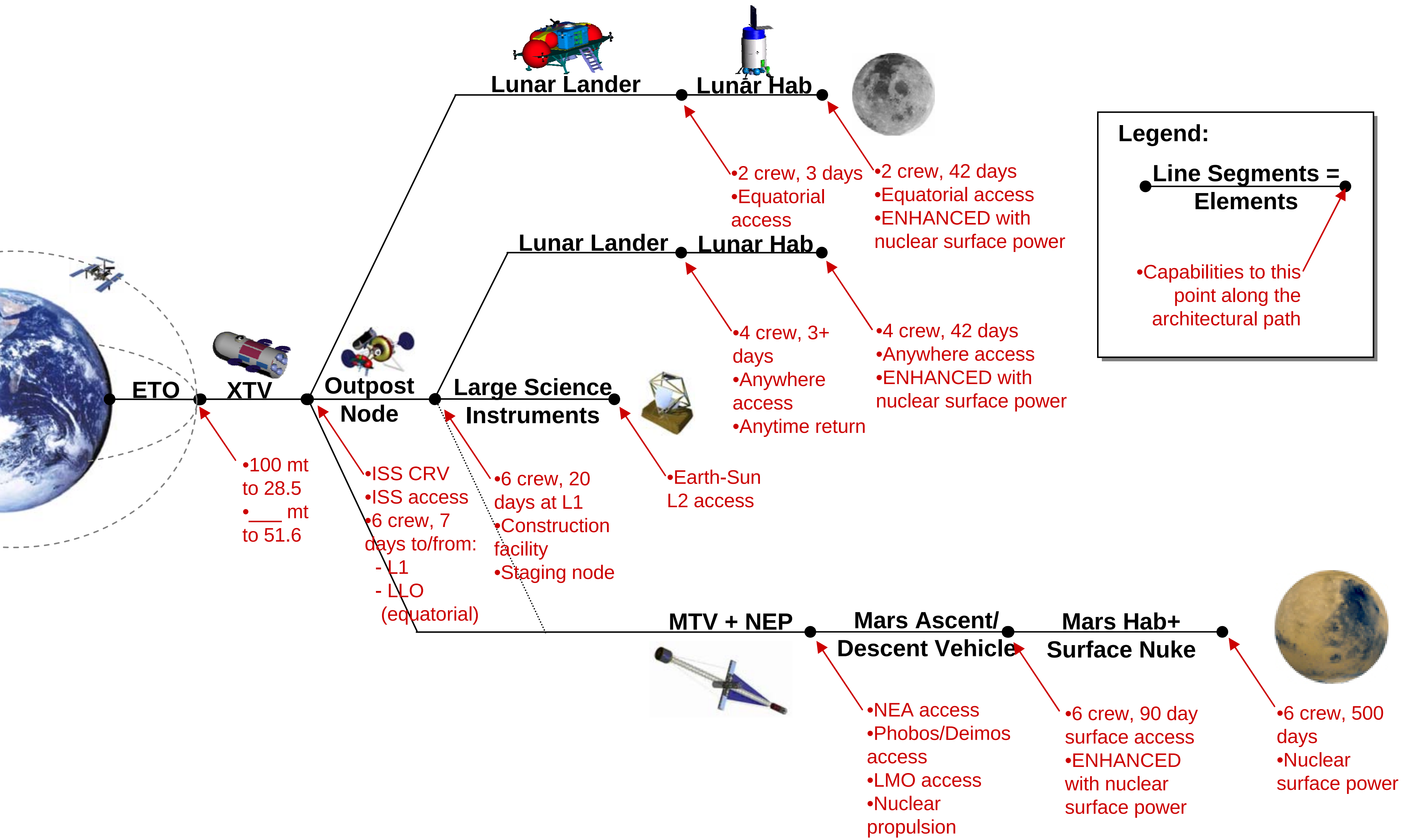
- **Many possible program strategies (see next chart)**
- **Strategy chosen will depend upon:**
  - Resulting funding profile
  - Relative priorities
  - Desired level of capabilities
- **Not all decisions must be made at outset**
  - XTV, HLLV appear to be constants required for any desired beyond-LEO capabilities

Examples of Possible Architecture Pathways

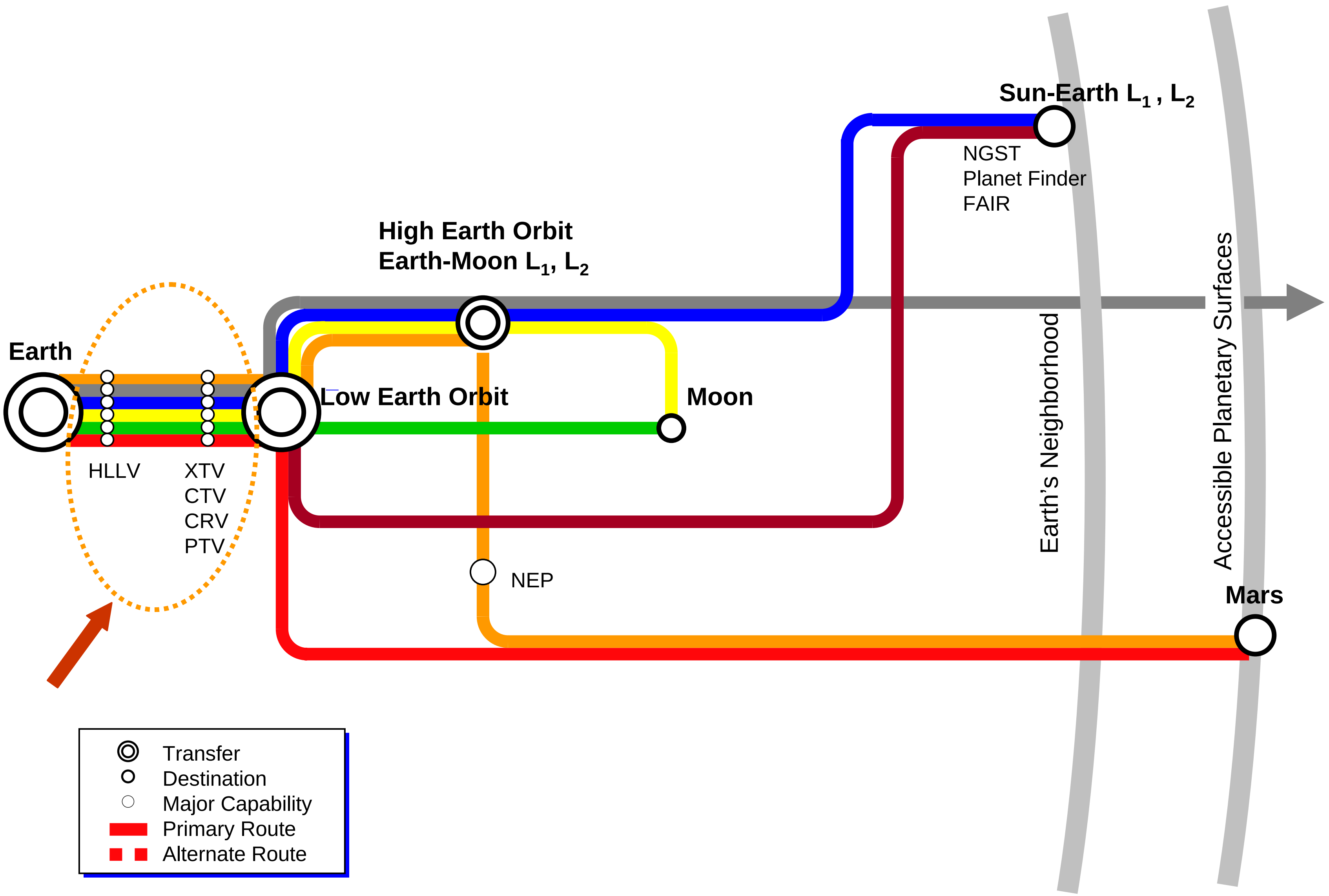


Architecture Decision Tree

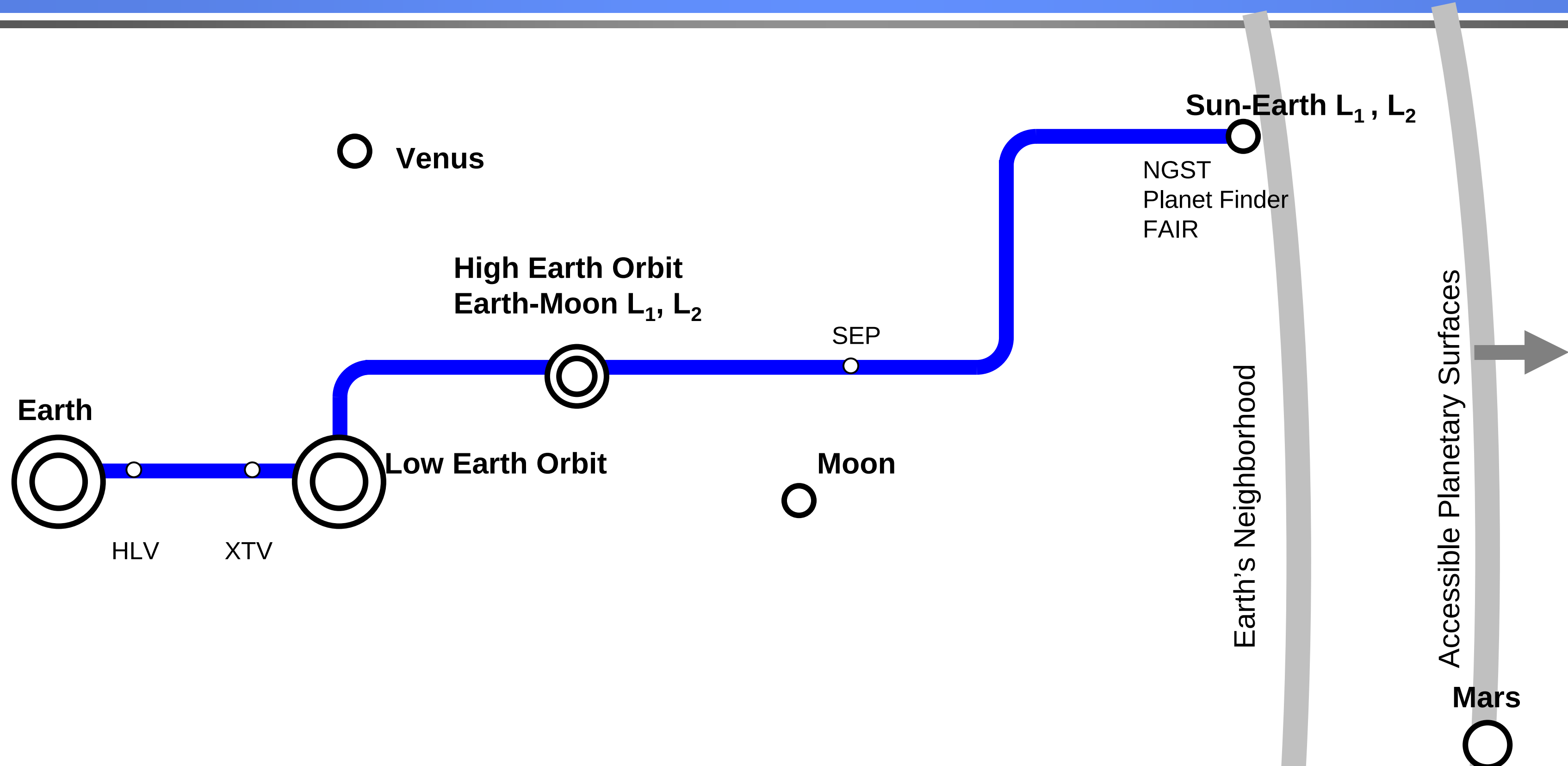
(Exploration Capability Growth by “Stepping Stones”)



Exploration Route Map



Exploration Route Map

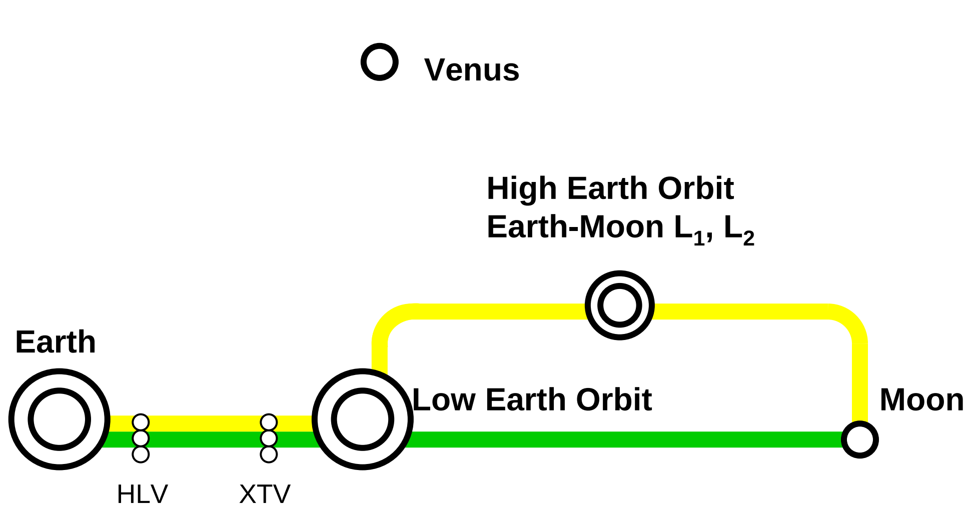


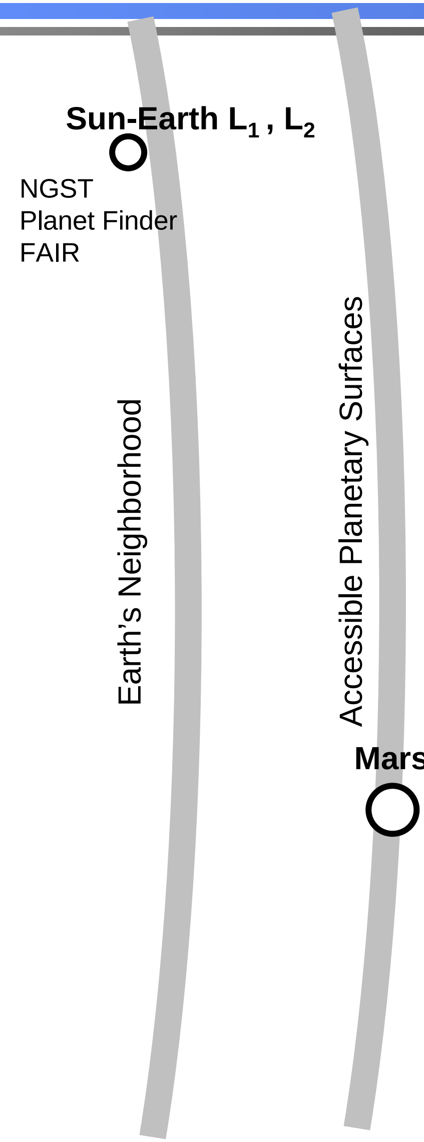
Routes that Support Large Telescope Requirements

Direct Requirements (Customer Needs)
•Deliver and Support Large Telescopes operating at Sun-Earth L_2

Derived Requirements (ways to do it)
•Complete assembly/perform maintenance at Low Earth Orbit, Earth-Moon L_1, L_2, or High Earth Orbit
•For Telescope construction: 6-8 2-person EVA sorties
•For Telescope maintenance: 4-6 2-person EVA sorties
•Support for telescope systems and structure
•Robotic/EVA support for construction, servicing, inspection

Exploration Route Map



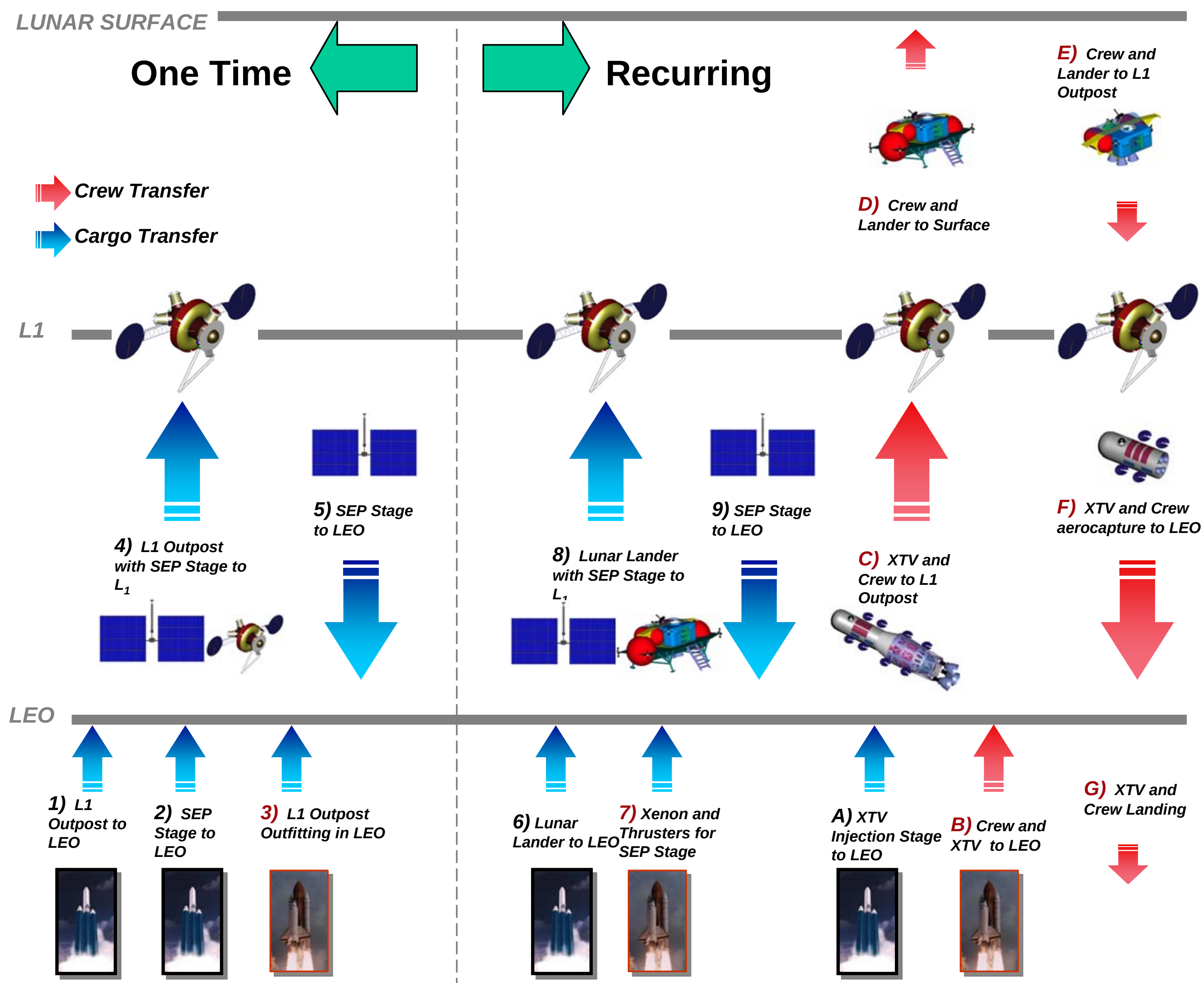


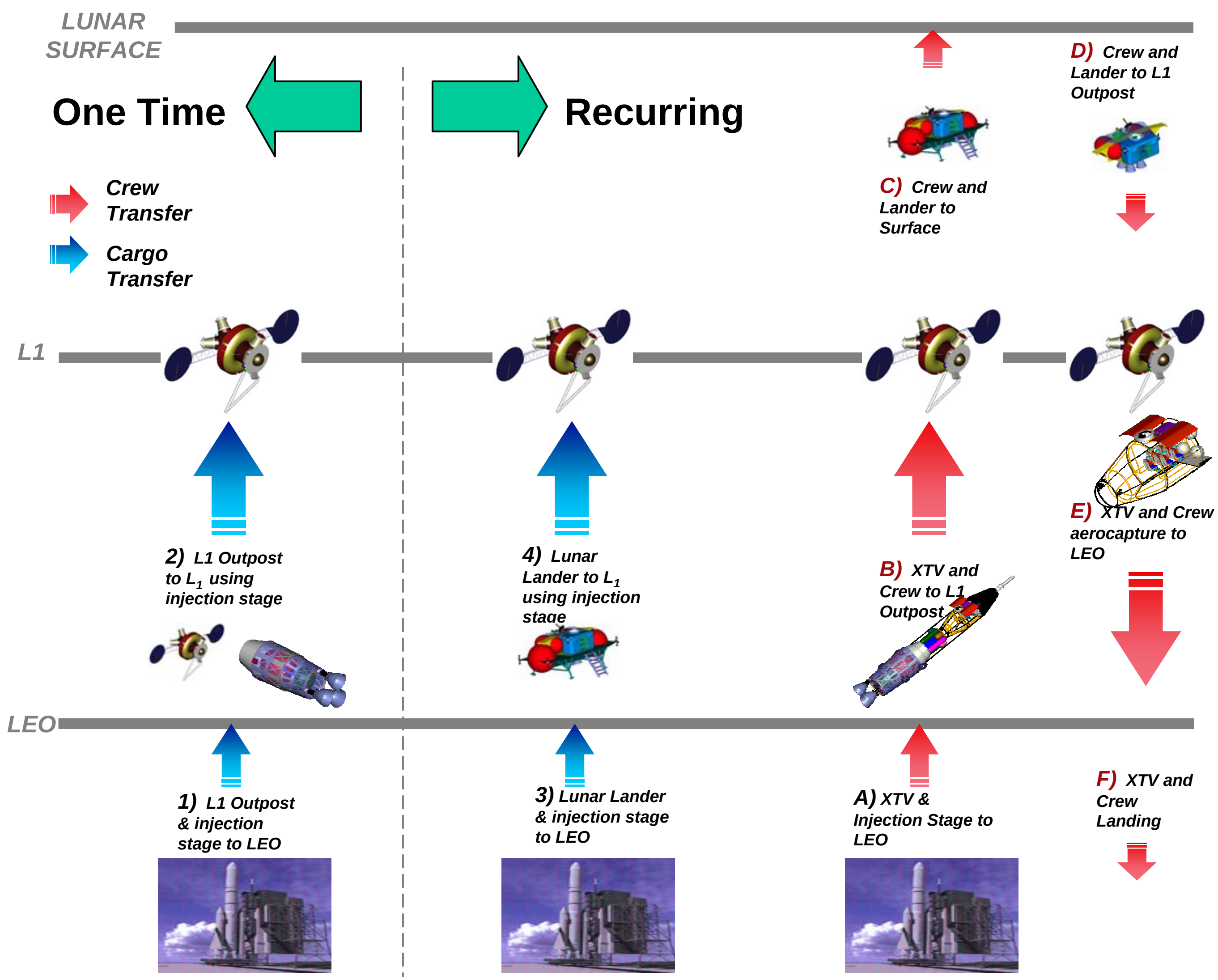
Routes that Support Lunar Exploration

Direct Requirements (Customer Needs)
•Transport crew in excellent condition with scientific equipment to the surface of the Moon
•Return the crew and scientific samples to Earth
•Sufficiently support the crew on the surface of the Moon to conduct scientific experiments
•Enable continued human research on the Lunar surface

Derived Requirements (ways to do it)
4 crewmembers to Lunar surface and return
Nuclear Surface power to support life support, vehicle needs, science sorties
Surface mobility to meet scientific requirements
Shelter (radiation, etc.), Crew health (G in route, exercise, medical, ,etc.)

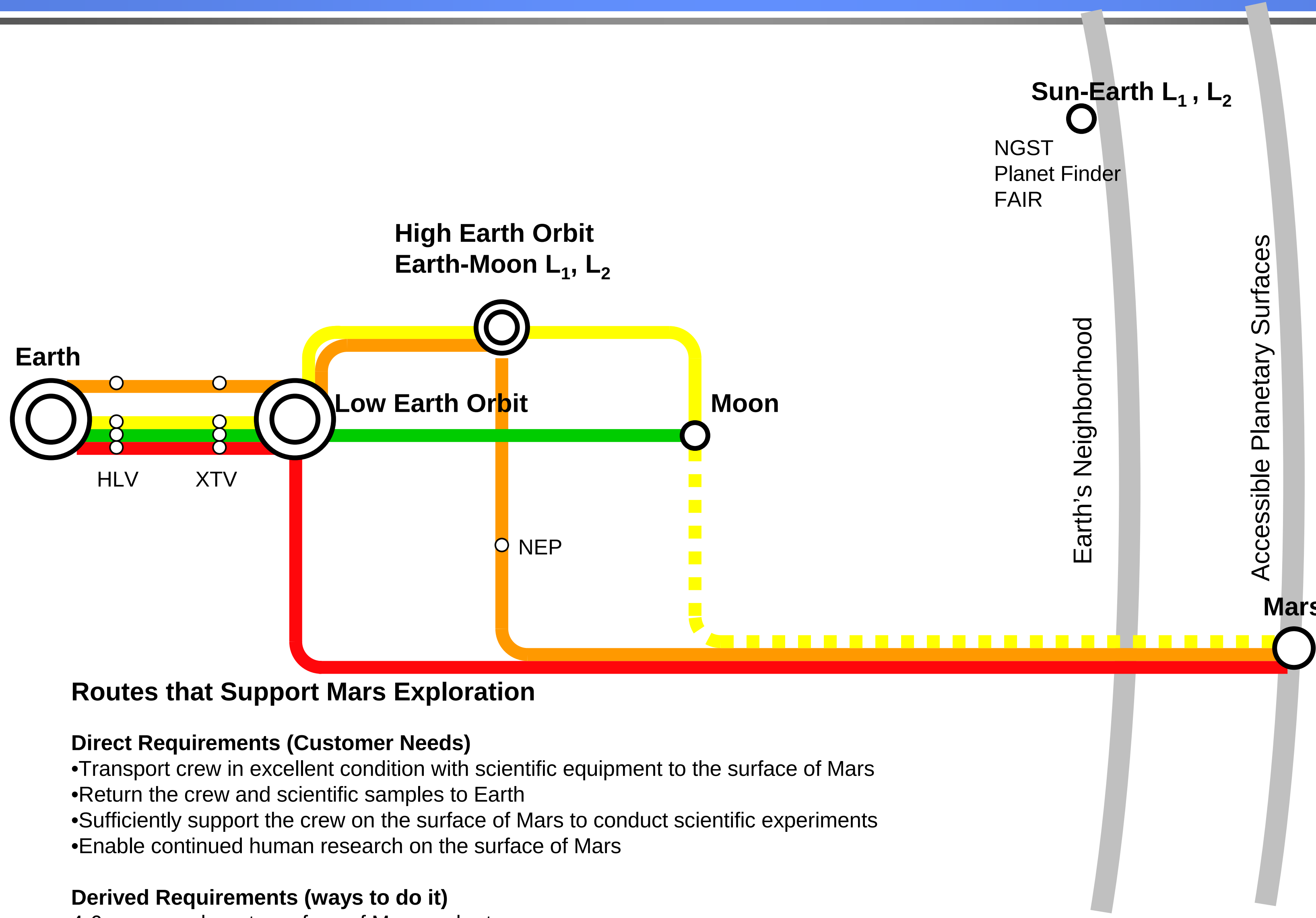
Architecture A Launch Synopsis:
Lunar Exploration Mission





LUNAR SURFACE
One Time
Recurring
Crew Transfer
Cargo Transfer
L1
LEO
1) L1 Outpost & injection stage to LEO
2) L1 Outpost to L_1 using injection stage
3) Lunar Lander & injection stage to LEO
4) Lunar Lander to L_1 using injection stage
A) XTV & Injection Stage to LEO
B) XTV and Crew to L1 Outpost
C) Crew and Lander to Surface
D) Crew and Lander to L1 Outpost
E) XTV and Crew aerocapture to LEO
F) XTV and Crew Landing

Exploration Route Map



Routes that Support Mars Exploration

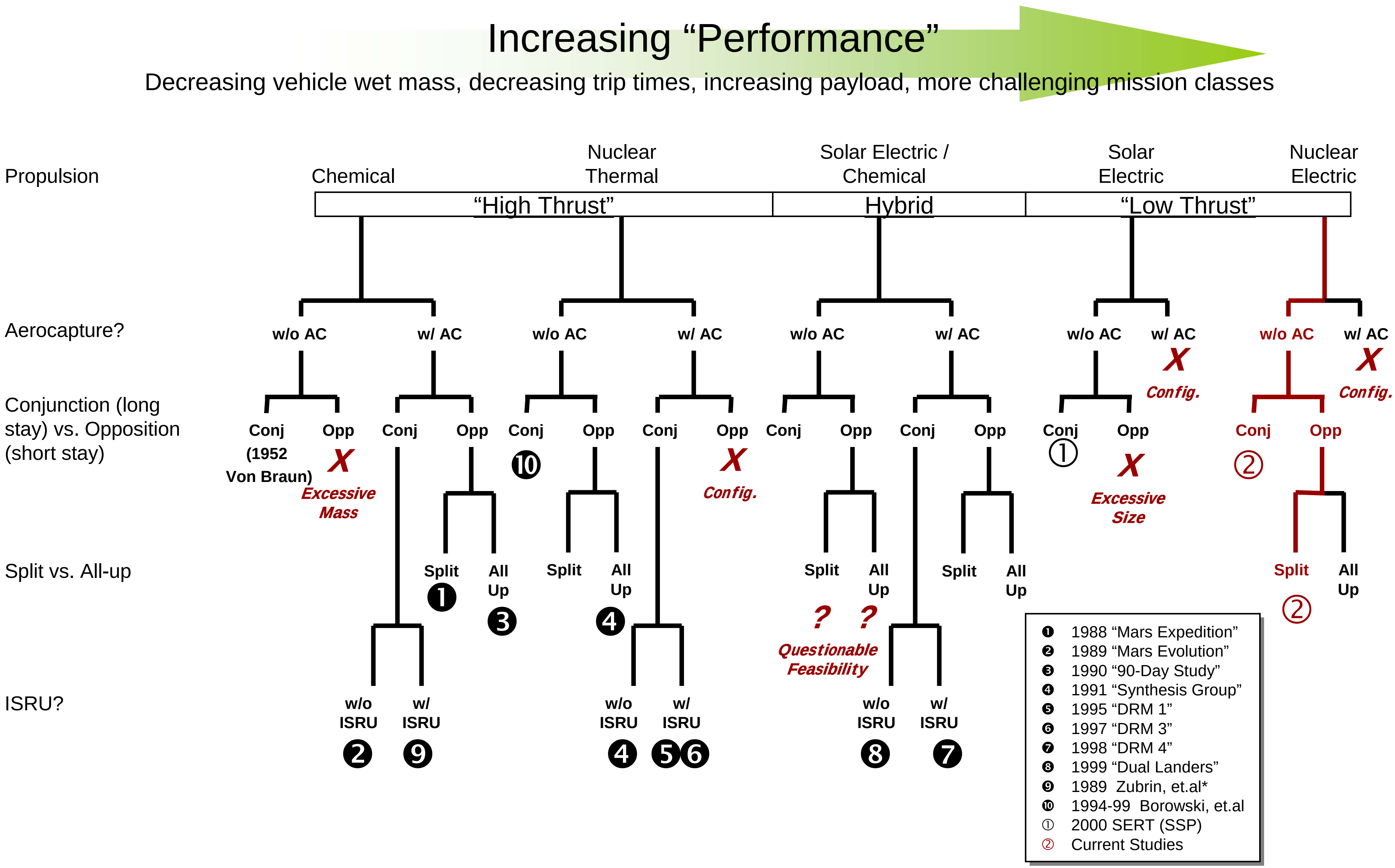
Direct Requirements (Customer Needs)

- Transport crew in excellent condition with scientific equipment to the surface of Mars
- Return the crew and scientific samples to Earth
- Sufficiently support the crew on the surface of Mars to conduct scientific experiments
- Enable continued human research on the surface of Mars

Derived Requirements (ways to do it)

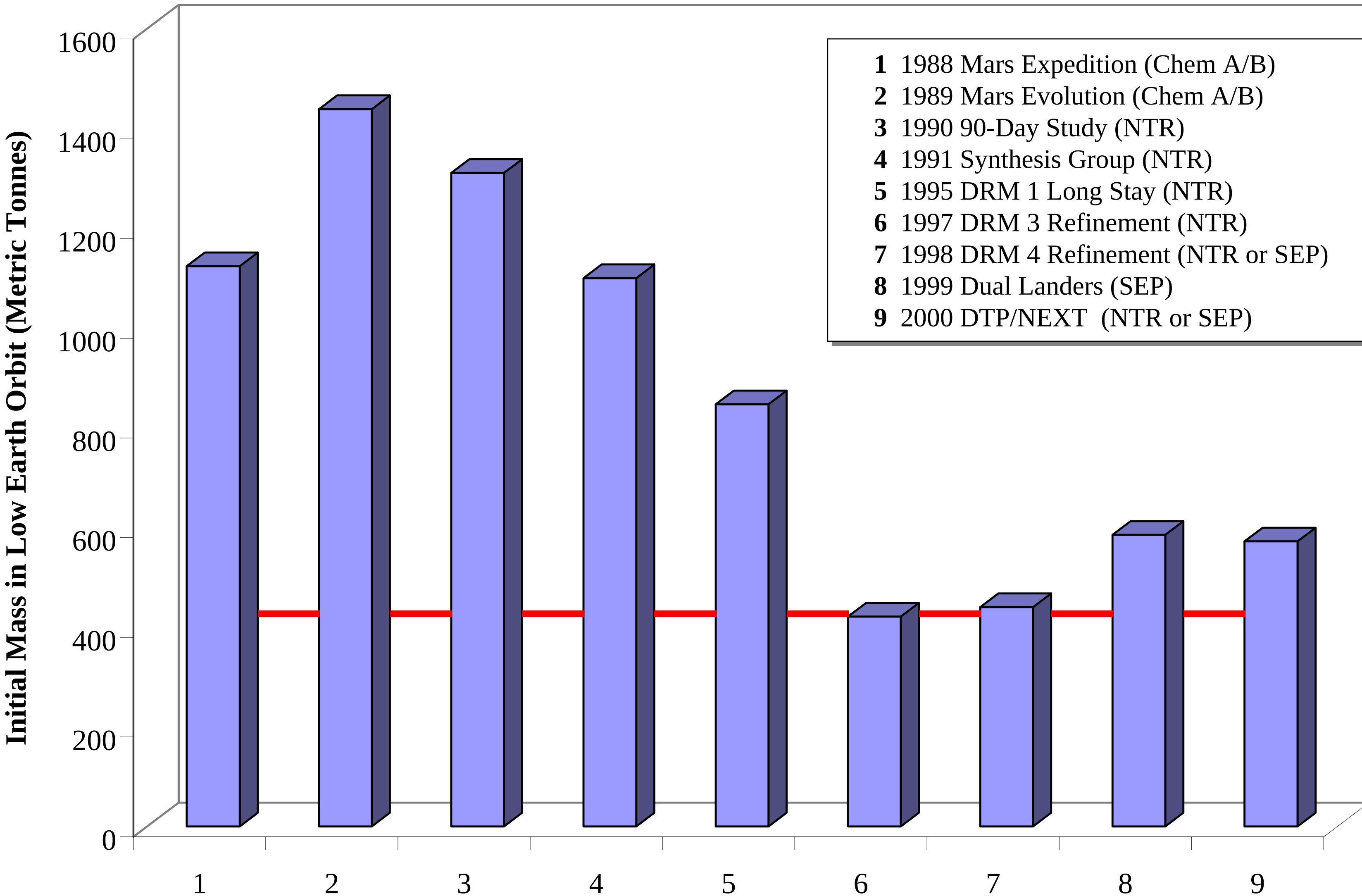
4-6 crewmembers to surface of Mars and return
Nuclear Surface power to support life support, vehicle needs, science sorties
Surface mobility to meet scientific requirements
Shelter (radiation, etc.), Crew health (G in route, exercise, medical, ,etc.)

Mars Mission Trade Space



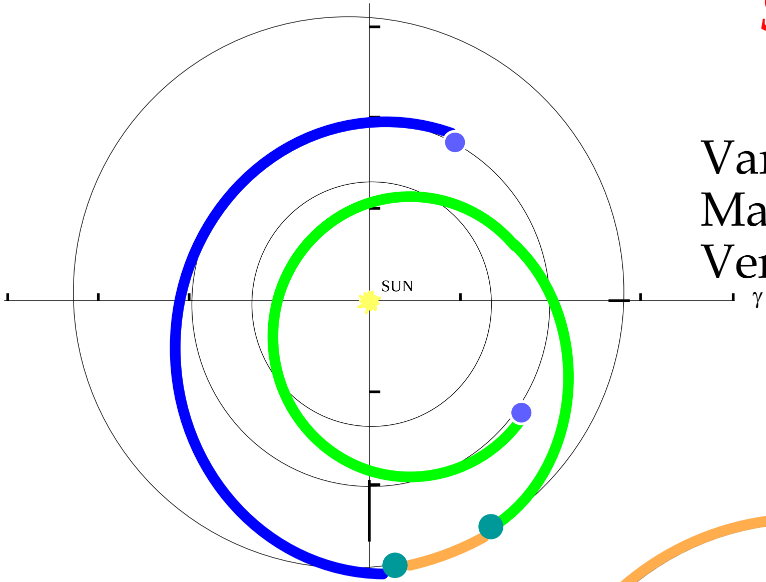
*Assumptions not necessarily consistent

Mars Architecture Mass History



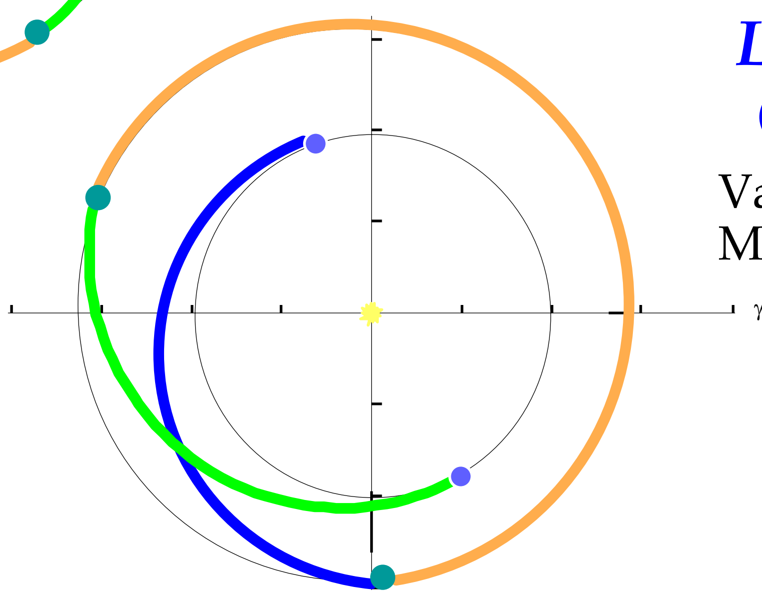
ISS @
Assembly
Complete
(470 tons)

Mars Mission Trajectory Options



Short-Stay Missions (Opposition Class)

Variations of missions with short Mars surface stays and may include Venus swing-by

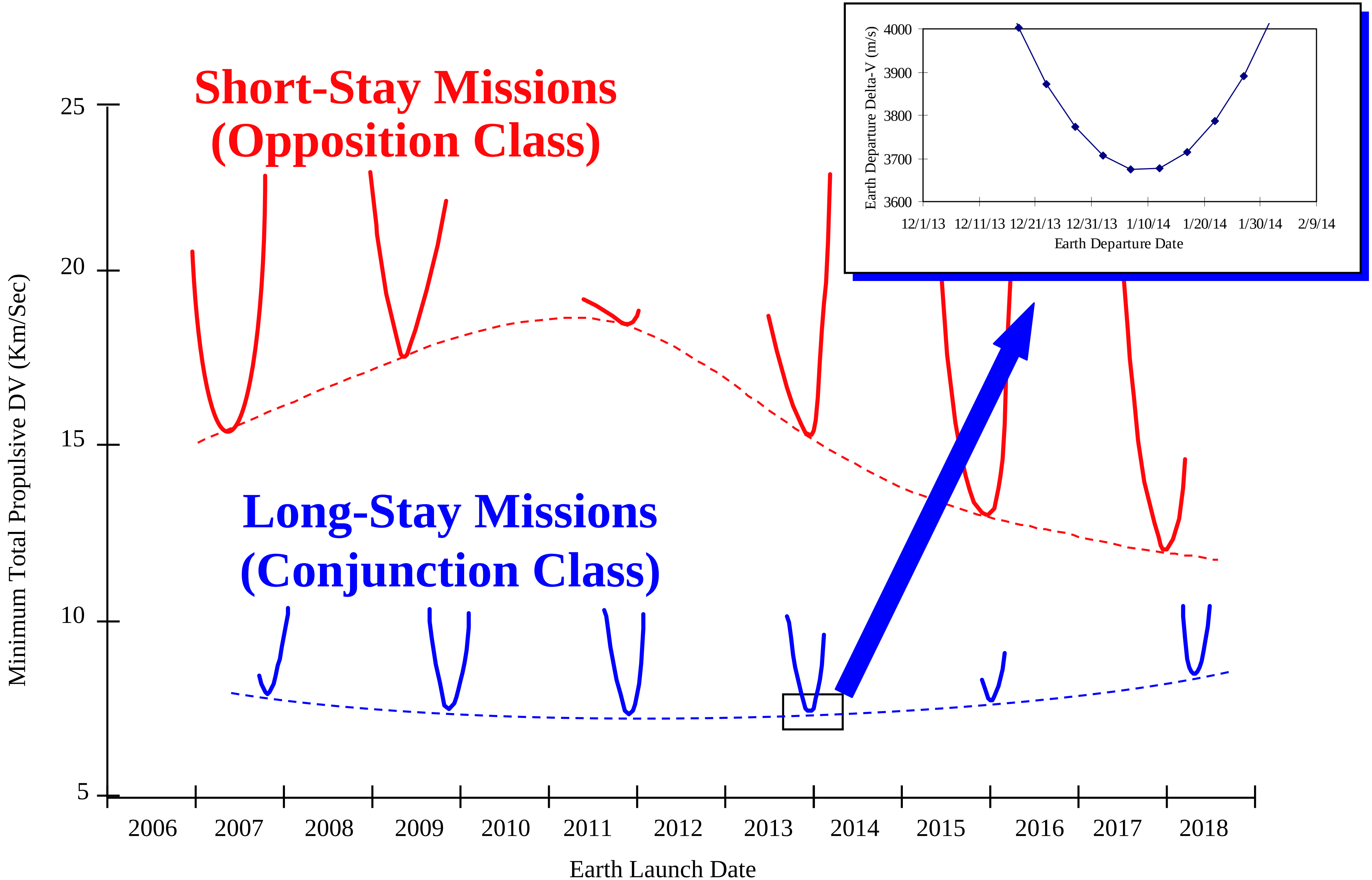


Long-Stay Missions (Conjunction Class)

Variations of missions with long Mars surface stays.

Outbound
Surface Stay
Inbound

Mars Mission Delta-V Variations



Advanced Concept Work in Support of the Integrated Space Plan

Section 4.0

Exploration Architecture Analysis

Introduction Backup

November 2002

Human Expedition to Mars

Objective

- Establishment of early leadership in human exploration of the solar system

Key Features

- 3 human expeditions to Mars
- Chemical/aerobrake propulsion
- Split/sprint mission profile
- Aerocapture at earth return
- Vehicle assembly in low-earth orbit (SSF)
- 8 crewmembers per expedition (2006, 2009, 2011)
- 440-500 day round trip (20 days on Mars surface)
- Total Mission mass = 1628 mt

1988

Principal Results

- Short-stay missions are energy intensive, thus requiring large transfer vehicles
- Advanced propulsion technologies (aerocapture and nuclear thermal rocket) can significantly reduce mass requirement (57-72%)
- On-orbit assembly, storage of cryogenic propellants, and vehicle checkout increase mission complexity
- Large mass in LEO requires a heavy-lift launch capability and potentially on-orbit assembly capability

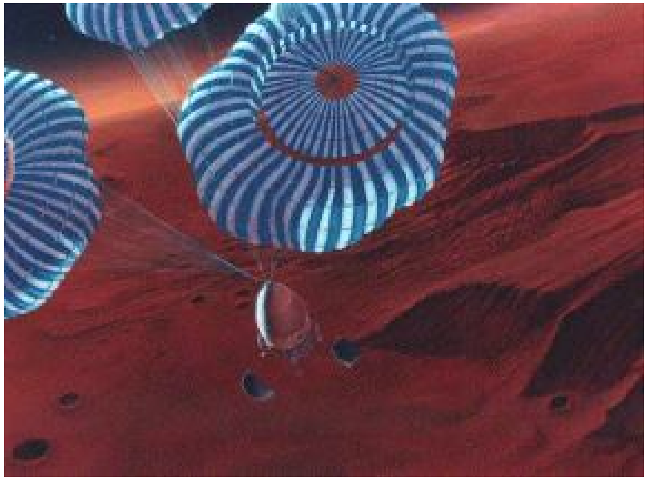
Mars Evolution

Objective

- Emplace a permanent, largely self-sufficient outpost on the surface of Mars

Key Features

- First human flight in 2007 (4 growing to 7 crew)
- Vehicles assembled in LEO (free-flyer platform)
- Chemical/aerobraking propulsion
- Propellant production at Phobos
- Artificial-gravity spacecraft
- Surface stay initially 30-days growing to 500



1989

Principal Results

- Heavy-Lift launch vehicle (140 t to LEO) required to support mass and flight rate requirements
- Even with HLLV, extensive on-orbit assembly and check-out required in low-earth orbit
- Use of nuclear thermal rocket, in addition to aerobraking, would increase payload capability and reduce flight times to and from Mars
- Advanced EVA systems are required to support the extensive surface operations required
- Significant research and development of in-situ resource utilization processes are required
- Architecture requires delivery of approximately 500t to low earth orbit per year

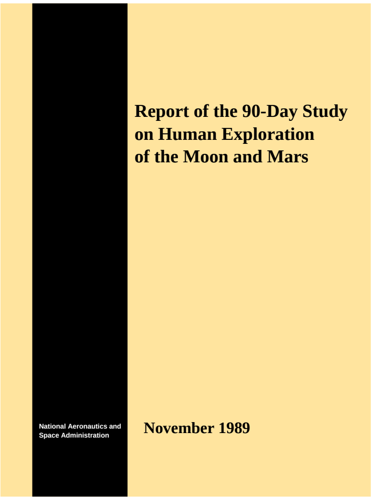
❸ NASA 90-Day Study

Objective

- To provide a database for the National Space Council to refer to as it considered strategic planning issues
- Agency-wide study commissioned by Admiral Truly after the President's July 20, 1989 speech

Key Features

- Five reference approaches (generally similar)
- Robotic - Moon - Mars pathway
- Extensive use of:
  - Space Station Freedom for assembly and checkout operations
  - Reusable transportation vehicles (initially expendable)
  - In-Situ Resource Utilization (oxygen from the lunar regolith)
  - Chemical/aerobrake propulsion



November 1989

Key Trades

- Launch Vehicle Size (80 - 140 mt)
- In-space assembly or direct to the surface
- Freedom, new spaceport, or direct assembly
- Chemical, electric, nuclear, or unconventional
- Aerobraking or all-propulsive
- Expendable or reusable spacecraft
- Propellant or tank transfer
- Open or closed life support
- Zero-gravity or artificial-gravity Mars vehicle
- In situ or Earth-supplied resources

Principal Results

- Premature discussion/disclosure of cost results can have unwanted effects, difficult to characterize long-term initiatives
- Use of local planetary resources can greatly enhance capabilities and reduce the cost of exploration
- Aerobraking reduces vehicle mass by as much as 50% as compared to all chemical systems
- Nuclear thermal propulsion provides a great deal of promise for Mars missions (40% mass reduction)

The White House Synthesis Group

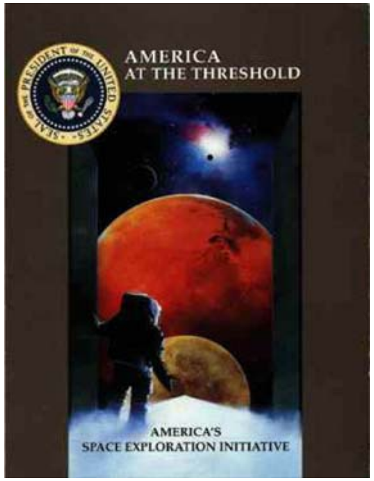
America At The Threshold

Charter

- Chartered by the National Space Council to develop several alternatives of exploration, future acquisition of scientific knowledge, and future space leadership.
- Chaired by Tom Stafford, Lieutenant General, U.S. Air Force (ret.)

Four Candidate Architectures

- Mars Exploration
- Science Emphasis for the Moon and Mars
- The Moon to Stay and Mars Exploration
- Space Resource Utilization



May 1991

Principal Results

- Several supporting technologies identified as key for future exploration:
  - Heavy Lift Launch Vehicle (150-250 mt)
  - Nuclear Thermal Propulsion
  - Nuclear electric surface power
  - Extravehicular activity suit
  - Cryogenic transfer and long-term storage
  - Automated rendezvous and docking
  - Zero-g countermeasures
  - Telerobotics
  - Radiation effects and shielding
  - Closed loop life support systems
  - Human factors for long duration space missions
  - Lightweight structural materials and fabrication
  - Nuclear electric propulsion for follow-on cargo deliv.
  - In situ resource evaluation and processing

Objective

- Develop a “Reference Mission” based on previous studies and data.
- Reference Mission serves as a basis for comparing different approaches and criteria from future studies

1994

Approach

- Limit the time that the crew is exposed to the harsh space environment by employing fast transits to and from Mars and abort to the surface strategy
- Utilize local resources to reduce mission mass
- Split Mission Strategy: Pre-deploy mission hardware to reduce mass and minimize risk to the crew of 6
- Examine three human missions to Mars beginning in 2009
- Utilize advanced space propulsion (Nuclear Thermal Propulsion) for in-space transportation
- Payloads sent directly to Mars using a large launch vehicle (200+ mt to LEO)
- Nuclear surface power for robust continuous power

Principal Results

- Total mission mass approximately 900 mt for the first crew (3 cargo vehicles, 1 piloted vehicle)
- Development of the large launch vehicle is a long-lead and expensive system. Approaches using smaller launch vehicles should be investigated.

Objective

- Refine DRM 1.0 to improve identified weaknesses
- Provide further refinement of systems design and concepts

Approach

- Refine launch strategy to eliminate the need for the large (200+ mt) launch vehicle. Dual launch (80 mt) strategy utilized.
- Repackage payload elements to reduce the physical size of the aerobrake used for Mars aerocapture and entry
- Investigate the need for the redundant surface habitat
- Incorporate emerging technologies and system concepts to reduce architectural mass

1997

Principal Results

- Reduced system masses allowed for the elimination of redundant surface habitat, thus eliminating one Mars cargo vehicle
- Incorporation of TransHab concept in conjunction with other systems improvements (ECLSS, power, etc) resulted in a mass savings of ~30% at Mars entry.
- System mass improvements and revision of mission strategy resulted in over 50% payload mass savings
- Emerging systems concepts including Solar Electric Propulsion and Bi-Modal NTR shown to be viable alternative concepts
- Total mission mass estimates:
    - Nuclear Thermal Propulsion: 418 mt
    - Solar Electric Propulsion: 409 mt (early estimate)

Objective

- Refine DRM 3.0 to improve identified weaknesses
- Provide further refinement of systems design and concepts
- Improve risk abatement strategy

1998

Approach

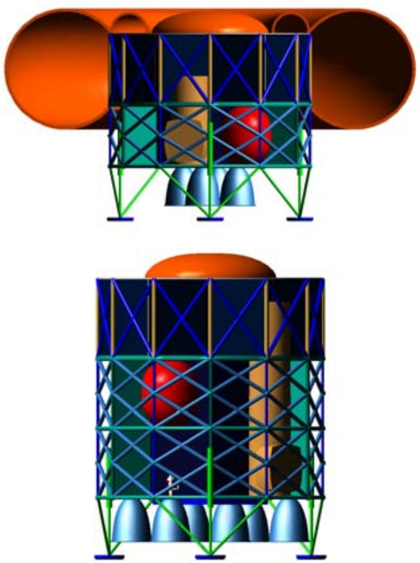
- Modify mission strategy to incorporate a round-trip crew transfer vehicle instead of pre-deploying the crew return habitat
- Place further emphasis on Solar Electric Propulsion concept (NTR and Chemical/Aerobrake investigated as options)
- Further refinement of In-situ resource utilization concept
- Shuttle derived launch vehicle (80 mt) used for LEO transportation

Principal Results

- Incorporation of a round-trip crew transfer vehicle reduces system reliability requirement from five to three years, but requires an additional rendezvous in Mars orbit
- End-to-end Solar Electric Propulsion vehicle mission concept is shown to be a viable concept, but vehicle packaging and size remain tall-poles
- Total mission mass estimates:
  - Solar Electric Propulsion: 467 mt
  - Nuclear Thermal Propulsion: 436 mt
  - Chemical/Aerobrake: 657 mt *

* similar but not same mission concept

Mars Exploration Mission Studies
Dual Landers



1999

Objective

- Refine Combo Lander approach to eliminate potential long-poles by separating the crew lander functions between two vehicles

Approach

- Long-duration stay mission with fast transits to and from Mars
- Aerobraking at Mars
- Descent/Ascent vehicle for crew transport from orbit, to surface, and back to Mars orbit
- Inflatable habitats for transit and surface vehicles
- CH_4/O_2 propellants brought with the crew of 6
- Solar surface power
- Solar Electric Propulsion used for interplanetary propulsion
- Magnum launch vehicle used for ETO transportation (100 mt to LEO)

Principal Results

- Six 100-mt launches required
- Significant improvement in aeroassist and parachute deployment conditions (as compared to Combo Lander II)
- Surface system reusability is enabled
- Greater improvement in Earth vicinity abort scenarios developed
- Total mission mass estimates:
    - Solar Electric Propulsion: 585 mt

Objective

- Develop a Mars mission approach embodying the philosophy:
  - Go Anywhere, anytime
  - Avoid political obstacles - No HLLV
  - Limit the total mission duration (goal of one-year)

Approach

- Include both short-stay and long-stay mission options
- Investigated both EELV-Exploration Class and 100-mt launch vehicles
- Solar Electric Propulsion and Nuclear Thermal Propulsion options
- Crew size of 6
- Understand trajectory sensitivities for all opportunities and various trip times

1999-2002

Principal Results

- Short-stay missions are very demanding missions
  - One-year round-trip missions occur infrequently (1 out of 7 opportunities)
  - Mission mass varies widely across launch opportunities (400-1600 mt)
  - Short-stay missions provide little time at Mars for contingencies
  - Round-trip mission times for short-stay missions range from 365 to 600 days
- Long-stay missions reduce mission complexity, but require longer overall mission
  - Mission mass constant across launch opportunities (30% variation)
  - Total mission times range from 892-945 days with surface stay times ranging from 501-596 days
- Utilizing EELV-Exploration Class launch vehicle impractical (excessive number of launches and complex orbital assembly and checkout)
- Estimated radiation exposure for long-stay missions is lower than short-stay missions

Advanced Concept Analysis in Support of the Integrated Space Plan

Section 4.1.1

Exploration Architecture Analysis
Earth's Neighborhood

November 2002

Outline

- Introduction & Architecture Considerations
  - Trade Space & Decision Tree
- Earth's Neighborhood
  - Requirements
  - Mission Modes
    - Mission Staging Points
    - Earth Entry Descent & Landing Mode
    - Utility of ISS
  - General Architecture Concept
  - Architecture Analysis
    - Architectures A & B
    - Element Design
- Mars
- Summary & Conclusions to Date

Key Architecture Requirements

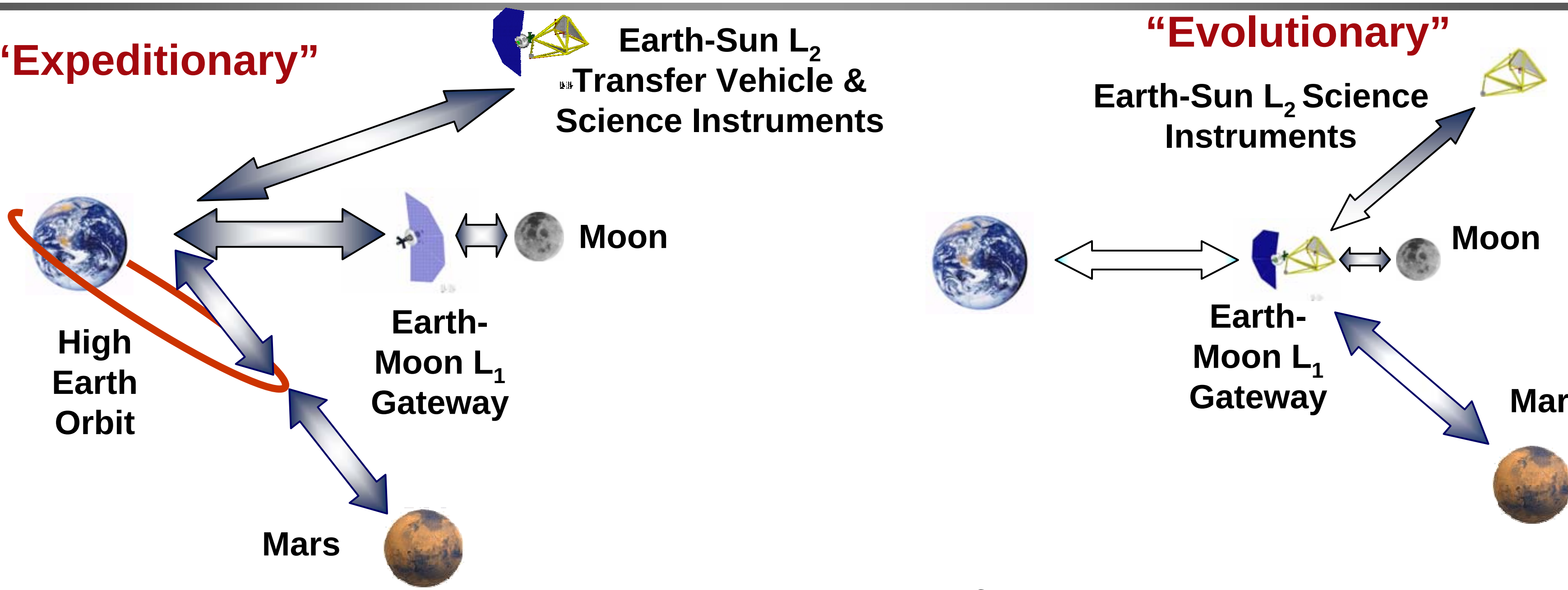
Programmatic Requirements:

- Support multiple destinations
  - Lunar Surface
  - Sun-Earth L_2 (operational location for IR telescopes)
  - Mars
- Serve as a test bed for future exploration
  - Technologies
  - Operations
  - Systems
- 1st human mission no earlier than 2012
- Crew sizes of 4-6 persons

System Requirements:

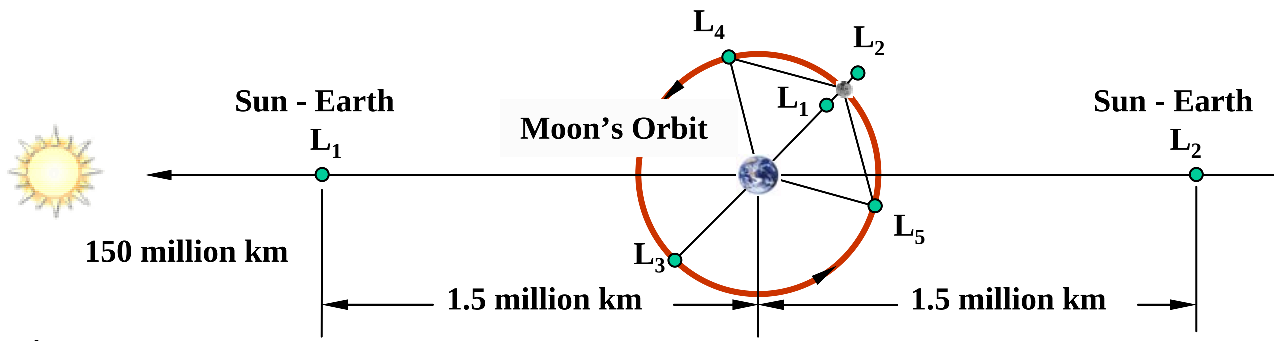
- Use existing or "near-existing" launch vehicle systems
  - Shuttle
  - Evolved Expendable Launch Vehicle
  - Shuttle-Derived Launch Vehicle(s)
- Enable access to entire Lunar Surface
  - Expeditionary mission (3-day mission)
  - Extended duration mission (30-day mission)
- Assemble, checkout, and maintain astronomical observatories in space

Mission Approaches

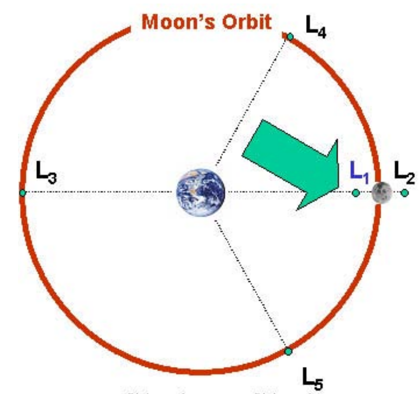


- Typical mission architectures are generally defined with each destination considered on its own basis and requiring its own infrastructure – an "expeditionary" mission architecture
  - Examples: Mercury, Gemini, Apollo, Skylab, Columbus' Voyage
- An "evolutionary" mission architecture is one which emphasizes an ongoing mission and a mission on which other future missions can be built.
  - Examples: ISS, Mars Orbiters as communications relay satellites

Utility of Libration Points



"Earth's Neighborhood"



	Distance from Earth's Center (km)	Distance from Moon's Center (km)
L_1	326740	57660
L_2	449748	65348
L_3	380556	764956
L_4	384400	384400
L_5	384400	384400

Environment:

- No orbital debris
- Nearly continuous *solar energy*
- Nearly continuous *full-sky viewing*
- True deep space environment
- *Continuous view* of Lunar nearside, Earth, terrestrial magnetosphere
- No *atmospheric drag*

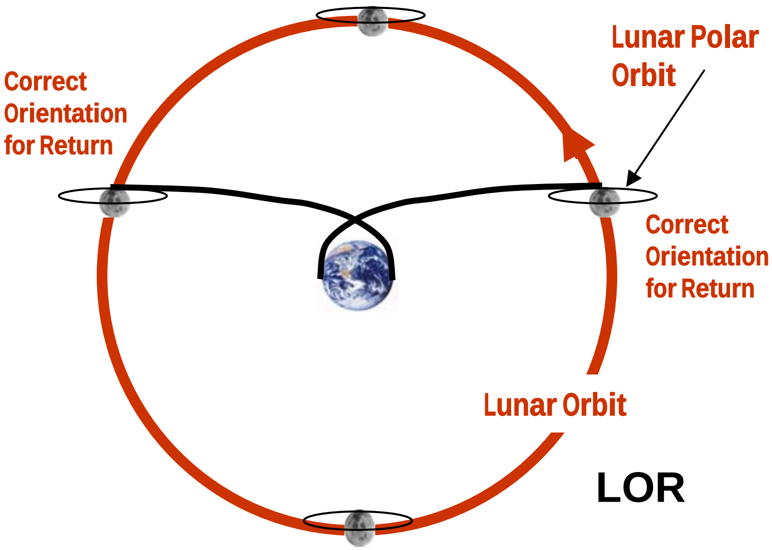
Operations:

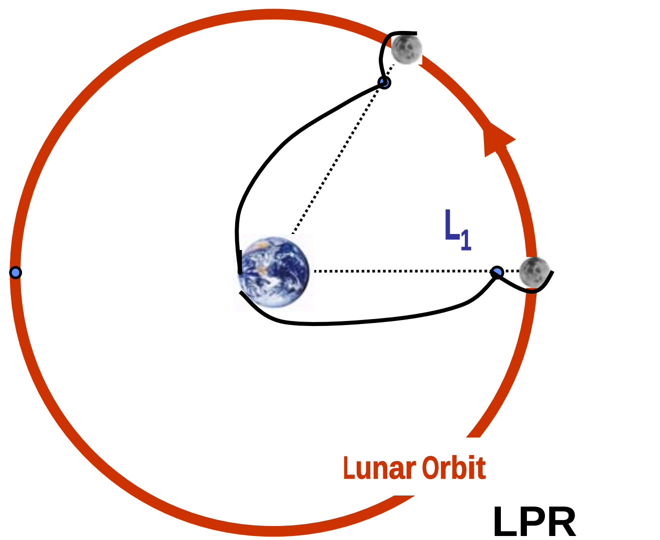
- Global anytime lunar access from L_1 for practically *no additional energy*
- Formation flying spacecraft mutually accessible with *minimal delta-v*, slow relative motion
- Excellent outpost/staging node for interplanetary missions
- Very low energy transfers available between libration points via *Interplanetary Superhighway System*

Interplanetary Superhighway

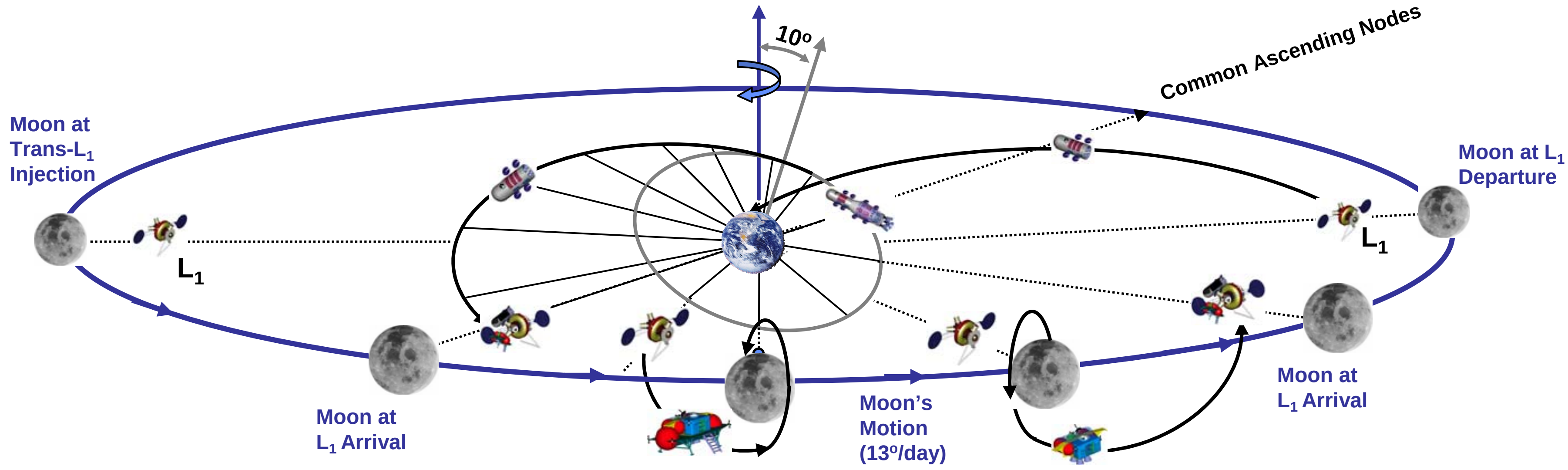
Lunar Mission Mode:
Libration Point vs. Lunar Orbit Rendezvous

- Operational Considerations
  - Lunar Orbit Rendezvous (LOR)
    - Access to lunar poles would require polar orbit if LOR mission mode utilized
    - Lunar polar orbit provides infrequent opportunities for trans-Earth injection (once every 14 days)
      - Orbit orientation inertially fixed, aligns with efficient trans-Earth trajectory twice a month
    - Total ΔV = 8951 m/s
  - Libration Point Rendezvous (LPR)
    - Continuous access from L_1 to lunar surface and return
      - Lunar rotation and libration point motion naturally synchronized
    - Continuous access to Earth - landing point partially controllable
    - Total ΔV = 10480 m/s
- Unique science opportunities at L_1
- Deep-space human exploration analogs exist at L_1
- Support for deep-space human exploration missions

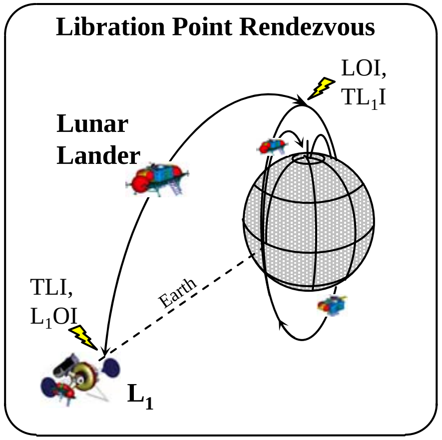




L_1 Staging Profile
3-Day Lunar Surface Mission

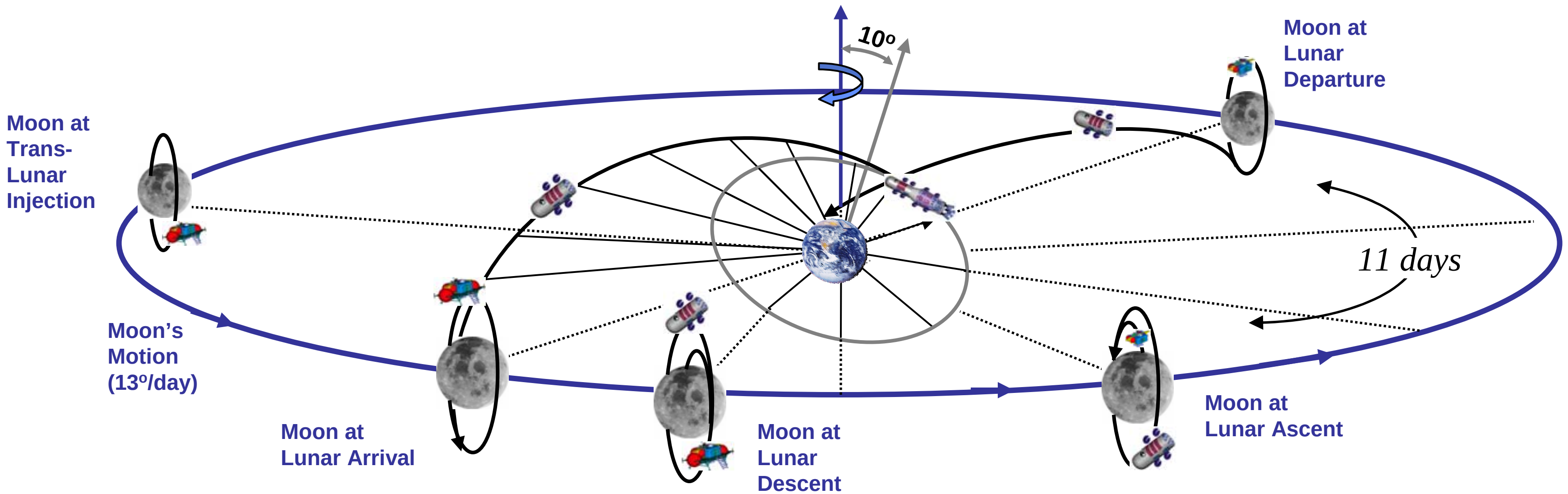


- Launch from Earth establishes orbital geometry for L1 departure
- Two direct-to-L1 injection opportunities available each day
- Transit opportunities continuously available between L1 and the lunar surface because of synchronized orbital geometry
  - All lunar landing sites available for practically no additional energy cost
- No wait at Lunar L_1 required for return opportunity orbital plane alignment at Earth

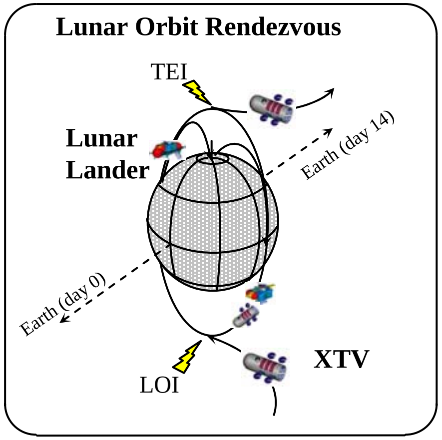


Lunar Orbit Staging Profile

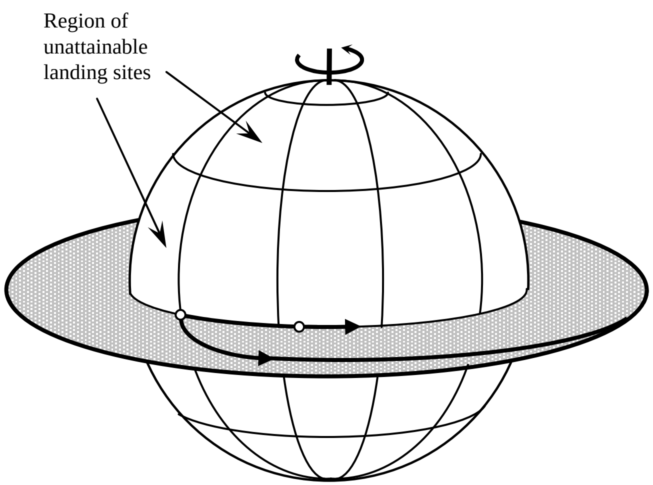
3-Day Lunar Surface Mission (Polar)



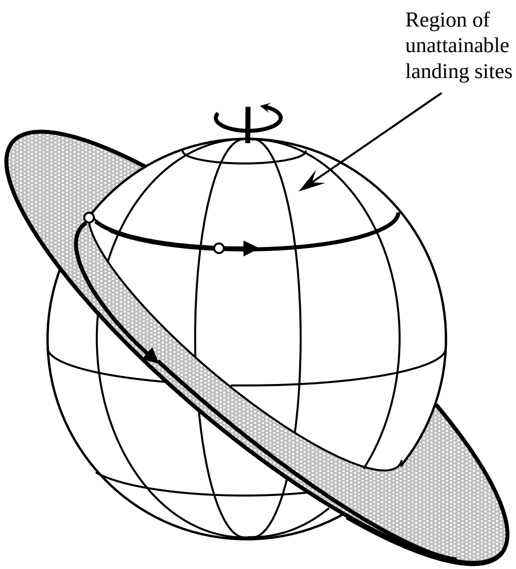
- Lunar Lander pre-deployed to polar lunar orbit
  - Lunar Lander orbit around Moon establishes orbital geometry for Earth departure
- Lunar injection opportunities available every 14 days
- Transit opportunities between polar lunar orbit and the lunar surface available every 2 hours for polar landing sites, every 14 days for all other latitudes
- Trans-Earth injection opportunities available every 14 days



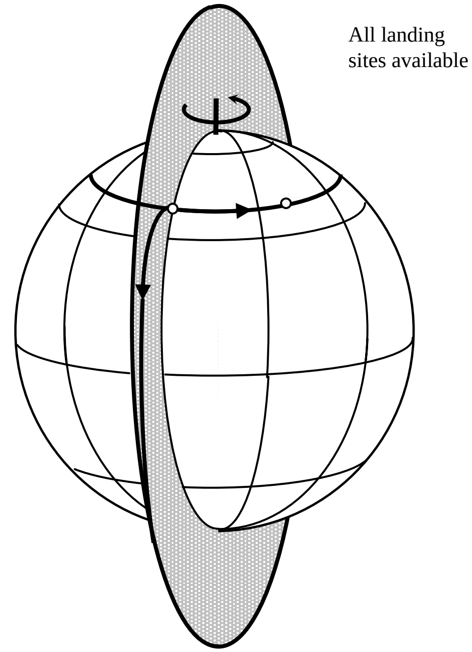
Landing Site Restrictions for LOR



In-plane lunar descent/ascent available every 2 hours



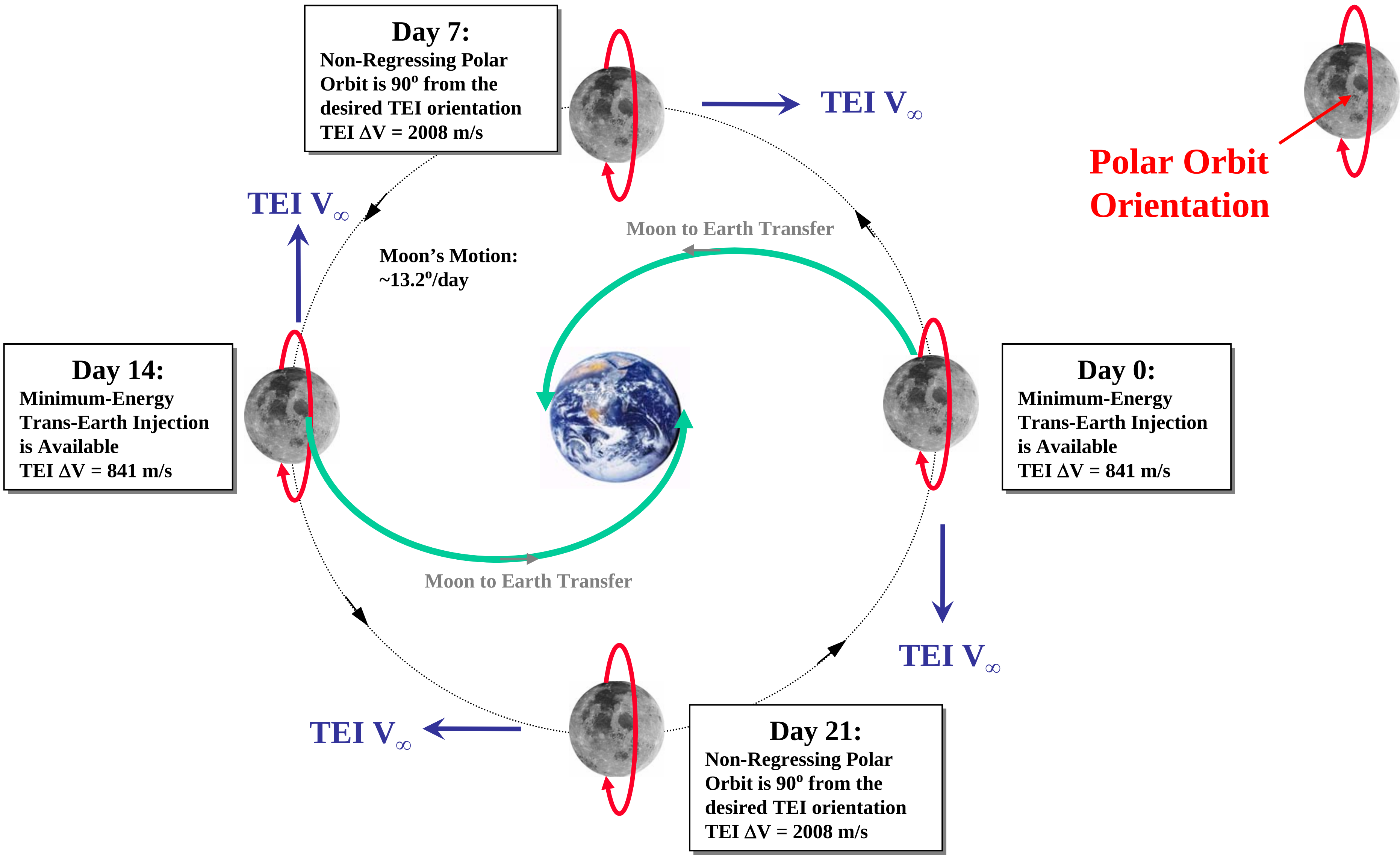
In-plane lunar descent/ascent available every 27 days



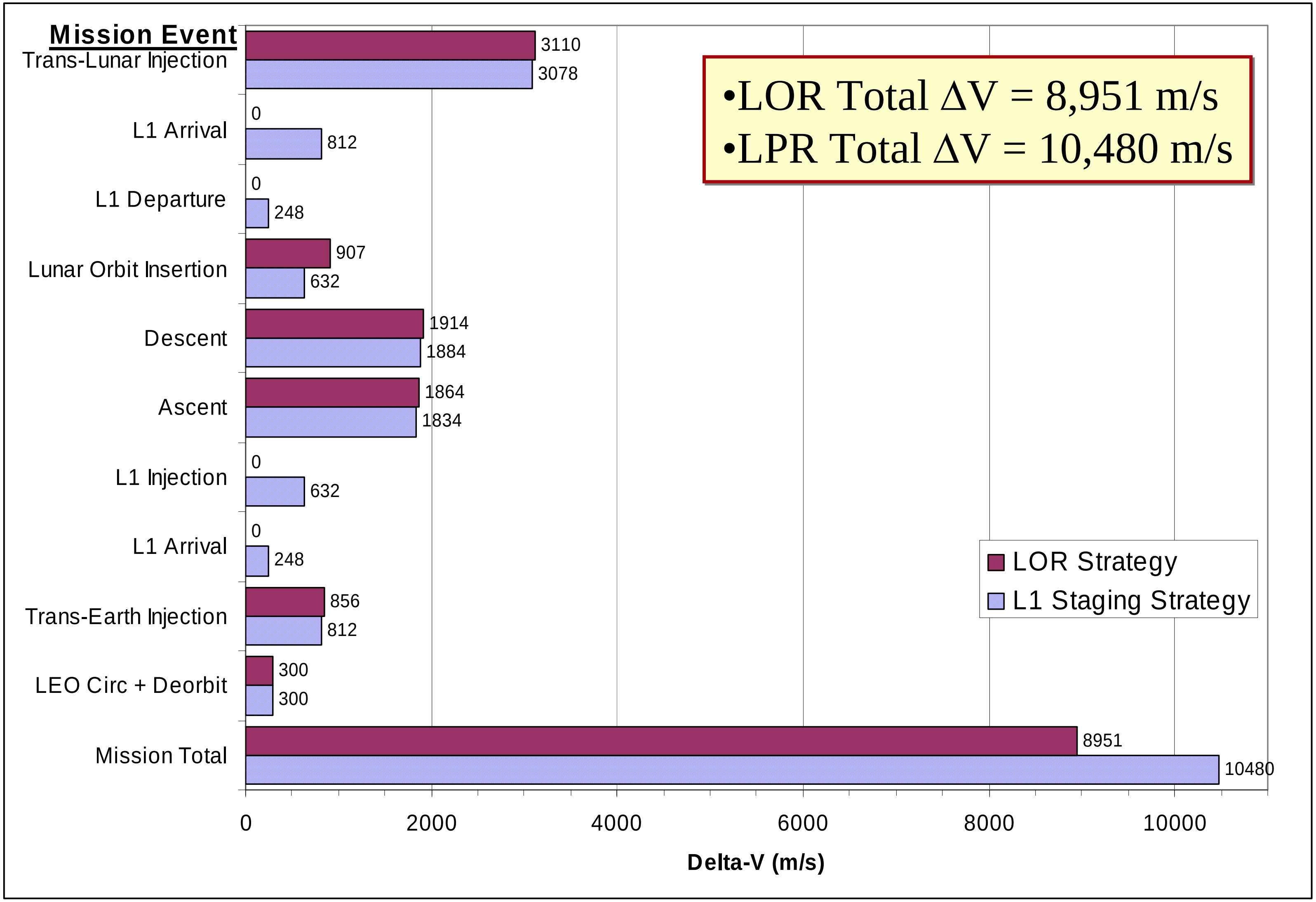
In-plane lunar descent/ascent available every 2 hours or 14 days depending on latitude of landing site

LOR Earth Return Opportunities:

100 km Polar Parking Orbit



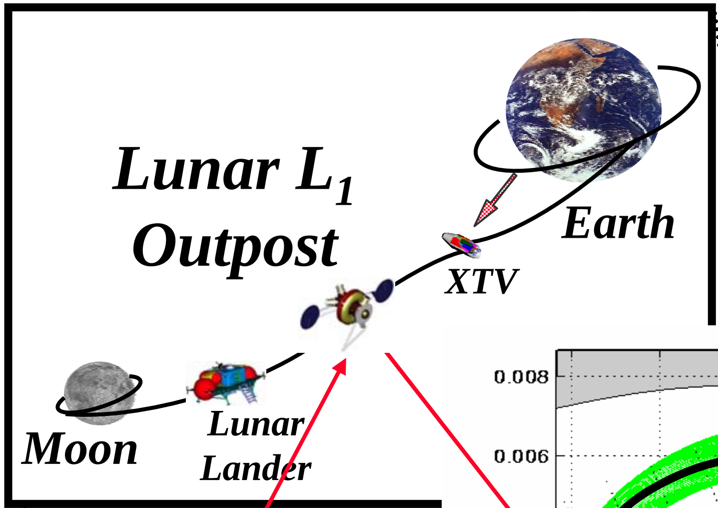
Lunar Mission ΔV Budget:
LOR vs. LPR



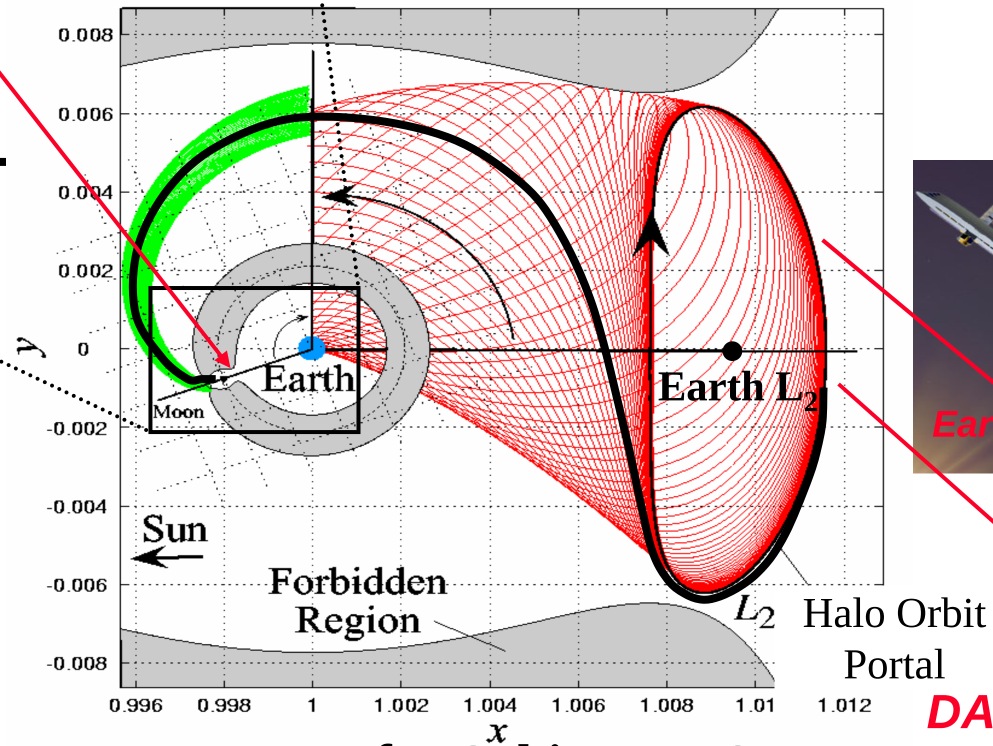
Other LPR Considerations:
Science Platform Servicing Missions

Interplanetary Superhighway System provides Low Energy Portals and Pathways (red/green tubes) generated by Libration points

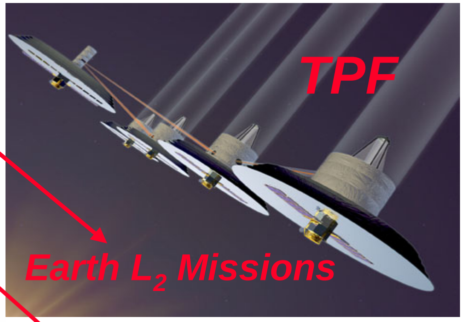
- Efficient for cargo transfers between Earth-Moon and Sun-Earth Libration points

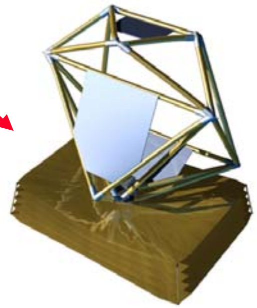


Building, Servicing Instruments & S/C at Lunar L_1 Station



Low Energy Transfer Orbit to L_1 Outpost

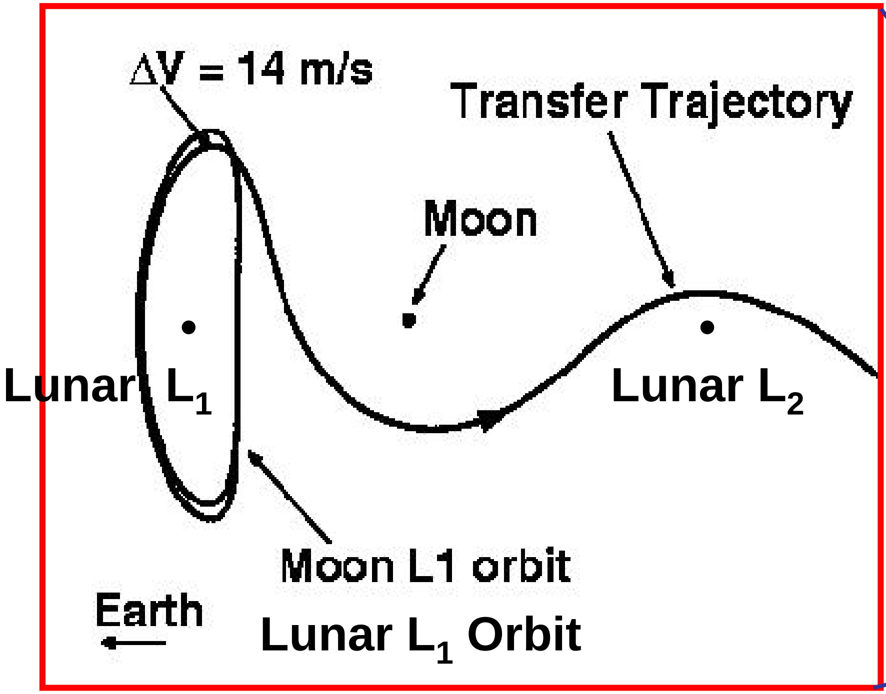




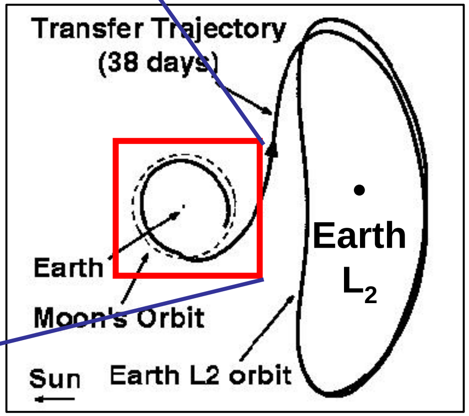
DART & Sail Missions

Lunar L_1 to Earth L_2 Transfers

- Assemble and deploy science platforms (advanced astronomical telescopes) at the Lunar L_1 Outpost
- Transfer platforms (14 m/s) from L_1 to a Earth L_2 halo orbit for operation
- Return platforms to Lunar L_1 for servicing and re-deploy



Lunar Rotating Frame

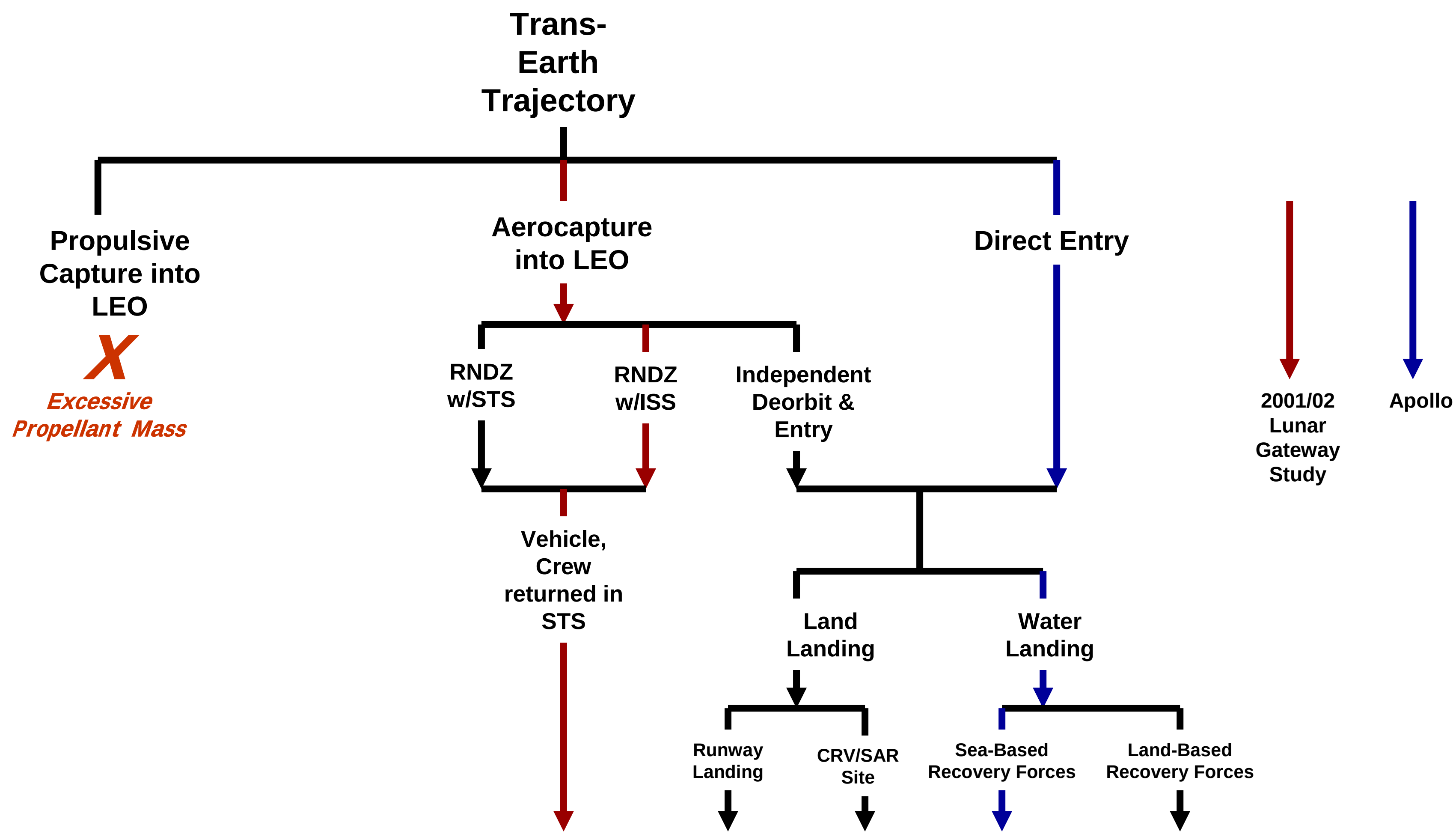


Earth Rotating Frame

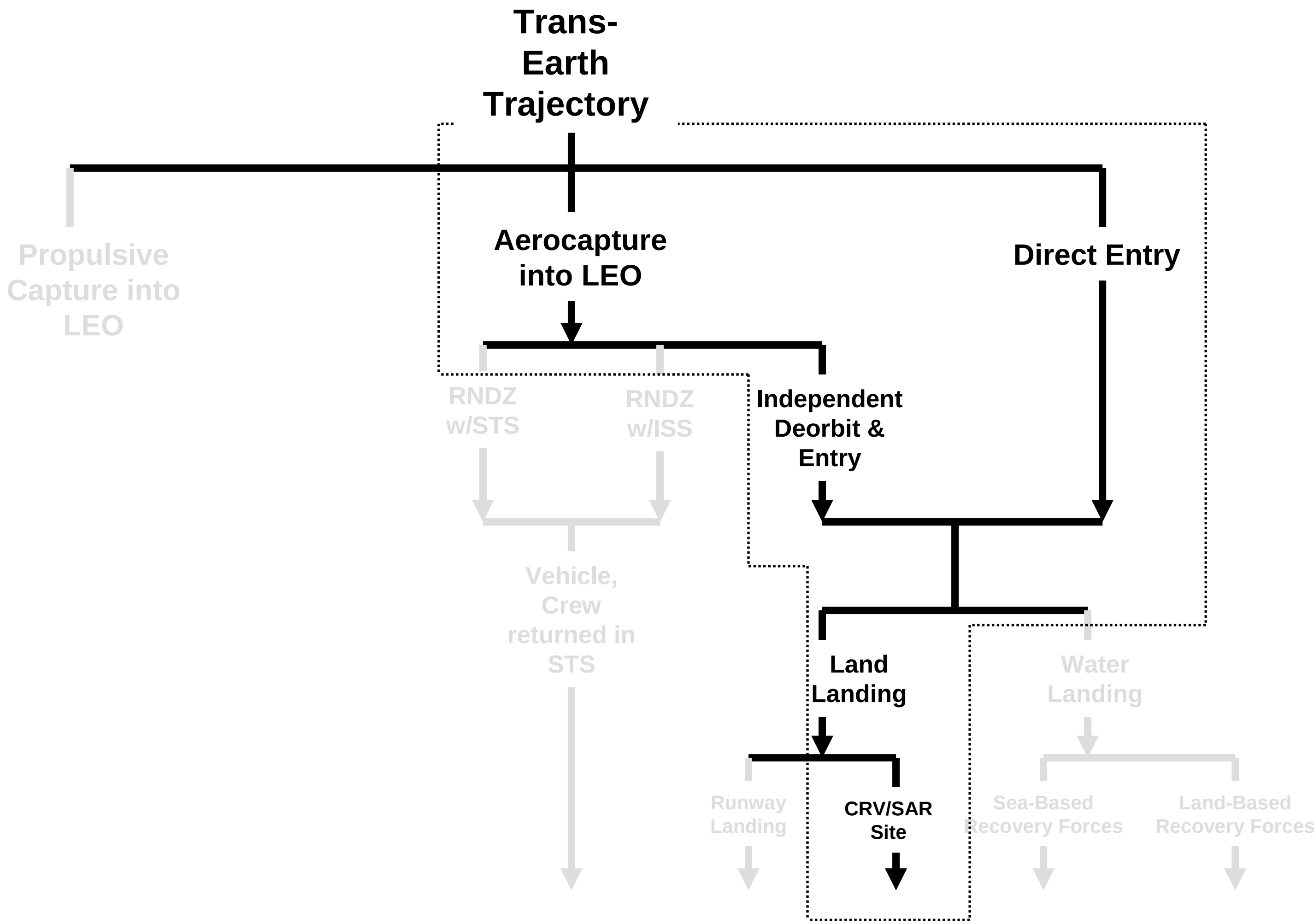
Lunar Mission Mode:
Preliminary Conclusions

- Lunar Orbit Rendezvous (LOR) offers a lower overall mission ΔV cost with fewer critical maneuvers at the expense of anytime departure capability
  - Ascent/Descent opportunities at non-polar, non-equatorial sites separated by at least 14 days)
- Libration Point Rendezvous (LPR) is favorable because it enables global lunar surface access for no additional cost, continuous access to and anytime return from the lunar surface, and the potential for reusability and support for other exploration programs
  - Requires a higher total mission ΔV (17%)
- Current Earth's Neighborhood architecture concepts incorporate LPR as a mission strategy for synergy with other exploration objectives

Earth Entry Descent & Landing Mission Mode Trade



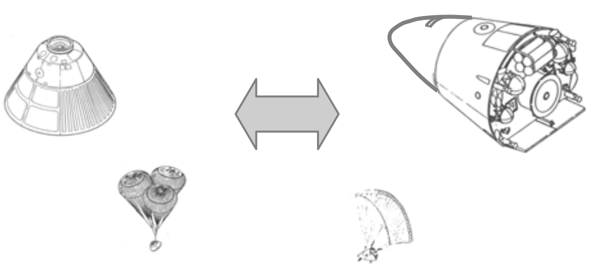
Suggested Trade:
Aerocapture vs. Direct Entry



Suggested Trade:
Aerocapture vs. Direct Entry

	Benefits	Challenges	Comments
Direct Entry	•Simplest, fewest events •Proven heritage •Shortest mission duration	•Large number of worldwide landing sites required (Wx alt.) •Earth landing lighting determined by lunar departure time •Stage/module disposal constraints •Higher peak heating	•Probably simplest entry configuration – no subsequent propulsive events
Aerocapture	•Control over landing site, lighting thru LEO phasing •Stage/module disposal flexibility •Lower peak heating	•Additional critical propulsive events required •Potentially additional propulsion system •Unproven maneuver (see comments) •Additional mission duration •Additional ΔV required (see comments)	•Candidate guidance strategies have existed for >20 years •Additional propellant required may be offset by reduced coazimuth, disposal ΔV

Related Design and Operational Considerations



- Desired degree of vehicle reusability
  - Final entry mass
  - System packaging
  - Recovery system mass, applicable recovery system options
- Post-aerocapture entry crossrange requirements
  - Orbit loiter time vs. number of landing sites & opportunities

1992 Landing & Recovery Options Study Results

- Three land landing zones are sufficient to allow any-time return from moon (or L_1): 15°-19°N, equatorial, and 15°-19°S, assuming:
  - No weather alternate sites required
  - No landing lighting constraints
  - "Coazimuth" control (~120 m/s ΔV)
  - ± 12 hrs TE flight time capability (longitude control)
- Stage or module disposal
  - 30 m/s ΔV at EI-15 to EI-60 provides 500 - 1300 km vacuum IP shift, -8° to -10° FPA (good for debris footprint control)
  - Nominal vehicle landing will be >1000 km downrange of vacuum IP (0.3 L/D)
  - Compatibility of landing zone will depend upon
    - Approach azimuth (controllable)
    - Debris footprint
- Bottom Line: Land Landing Preferred over Water
  - Pros:
    - Crew Safety (emergency egress, water motion, vehicle sinking, etc.)
    - High proximity to SAR, Med facilities
    - Higher synergy with ACRV (shared support infrastructure)
    - LCC (recovery ops, vehicle refurbishment, etc.)
  - Cons:
    - Higher ΔV req. (coazimuth & stage disposal)
    - Potential stage/module disposal issues

Earth EDL Mission Mode:
Preliminary Conclusions

- Land landing looks favorable for the same reasons concluded in Landing & Recovery Options study
- However, considerable accessibility constraints exist when combined with direct entry – aerocapture scenarios should be traded
- Effects of higher (L/D>0.3) ranging/crossranging capability have not been assessed and may be significant (direct)
- Vehicle degree of reusability and packaging trades may influence configuration & performance

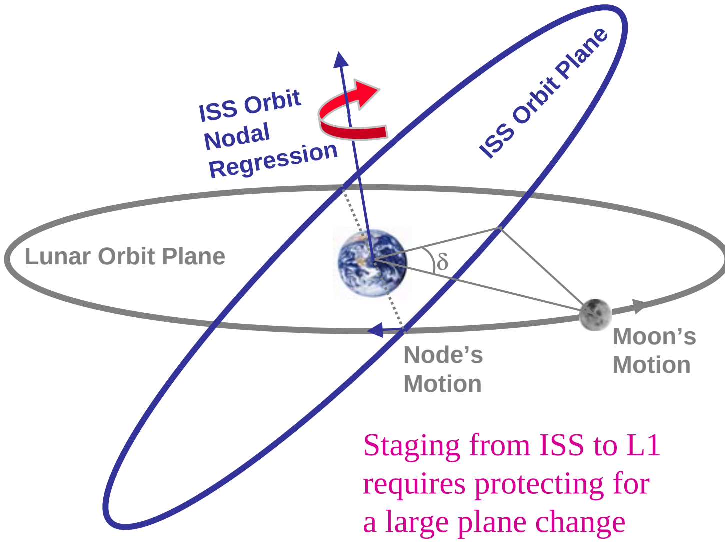
LEO Staging Mission Mode:
ISS Staging – Why Not?

Negative impacts on ISS operations:

- A full ISS crew (7) + exploration crew (4-6) exceeds planned ISS habitation capabilities
- Increased traffic interferes with ISS μ-g quiescent periods
- Dedicated infrastructure and mission support would be required to support exploration
  - Customized docking port(s)
  - Crew consumables and habitation support
  - Power and thermal heat rejection for docked vehicles

Negative impacts to exploration missions:

- Lengthens overall mission duration by requiring wait periods for orbit planes to align
  - Departure opportunities to and from L_1 only available once every 10 days
  - Departure opportunities to a fixed lunar orbit extremely rare
- Increases mission complexity by adding critical rendezvous & docking events to the mission sequence
- Launching payloads to higher-inclination orbits (such as ISS) penalizes launch vehicle lift capability
- ISS staging increases total mission ΔV, reducing useful payload mass

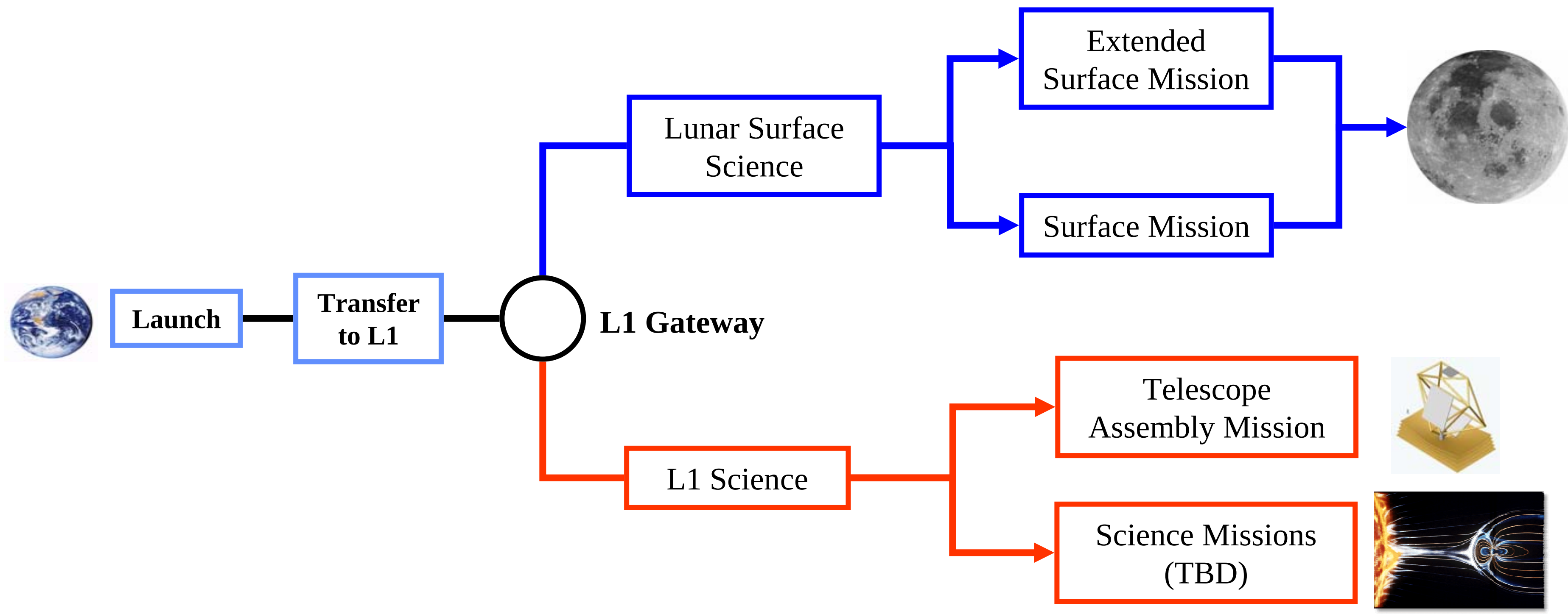


Staging from ISS to L1 requires protecting for a large plane change

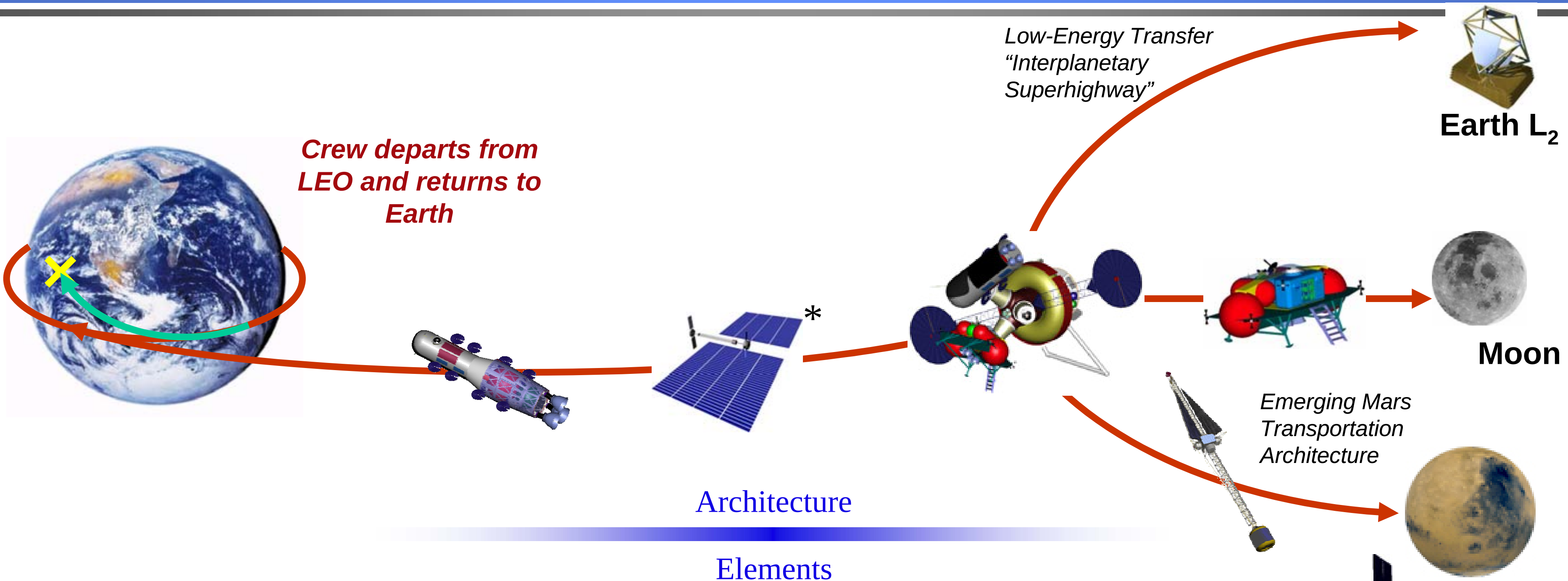
Architecture Mission Modes Summary

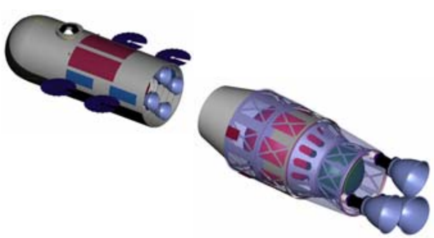
- Use **libration point rendezvous** for lunar mission staging and science platform assembly, deployment, and servicing missions
- The nominal Earth entry, descent, and landing mode will be either **LEO aerocapture + deorbit** or **direct entry** pending the results of further trade studies with **land landing** as the nominal landing mode
- The ISS **will not** be used for LEO mission staging

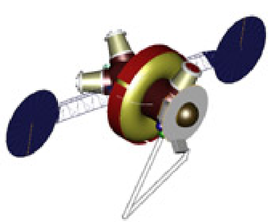
Architecture Functional Breakdown

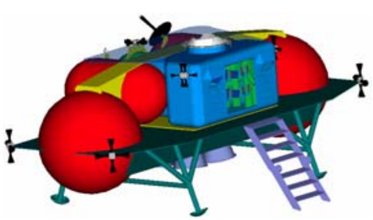


General Architecture Concept









Exploration Transfer Vehicle & High Energy Injection Stage
- Transports crew and cargo between LEO and Lunar L_1
- Nominal aerocapture+entry with contingency direct Earth return

L_1 Outpost
- “Gateway” to the Lunar surface
- Outpost for staging missions to Moon, Mars and telescope construction

Lunar Lander
- Transports crew between Outpost and Lunar Surface
- 9-day mission (3 days on Lunar surface)

Solar Electric Propulsion Stage* [Architecture-Dependent]
- High-efficiency SEP used to deliver cargo from LEO to a final destination.
- SEP Stage returns to Earth for reuse.

Lunar Habitat
- 30-day surface habitat placed at Lunar South Pole

Architecture Analysis Overview

- Two reference architectures have been developed for comparison purposes
- The first architecture (known henceforth as Architecture A) is distinguished by the use of the medium-lift Space Shuttles and augmented expendable launch vehicles for launch needs
- Architecture B incorporates Shuttle-derived heavy-lift launchers for ETO launch

Architecture A Overview

- Architecture A utilizes the Shuttle (24 mt to LEO) and augmented Evolved Expendable Launch Vehicles (40 mt to LEO) for Earth-to-orbit launch of architecture elements

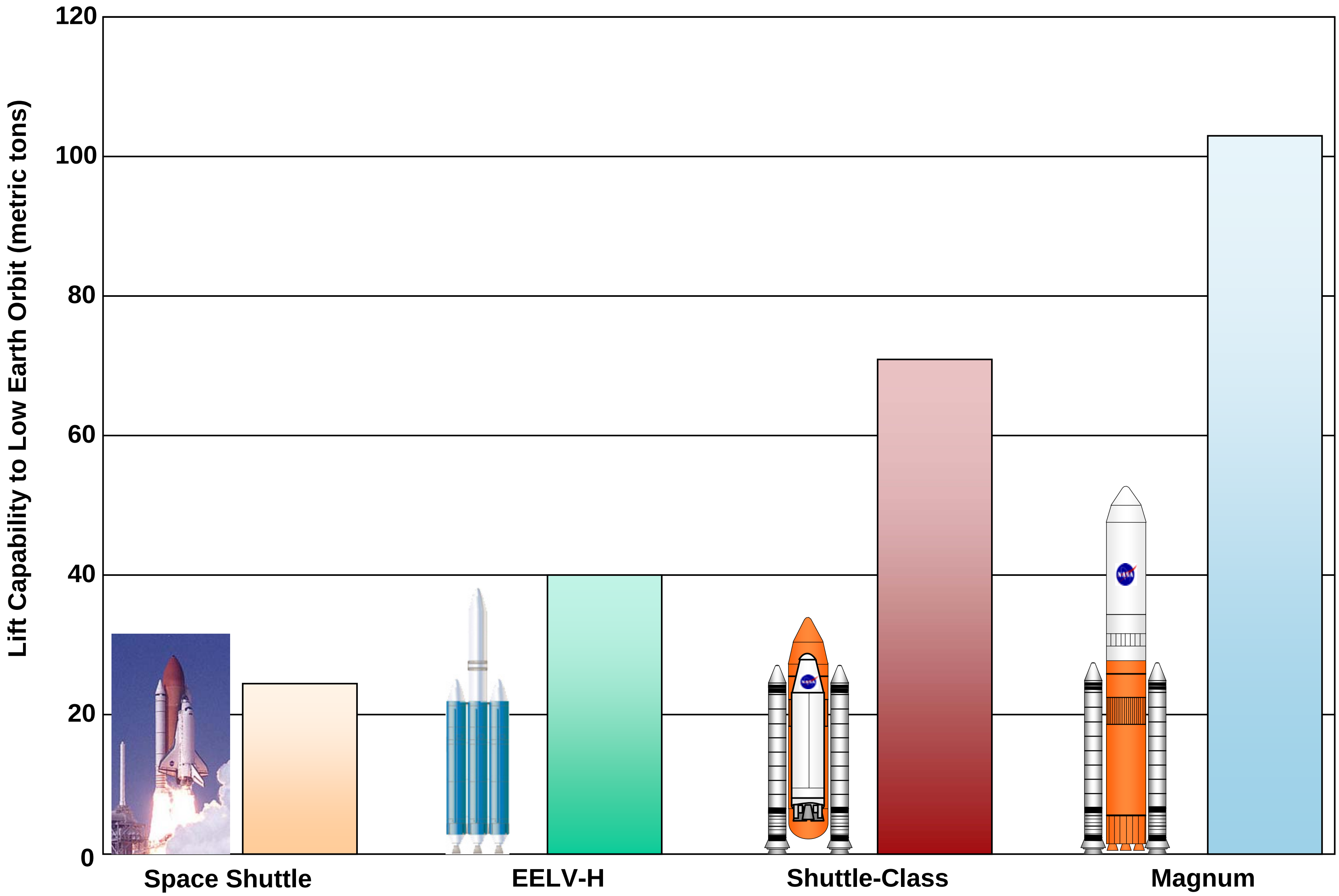
- Architecture A will launch the transfer vehicle/crew and injection stage separately to a circular low-Earth orbit of 400 km x 28.5^{o} with the transfer vehicle returning directly to Earth at the end of the mission
  - <u>Step 1:</u> Launch the Exploration Transfer Vehicle (XTV) injection stage to LEO on an EELV.
  - <u>Step 2:</u> Launch the entire XTV and exploration crew to LEO with the Shuttle or EELV. The XTV will rendezvous and dock with the injection stage, and depart to L_1.

- A low-thrust solar electric propulsion (SEP) stage will be used to deliver architecture cargo elements such as landers and habitats to Lunar L1 and Low Lunar Orbit

Architecture B Overview

- Architecture B utilizes the Shuttle-derived Magnum launch vehicle for Earth-to-orbit launch of architecture elements (100 mt to LEO)
- Architecture B will launch the transfer vehicle, crew and injection stage in a single launch to a circular low-Earth orbit of 278 km x 28.5^{o} with the transfer vehicle returning directly to Earth at the end of the mission
- The high-energy injection stage used for the Exploration Transfer Vehicle (XTV) will be used (scaled as necessary) to deliver architecture cargo elements to Lunar L1 and Low Lunar Orbit

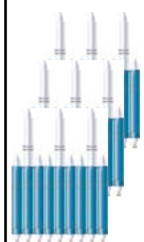
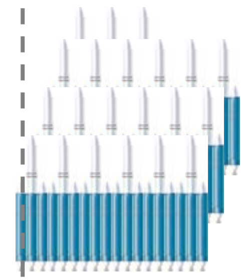
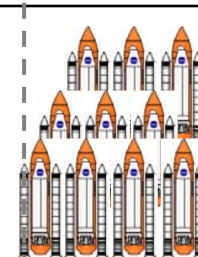
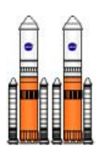
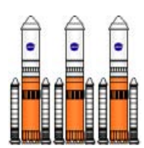
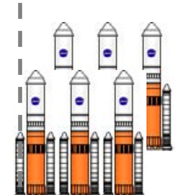
Launch Vehicle Candidates & Payload Performance



Exploration Launch Comparison

* Note: A launch mass packaging efficiency of 75% is assumed for on-orbit assembly

Earth's Neighborhood Missions

	Telescope Assembly IMLEO = 150 mt *	**Lunar Expedition** IMLEO = 240 mt *	**Mars Mission** IMLEO = 450 mt *
EELV-H Payload to LEO = 23 mt Probability of Launch Failure = 1/40	 9 Launches 80% Prob. Of Launch Success	 13 Launches 72% Prob. Of Launch Success	 27 Launches 50% Prob. Of Launch Success
Shuttle-Class Payload to LEO (small shroud) = 71 mt Payload to LEO (large shroud) = 60 mt [Assumes 4-segment SRMs] Probability of Launch Failure = 1/400	 3 Launches 99% Prob. Of Launch Success	 5 Launches 99% Prob. Of Launch Success	 10 Launches 97% Prob. Of Launch Success
Magnum Payload to LEO = 100 mt Probability of Launch Failure = 1/400	 2 Launches 99% Prob. Of Launch Success	 3 Launches 99% Prob. Of Launch Success	 6 Launches 98% Prob. Of Launch Success

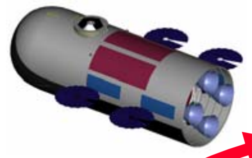
Telescope Assembly mission includes launches for infrastructure buildup

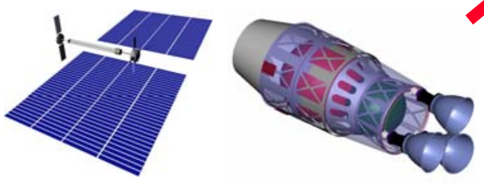
Lunar Expedition includes launches for infrastructure buildup

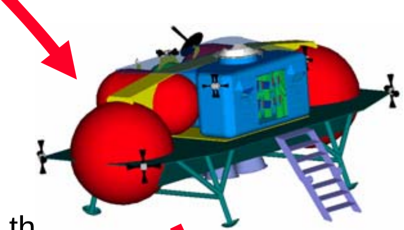
Architecture Elements

- Exploration Transfer Vehicle
  - Human transport from Earth to Lunar L_1 and return
- High-Energy Transportation Stage
  - Injection Stage
    - Provides initial boost for XTV
    - Delivers cargo to Lunar L_1 and Lunar Orbit [Arch. B]
  - Solar Electric Propulsion Stage [Arch. A only]
- L_1 Outpost
- Lunar Lander
  - Human transport from Lunar L_1 to surface and return
- Lunar Habitat

Architecture Transportation Elements







In-Space Transportation

- Deep-space propulsion for capture, orbital maintenance, and element return to Earth
- Key Technologies & Options:
  - Advanced Chemical (CH_4/O_2)
  - Long-term Cryo Storage

High-Energy Injection

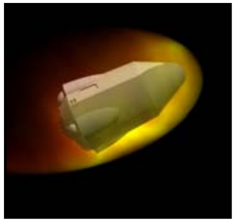
- Injects mission payloads from low-Earth orbit toward their intended destination
- Key Technologies & Options:
  - Advanced Chemical (H_2/O_2)
  - Solar Electric Propulsion
  - Long-term Cryo Storage

Descent / Ascent

- Deep-space propulsion for descent to and ascent from the lunar surface
- Key Technologies & Options:
  - Advanced Chemical (CH_4/O_2)
  - Long-term Cryo Storage

Earth-to-Orbit

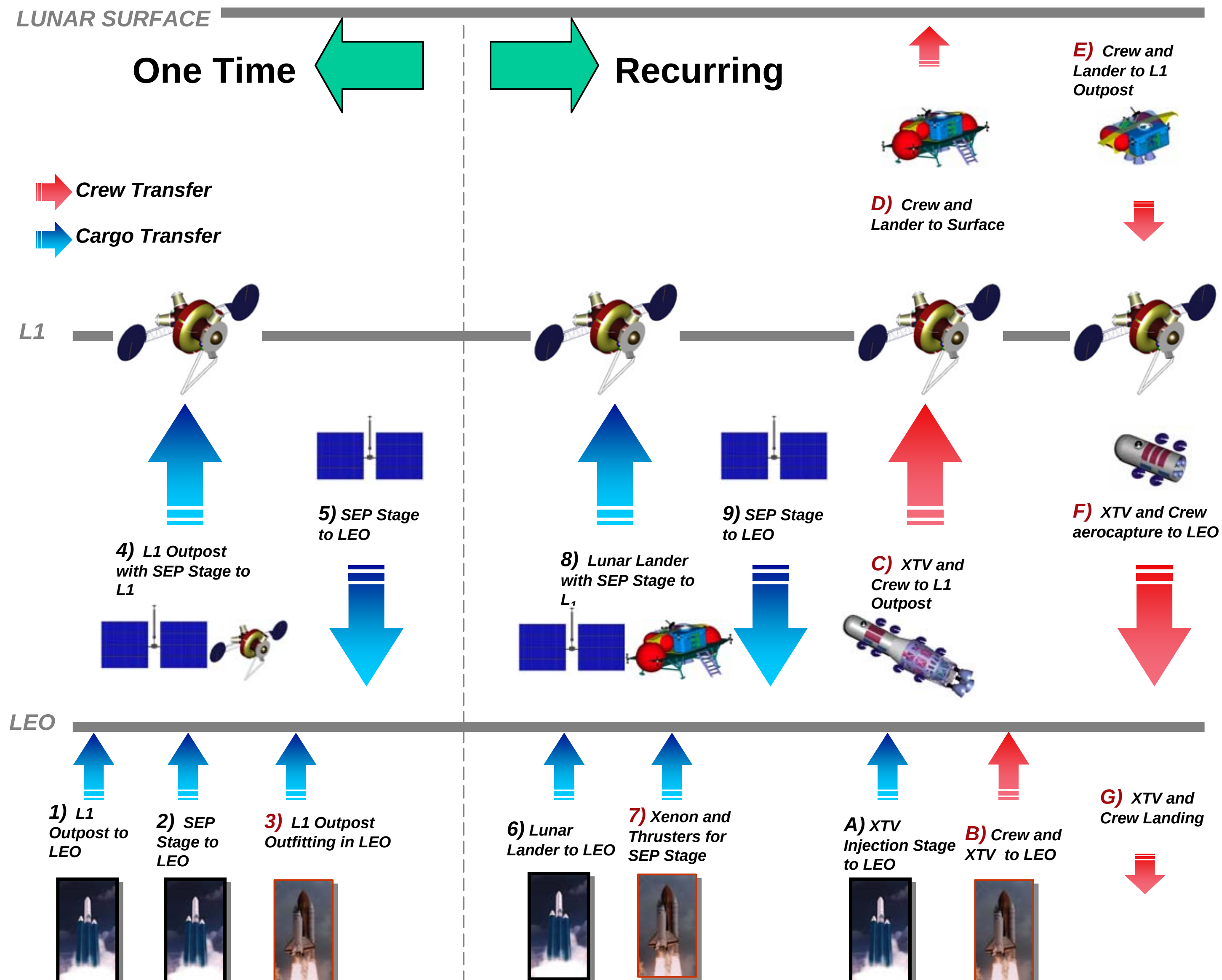
- Transports cargo elements and crew from Earth to low-Earth orbit
- Options:
  - Shuttle-derived
  - Evolved EELV



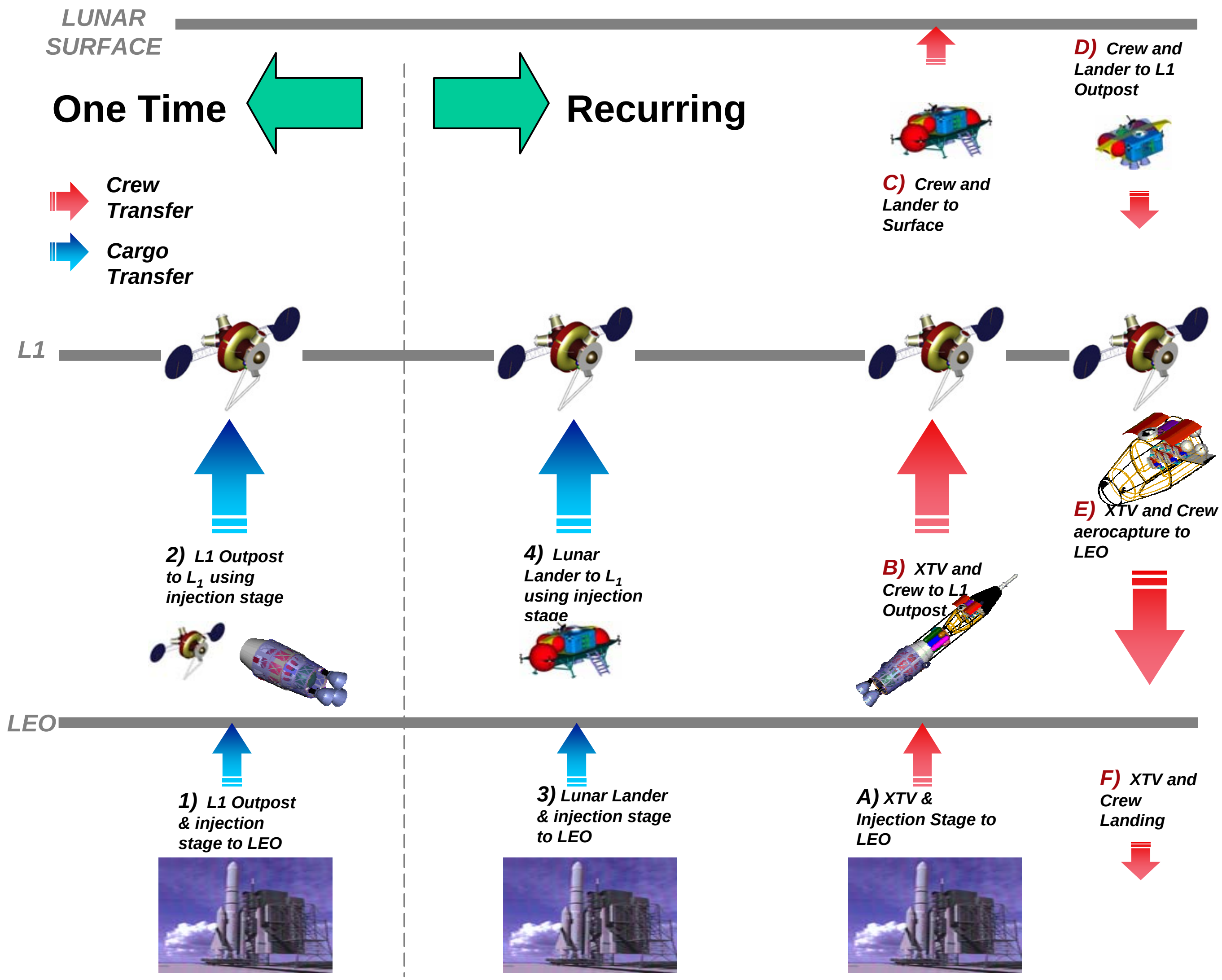
Earth Return

- High-energy aeroassist for orbital capture and entry of Earth's atmosphere
- Key Technologies & Options:
  - Advanced Ablators

Architecture A Launch Synopsis:
Lunar Exploration Mission

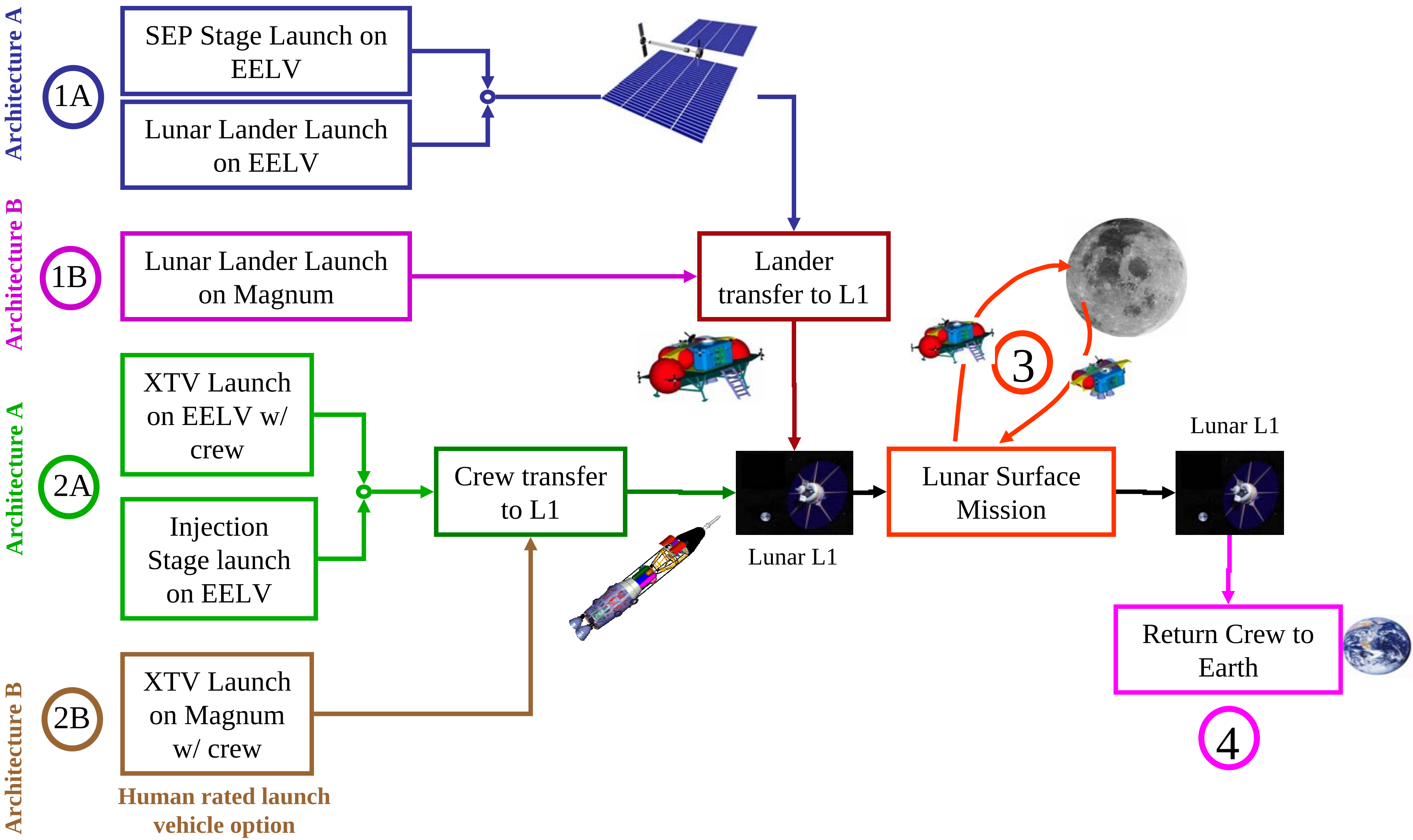


Architecture B Launch Synopsis:
Lunar Exploration Mission

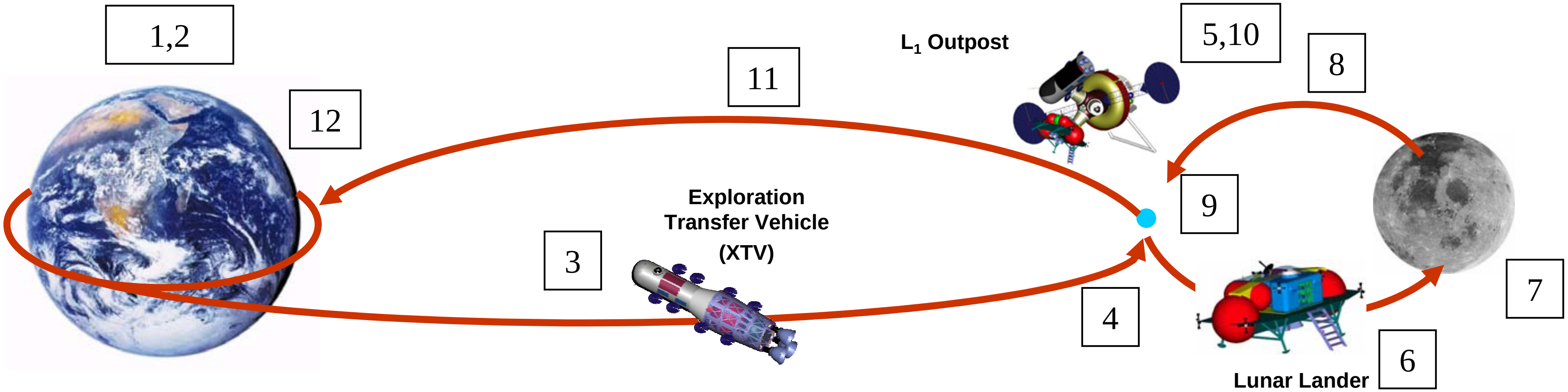


Human rated launch vehicle option

Lunar Surface Expedition Mission Events

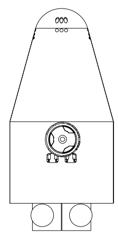


Mission Timeline Comparison:
3-Day Lunar Surface Mission



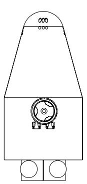
	Mission Phase	Phase Duration	Mission Elapsed Time
1A.	Injection Stage to LEO [Architecture A]	0 days	-24 days
	XTV w/ crew to LEO [Architecture A]	0 days	-3 days
	XTV Rendezvous & Dock w/ Injection Stage [Architecture A]	2.5 days	-0.5 days
1B.	XTV w/crew & Injection Stage Launch to LEO [Architecture B]	0 days	-0.5 days
2.	XTV Checkout in LEO	0.5 days	+0.0 days
3.	LEO to L1 Transit	3.5 days	+3.5 days
4.	Outpost Prox-Ops & Docking	1 day	+4.5 days
5.	Lunar Mission Prep. / Lunar Lander Checkout	2 days	+6.5 days
6.	L1 to Lunar Surface Transit	2.5 days	+9 days
7.	Lunar Surface Mission (3-day mission)	3 days	+12 days
8.	Lunar Surface to L1 Transit	2.5 days	+14.5 days
9.	Outpost Prox-Ops & Docking	1 day	+15.5 days
10.	Outpost Ops and XTV Checkout	2 days	+17.5 days
11.	L1 to LEO Transit & Aerocapture	3.5 days	+21.0 days
12.	Post-Aerocapture Ops to Landing	<0.5 day	+21.5 days

Common Crew Vehicle Design Capture



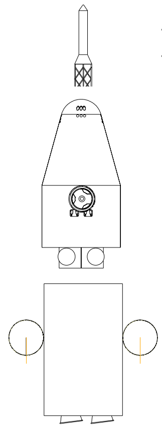
Core Crew Vehicle

- Common crew element satisfying multiple mission capabilities
- Key Design Requirements :
  - Re-configurable for 4-7 crew
  - Independent one day mission duration
  - Autonomous / manual operations
  - Propulsive orbital maneuvering
  - Controlled aerodynamic flight



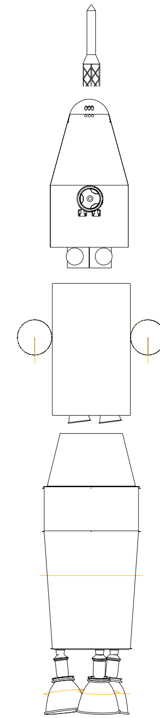
ISS Crew Return

- Provides safe and expeditious recovery of astronauts from low-Earth orbit
- Core Vehicle Configuration Changes:
  - Configured for 4 deconditioned crew
  - Medical emergency provisions
  - Emergency undock capability
  - ISS interfaces and six-month to two-year on-orbit stay
- Key Issues:
  - EELV launch compatibility including automated delivery to ISS
  - Degree of vehicle reusability



LEO Crew Transfer

- Crew transfer to low-Earth orbit and return
- Core Vehicle Configuration Changes:
  - Crew escape for aborts
  - Configured for 5 crew (3 ISS transfer)
  - 12 day mission duration for ISS support
- Service Module for extended mission duration (propulsion, power, thermal control, life support consumables)
- EVA systems for on-orbit satellite servicing and repair
- Key Issues:
  - EELV launch compatibility and human rating
  - Degree of vehicle reusability



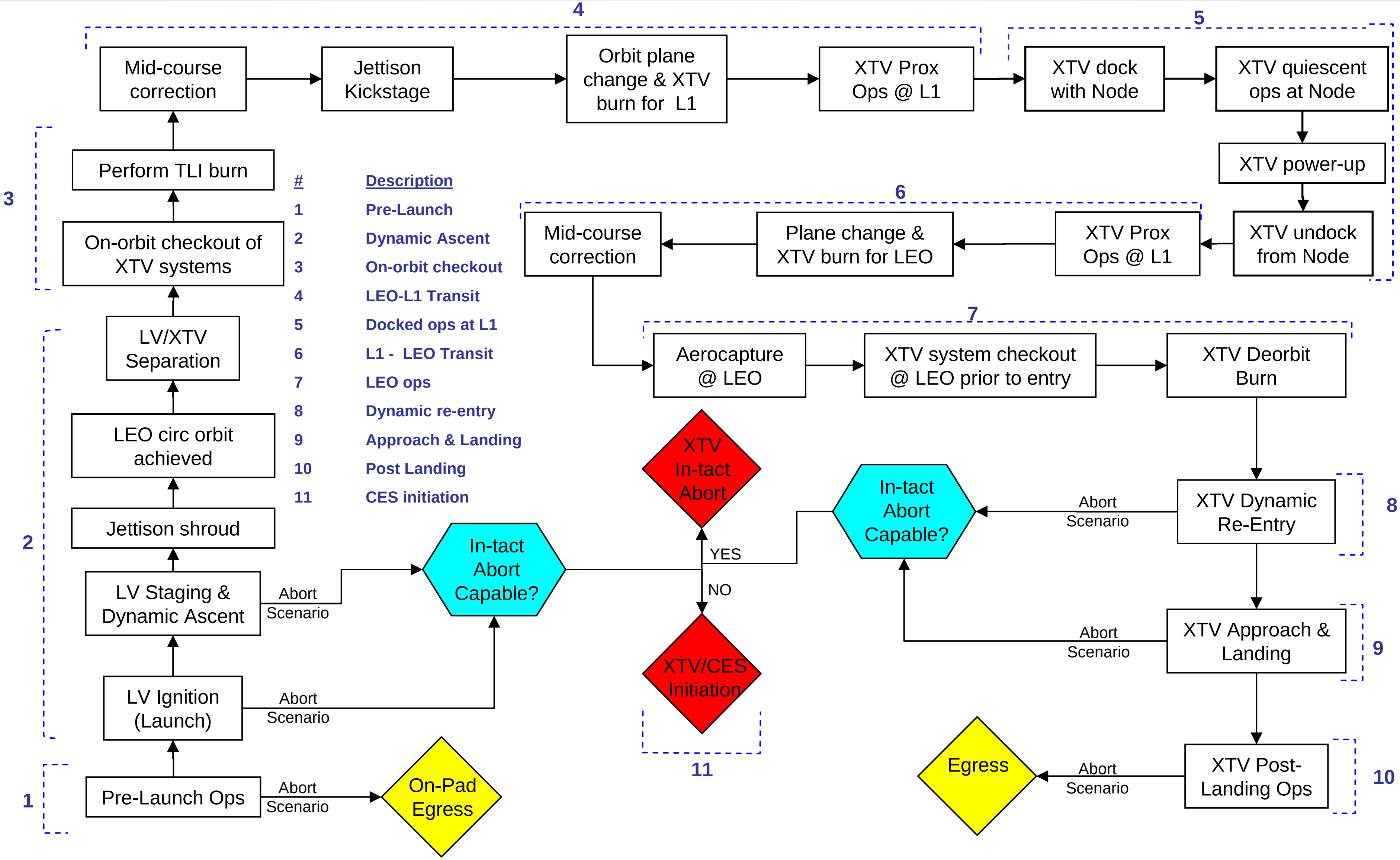
Near-Earth Transfer

- Transport crew to lunar vicinity and return to Earth
- Core Vehicle Configuration Changes:
  - Configured for 4-6 crew (mission dependent)
  - Crew escape for aborts
  - 12+8 day mission
  - Deep-space environmental conditions
- Service Module for extended mission duration (propulsion, power, thermal control, life support consumables)
- EVA systems for servicing and repair as required
- Injection stage for trans-lunar injection
- Key Issues:
  - Lunar return velocities
  - Large launch vehicle
  - Degree of vehicle reusability

XTV Capabilities Comparison

Architecture A	Architecture B
6 crew	6 crew (Room for 7)
Crew time in XTV = 12 days	Crew time in XTV = 12.5 days
ISS not used for XTV staging	ISS not used for XTV staging
XTV launched in STS or EELV to 400 km circ., 28.5^o inclination	XTV launched in Magnum to 278 km circ., 28.5^o inclination
Injection stage launched on EELV	Combined Injection stage and XTV launch
EELV payload capability to staging orbit = 40,000 kg	Magnum payload capability to staging orbit = 100,000 kg
XTV pressurized volume = 8.25 m^3/person	XTV pressurized volume = 8.25 m^3/person
XTV cargo = 300 kg	XTV cargo = 300 kg
Aero shape is an ellipsled	Aero shape is TBD

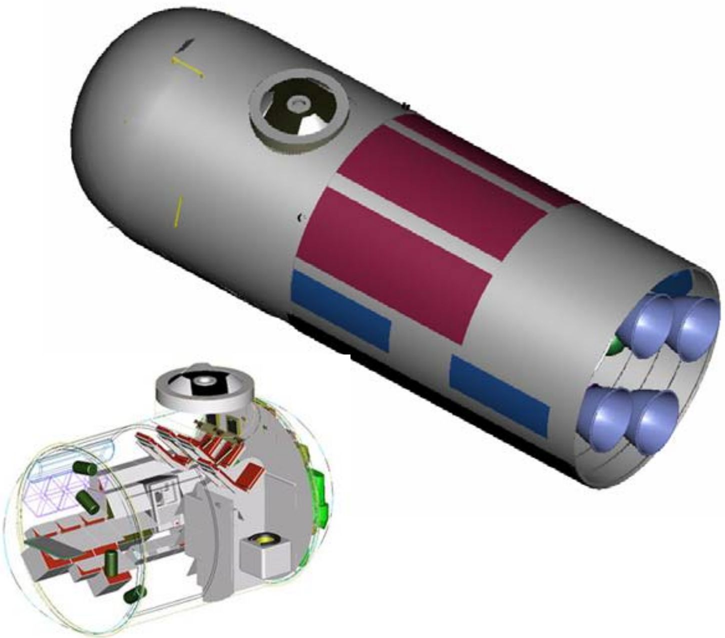
XTV Ops Event Flow to L1



#	Description
1	Pre-Launch
2	Dynamic Ascent
3	On-orbit checkout
4	LEO-L1 Transit
5	Docked ops at L1
6	L1 - LEO Transit
7	LEO ops
8	Dynamic re-entry
9	Approach & Landing
10	Post Landing
11	CES initiation

Exploration Transfer Vehicle:
Architecture A

- **Requirements**
  - **Launch in Space Shuttle or EELV**
  - **Utilize space storable propellants**
  - **Crew of six**
  - **Total ΔV capability of 1955 m/s**
  - **Nominal return mode of aerocapture followed by Earth entry and land landing**
  - **25% inert mass margin**
- **Current Concept**
  - **Integral LOX/CH_4 propulsion system**
  - **Slender-body, mid L/D shape for structural simplicity, good flying qualities, and lower stagnation point temperatures**
  - **PEM Fuel Cells for power generation**
  - **Parachute for descent and landing**
- **Launch Requirements for Mission to L1**
  - **XTV: 1 Shuttle/EELV**
  - **Injection Stage: 1 EELV**



	XTV
Dry Mass	9,971
Growth	2,493
Propellant	9,972
TOTAL	22,436

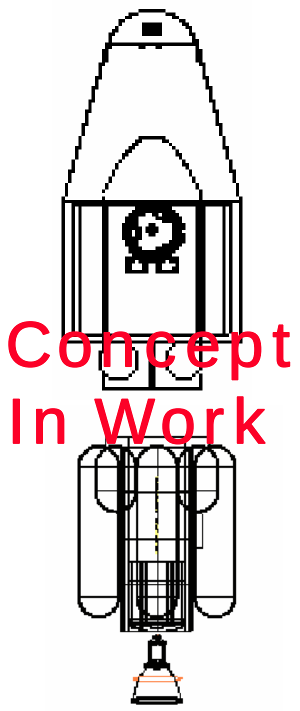
NOTE: All masses in kg

Exploration Transfer Vehicle:
Architecture B

- **Requirements**
  - **Launch on Magnum class vehicle**
  - **Utilize space storable propellants**
  - **Crew of six**
  - **Total ΔV capability of 1955 m/s**
  - **Nominal return mode of aerocapture followed by Earth entry and land landing**
  - **25% inert mass margin**

- **Current Concept**
  - **Crew Escape for human-rated launch option**
  - **Integral LOX/CH_4 propulsion system**
  - **Slender-body, mid L/D shape for structural simplicity, good flying qualities, and lower stagnation point temperatures**
  - **Service module for consumables storage**
  - **PEM Fuel Cells/Batteries/PV Arrays for power generation**

- **Launch Requirements for Mission to L1**
  - **XTV & Injection Stage: 1 Magnum**



	XTV
Dry Mass	15,060
Growth	3,760
Propellant	11,830
TOTAL	30,650

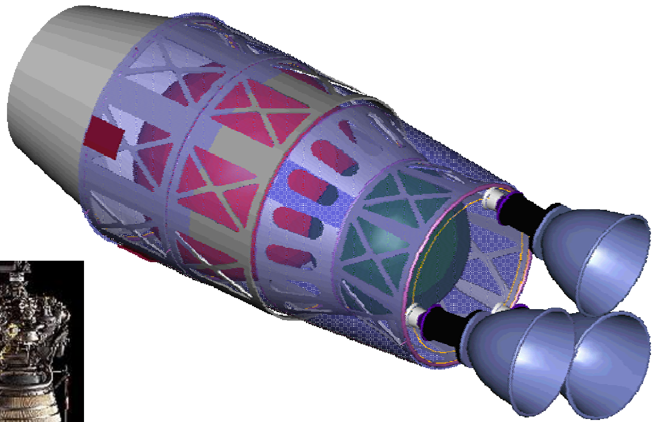
Injection Stage:
Architecture A

- **Requirements**
  - **Launch on EELV (40 mt/launch)**
  - **Utilize high performance cryogenic propellants**
  - **Capability to loiter in LEO for 21 days**
    - **Rationale: Launch timing for Architecture A; missed departure opportunities for LEO staging**
  - **Total ΔV capability of 3120 m/s for trans-L_1 injection from 400 km x 400 km LEO**
  - **20% inert mass margin**

	Resupply	XTV	Habitat	Lander
Payload	TBD	22,436	N/A	N/A
ΔV (m/s)	TBD	3,120	N/A	N/A
Dry Mass	TBD	5,360	N/A	N/A
Growth	TBD	1,340	N/A	N/A
Propellant	TBD	30,300	N/A	N/A
TOTAL	TBD	37,000	N/A	N/A

NOTE: All masses in kg

- **Current Concept**
  - **LOX/LH_2 propulsion system**
  - **Propellant storage via solar arrays and cryocoolers**
  - **Disposable blanket/MMOD shield**



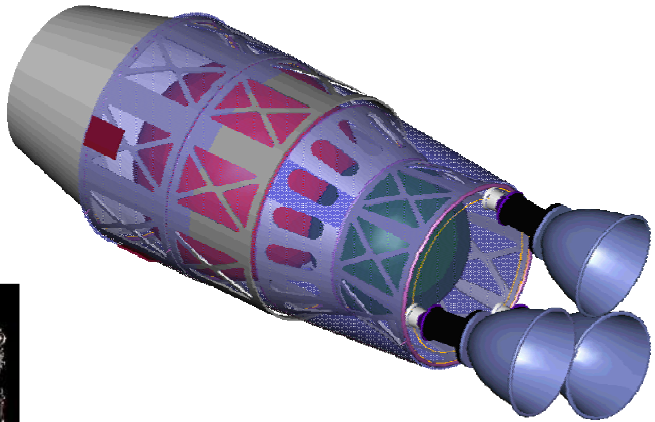
- **Launch Requirements for Mission to L1**
  - **Injection Stage: 1 EELV**
  - **XTV: 1 STS/EELV**

Injection Stage:
Architecture B

- **Requirements**
  - **Launch on Magnum class vehicle**
  - **Launch with other Architecture B elements**
  - **Utilize high performance cryogenic propellants**
  - **Total ΔV capabilities:**
    - **Lunar Habitat: 4052 m/s for 100 km LLO insertion from 278 km x 278 km LEO**
    - **Lunar Lander: 3254 m/s for low-energy weak-stability boundary trajectory to L_1 from 278 km x 278 km LEO**
  - **20% inert mass margin**
- **Current Concept**
  - **LOX/LH_2 propulsion system**
- **Launch Requirements**
  - **1 Magnum class vehicle**

	Resupply	XTV	Habitat	Lander
Payload	TBD	30,653	27,200	35,000
ΔV (m/s)	TBD	3,120	4,052	3,254
Dry Mass	TBD	5,930	6,860	6,220
Growth	TBD	1,180	1,370	1,240
Propellant	TBD	40,100	57,460	49,180
TOTAL	TBD	47,210	65,690	56,640

NOTE: All masses in kg

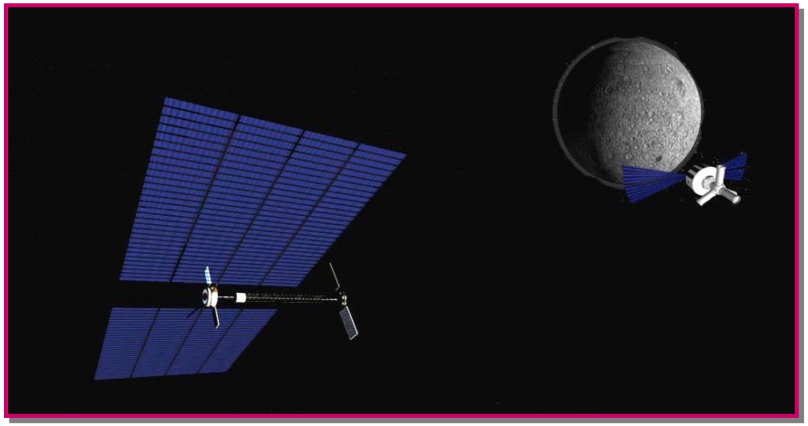


Injection Stage Trades:
Architecture B

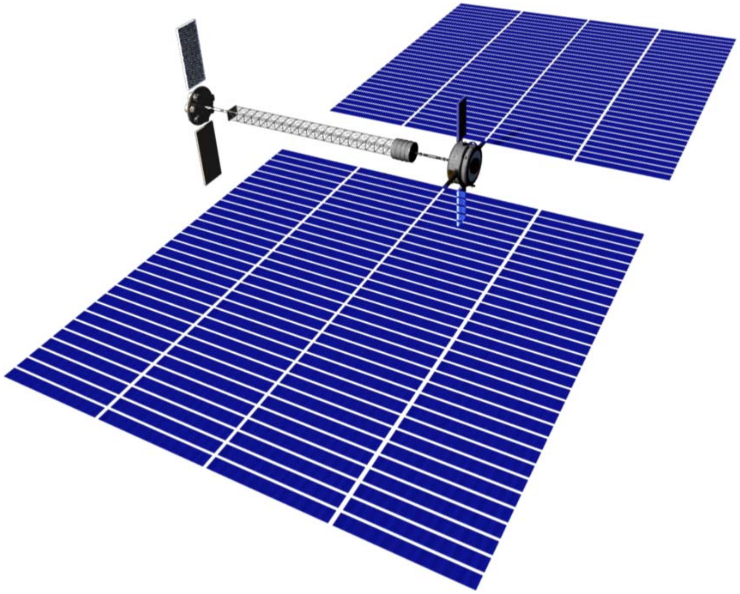
	Direct Insertion			Weak Stability Boundary		
Element	XTV	Lander	Habitat	XTV	Lander	Habitat
Departure Point	LEO 278 km circ	LEO 278 km circ	LEO 278 km circ		LEO 278 km circ	LEO 278 km circ
Destination	L1	L1	LLO 100 km circ		L1	LLO 100 km circ
ΔV (m/s)	3,120	3,905	4,052		3,254	3,862
Payload Mass (kg)	30,653	35,000	27,200		35,000	27,200
Trip Time	82 hrs	82 hrs	96 hrs		90-180 days	90-180 days
Injection stage Mass (kg)	**47,210**	**77,340**	**65,690**		**56,640**	**60,130**
Propellant	40,100	67,910	57,460		49,180	52,430
Dry mass	5,930	7,860	6,860		6,220	6,410
Margin	1,180	1,570	1,370		1,240	1,280
Total Launch Mass (kg)	**77,860**	**112,340**	**92,890**		**91,640**	**87,330**

Solar Electric Propulsion Stage
[Architecture A Only]

Mission: High-efficiency solar electric propulsion (SEP) is used in the Earth's Neighborhood architecture to deliver uncrewed elements from low-Earth orbit to a final destination. The SEP Stage subsequently returns to Earth for reuse.



- **Destination:** **LEO/Lunar L_1**
- **Element Design Lifetime:** **2-5 missions**
- **Crew Size:** **N/A**
- **Mission Duration:** **170 days out/50 back**
- **Element Mass:**
  - **Stage:** **35,000 kg**
  - **Payload:** **30,000 kg**
  - **Post-outfitting:** **65,000 kg (145,000 lb)**
- **Element Volume:**
  - **PV Array Area** **7,300 m^2**
- **Power & Propulsion System:**
  - **Average/Peak:** **580 kWe**
  - **Power Generation:** **Photovoltaic Arrays**
  - **Energy Storage:** **Batteries**
  - **Propellant:** **Xenon**
- **Support Missions:**
  - **Propellant resupply:** **Every mission**
  - **Electric Thrusters:** **Every mission**

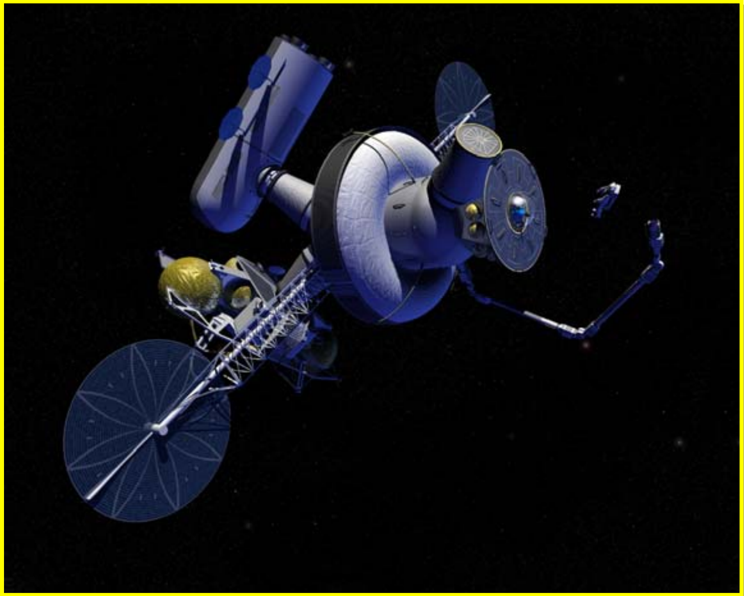


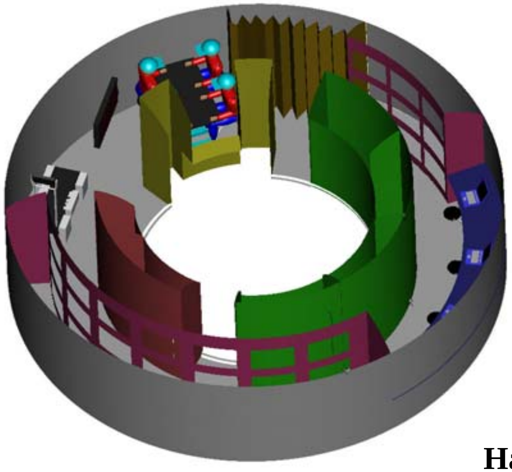
Lunar L1 Outpost

[Architectures A & B]

Mission: The Lunar L_1 Outpost is a mission staging and crew habitation platform stationed at the Lunar L_1 libration point for assembling and maintaining large astronomical observatories and conducting expeditions to the lunar surface.

- **Destination:** **Lunar L_1**
- **Element Design Lifetime:** **15 yrs**
- **Crew Size:** **4 persons**
- **Mission Duration:** **10-30 days**
- **Element Mass:**
  - **Launch:** **22,800 kg**
  - **Outfitting:** **600 kg**
  - **Post-outfitting:** **23,400 kg (52,000 lb)**
- **Element Volume:**
  - **Launch:** **145 m^3**
  - **Inflated:** **275 m^3**
- **Power & Propulsion System:**
  - **Average/Peak:** **12 kWe/15 kWe**
  - **Power Generation:** **Photovoltaic Arrays**
  - **Energy Storage:** **Li-ion Batteries**
  - **Propellant:** **O_2/CH_4**
- **Support Missions:**
  - **Outfitting at LEO:** **One mission/architecture**
  - **Life Support resupply:** **One mission/two years**



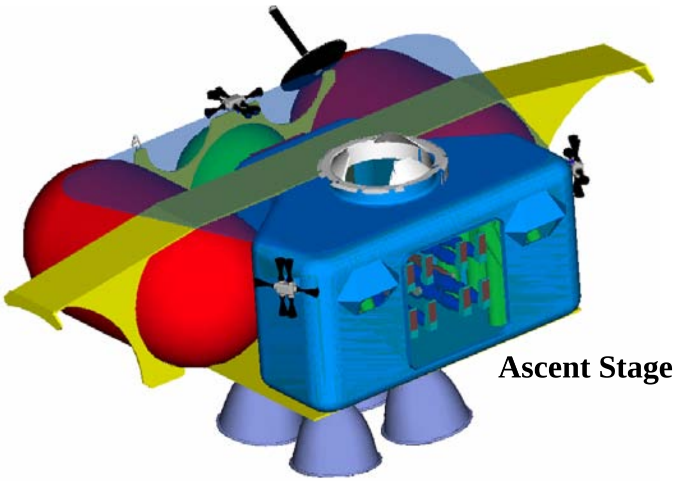


Hab Layout

Lunar Lander
[Architectures A & B]

Mission: The Lunar Lander is capable of delivering a crew of four to any site on the lunar surface and supporting that crew for three days on the surface. The Lander returns the crew to L1 at the end of the mission.

- **Destination:** **Lunar L_1/Lunar Surface**
- **Element Design Lifetime:** **1 mission**
- **Crew Size:** **4 persons**
- **Mission Duration:** **8 days (3 on Moon)**
- **Element Mass:**
  - **Propellant:** **26,900 kg**
  - **System Mass:** **8,000 kg**
  - **Total:** **34,900 kg (77,000 lb)**
- **Element Volume:**
  - **Pressurized:** **21 m^3**
  - **Habitable:** **16 m^3**
- **Power & Propulsion System:**
  - **Average:** **1.3 kWe/3.1 kWe**
  - **Power Generation:** **PEM Fuel Cells**
  - **Propellant:** **O_2/CH_4**
- **Support Missions:**
  - **None (Disposable Vehicle)**

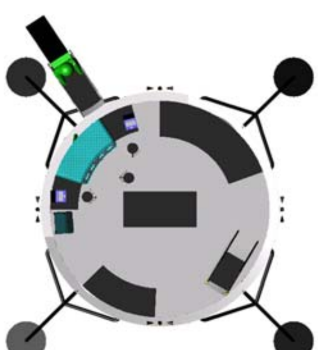


Ascent Stage

Lunar Habitat
[Architectures A & B]

Mission: Long-duration planetary surface missions are enabled in the Earth's Neighborhood architecture through the use of a Lunar Habitat pre-deployed to the lunar polar regions. Mission crews are delivered to the Lunar Habitat and return to L1 via the Lunar Lander.

➢ **Destination:**	**Lunar Surface (North or South Pole)**
➢ **Crew Size:**	**4 persons**
➢ **Mission Duration:**	**30 days**
➢ **Element Mass:**	
▪ **Propellant:**	**14,300 kg**
▪ **System Mass:**	**12,900 kg**
▪ **Total:**	**27,200 kg (60,000 lb)**
➢ **Element Volume:**	
▪ **Pressurized:**	**240 m^3**
➢ **Power & Propulsion System:**	
▪ **Average:**	**2.4 kWe/4.1 kWe**
▪ **Power Generation:**	**Photovoltaic Arrays**
▪ **Energy Storage:**	**Li-ion Batteries**
▪ **Propellant:**	**O_2/CH_4**
➢ **Support Missions:**	
▪ **Human Consumables**	**Every mission**



Mission Element Summary:

Architecture A

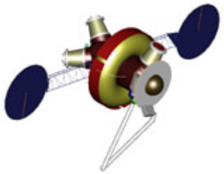
L1 Lunar Lander

Number of crew: 4
Mission duration: 8 days
Launch mass: ~35,000 kg
Mission: L1 to Moon to L1
Number of launches: 1 EELV per lander

Exploration Transfer Vehicle

Number of crew: 6
Mission duration: 12 days
Launch mass: 22,440 kg
Mission: LEO to L1 to Earth
Number of launches for element: 1 STS

L1 Outpost

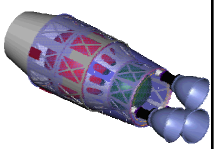


Number of crew: 6
Mission duration: Indefinite
Launch mass: 22,900 kg
Mission: LEO to L1
Number of launches: 1 EELV and 1 STS (for outfitting)

Lunar Habitat

Number of crew: 4
Mission duration: 30 days
Launch mass: 27,200 kg
Mission: LEO to Moon
Number of launches: 1 EELV

Injection Stage



Number of crew: N/A
Mission duration: 14 days (loiter)
Payload: Lunar Transfer Vehicle
Launch mass: 37,000 kg
Mission: LEO to L1
Number of launches for element: 1 EELV

Solar Electric Propulsion Stage

Number of crew: N/A
Payload: Lander, Hab, Outpost
Launch mass: ~35,000 kg
Mission: LEO to L1 to LEO
Number of launches: 1 EELV and 1 STS (recurring)

Mission Element Summary:

Architecture B

L1 Lunar Lander

Number of crew: 4

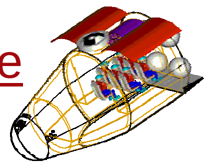
Mission duration: 8 days

Launch mass: ~35,000 kg

Mission: L1 to Moon to L1

Number of launches: 1 Magnum launch per lander

Exploration Transfer Vehicle



Number of crew: 6

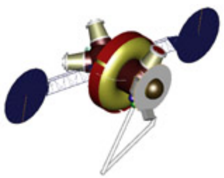
Mission duration: 12.5 days

Launch mass: 30,650 kg

Mission: LEO to L1 to Earth

Number of launches: 1 Magnum launch per mission

L1 Outpost



Number of crew: 6

Mission duration: Indefinite

Launch mass: 22,900 kg

Mission: LEO to L1

Number of launches: 1 Magnum launch

Lunar Habitat

Number of crew: 4

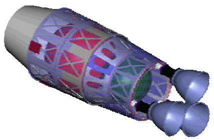
Mission duration: 30 days

Launch mass: 27,200 kg

Mission: LEO to Moon

Number of launches: 1 Magnum launch

Injection Stage



Number of crew: N/A

Mission duration: 14 days (loiter)

Launch mass: 65,690 kg

Mission: LEO to L1

Number of launches: 1 Magnum

*Note: Injection stage sized for Lunar Habitat to LLO

Advanced Concept Analysis in Support of the Integrated Space Plan

Section 4.1.2

Exploration Architecture Analysis
Mars

November 2002

Outline

- **Introduction & Architecture Considerations**
  - Trade Space & Decision Tree
- **Earth's Neighborhood**
  - Requirements
  - Mission Modes
    - Mission Staging Points
    - Earth Entry Descent & Landing Mode
    - Utility of ISS
  - General Architecture Concept
  - Architecture Analysis
    - Architectures A & B
    - Element Design
- **Mars**
- **Summary & Conclusions to Date**

Exploration of Mars Objectives

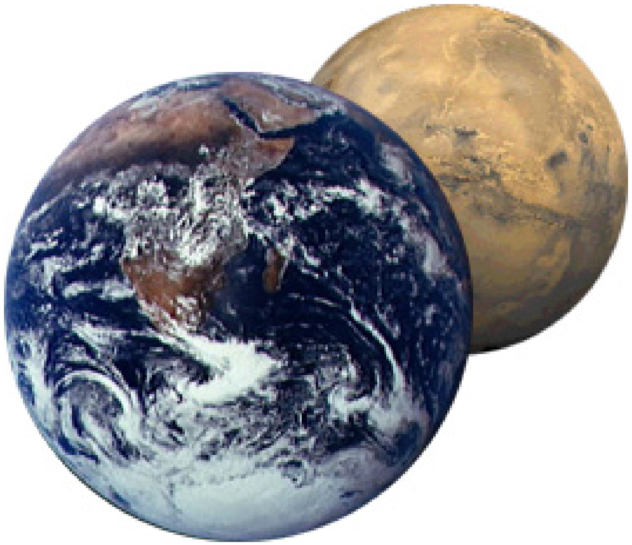


Chart Our Destiny

- Send explorers to the limits of technology
- Understand the solar system forces and processes that affect the future habitability of Earth
- Find extraterrestrial resources of human interest
- Assess suitability of selected planetary locales for future human exploration and commercialization
- Conduct in-depth scientific investigations

Origin of Life and its Existence Beyond Earth

- Understand the sources and reservoirs of water and organics … the building blocks of life
- Determine the planetary conditions required for the emergence of life
- Search for evidence of past and present life elsewhere in the solar system

Solar System Formation and Evolution

- Understand the origin of the solar system and the forces that formed Earth and the other planets
- Determine the evolutionary processes that led to the diversity of solar system bodies and the uniqueness of the planet Earth
- Use the exotic worlds of our solar system as natural science laboratories

Mars Mission Goals and Objectives

Goals and Objectives

- Balance technical, programmatic, and safety risks
- Maximize scientific return
- Provide an operationally simple mission
- Develop a flexible implementation strategy
- Maximize human health and safety
- Low mission mass

Groundrules and Assumptions

- Examine multiple missions to Mars
- Programmatic assumption of first human mission in 2018, with cargo in 2016
- Insure that the systems are capable of operating in each injection opportunity through the 15-year synodic cycle
- Crew size should be minimized, but sufficient to meet science and operational needs
- Do not assume that crews return to the same site

Mission Design Considerations

Mission Class

- Short-Stay (opposition class)
- Long-Stay (conjunction class)

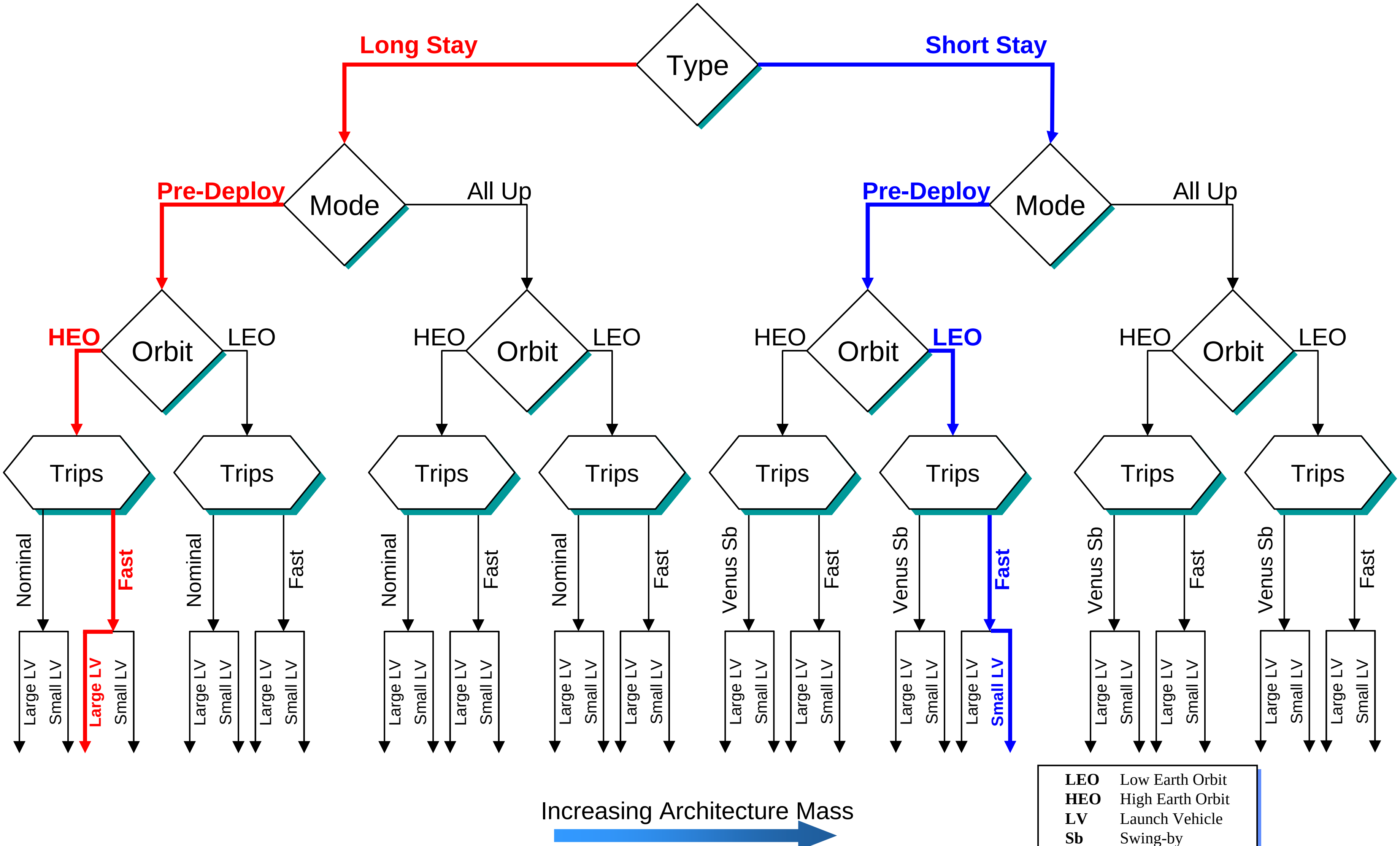
Crew Risk Exposure

- Zero-gravity
- Radiation
- Mission duration

Other Considerations

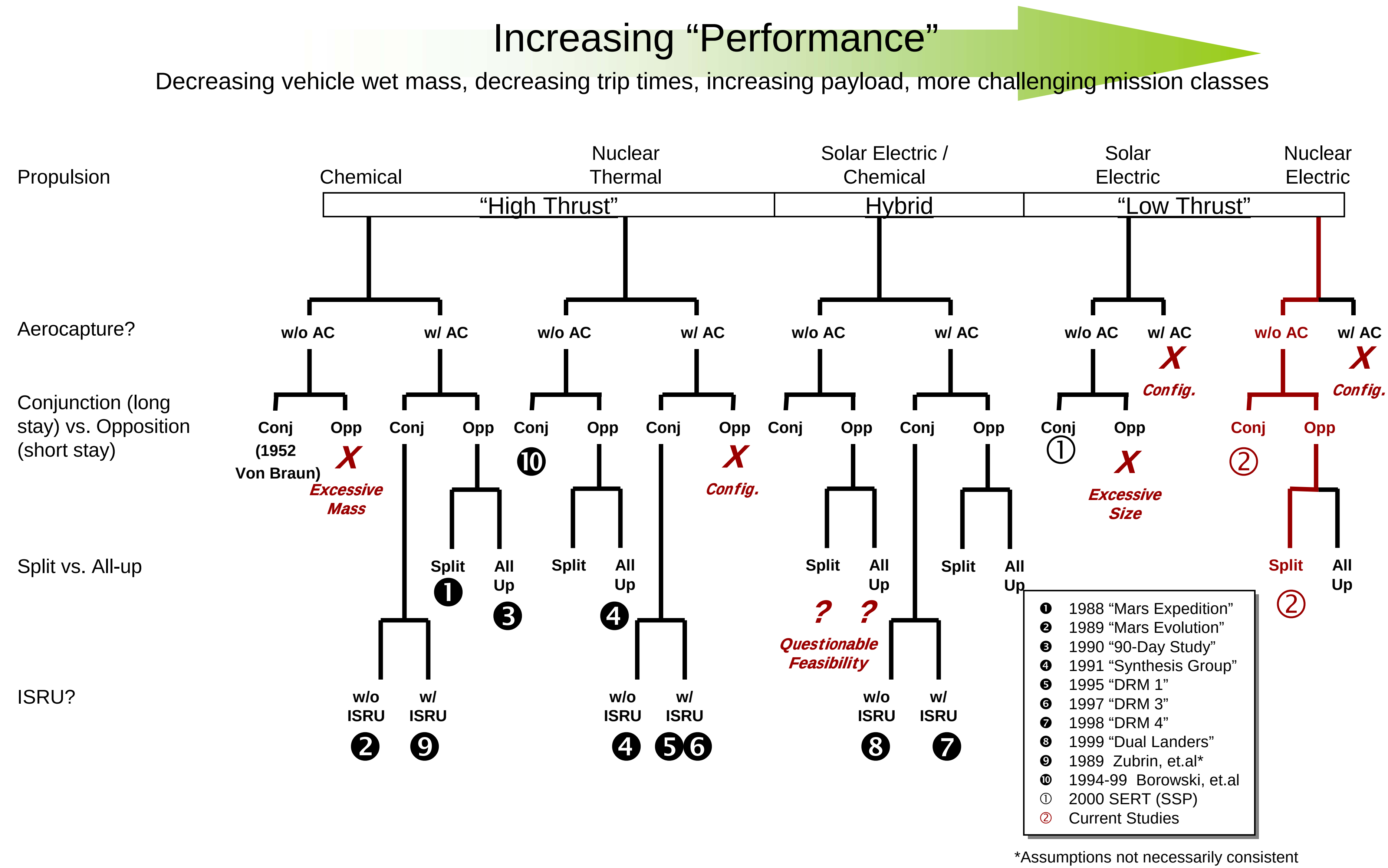
- Mission aborts
- Mission mass and launch strategy
- Pre-deployment (spilt mission) strategies
- Technology assumptions
- Departure and staging scenarios

Example Human Mars Mission Decision Tree

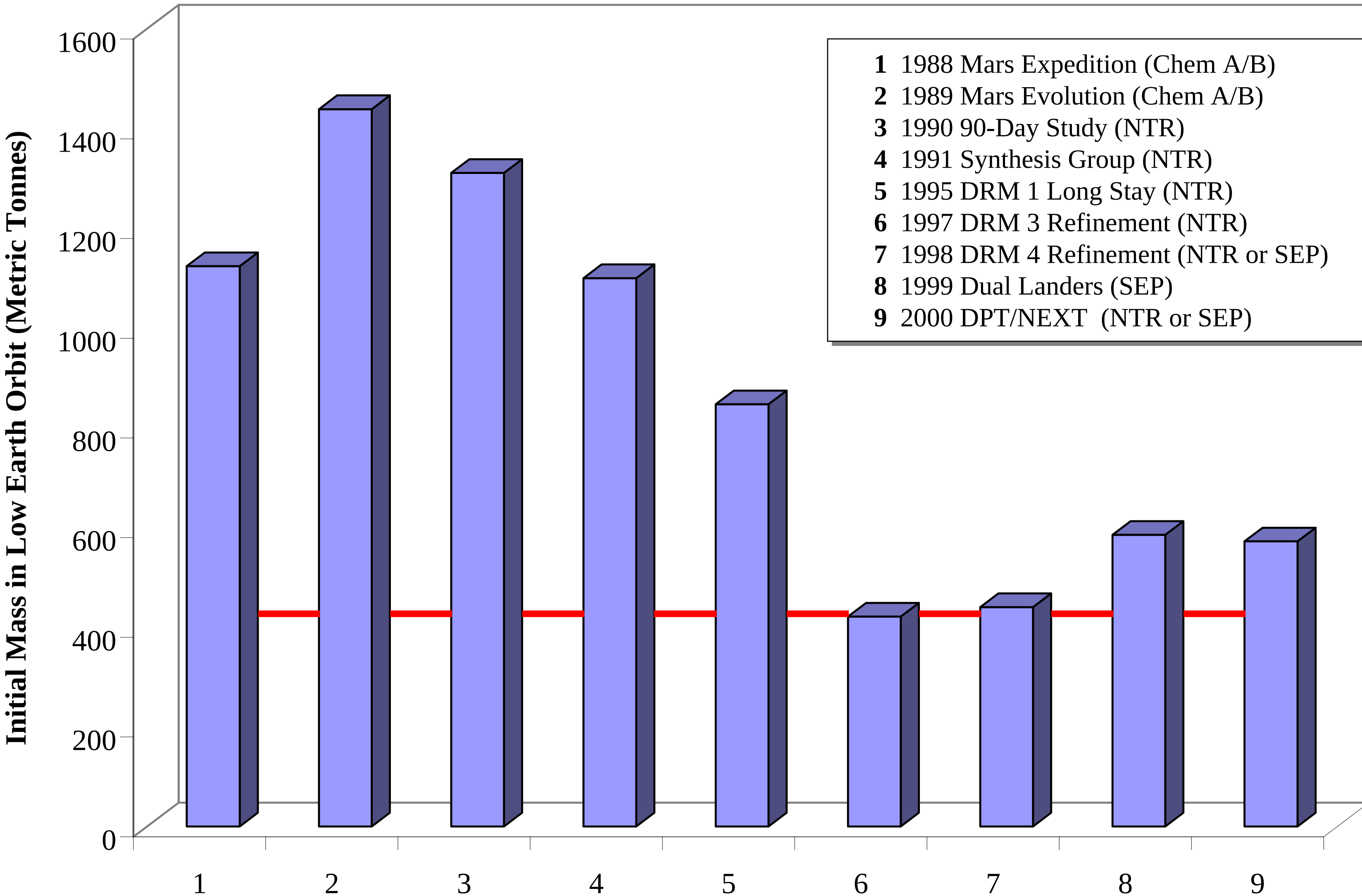


LEO	Low Earth Orbit
HEO	High Earth Orbit
LV	Launch Vehicle
Sb	Swing-by

Mars Mission Trade Space



Mars Architecture Mass History



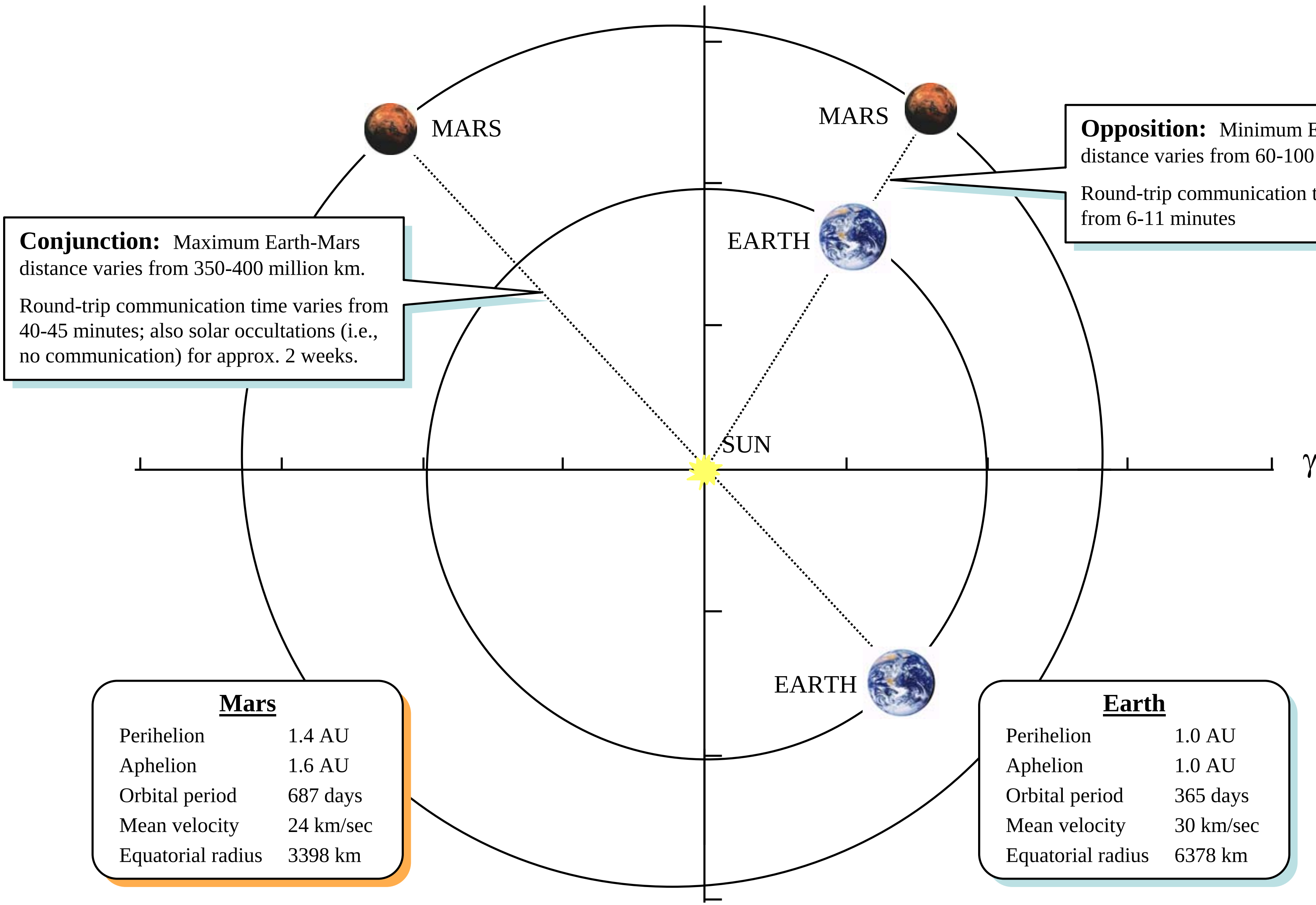
ISS @ Assembly Complete (470 tons)

Mars Mission Planning

- Earth-Mars Mission Planning
  - Trips to Mars and back are, in effect, a double rendezvous problem
  - First rendezvous outbound (with Mars) must be developed considering influence of the rendezvous inbound (with Earth)
  - Practical considerations dictate favorable (and different) planetary alignments relative to the sun for both transfers

- Synodic Period
  - is the period of time necessary for the phase angle between Earth and Mars to repeat itself
  - Repetition rate for identical Earth-Mars phasing, and therefore launch opportunities for similar mission classes, is ~26 months
  - The eccentricity of Mars' orbit causes significant variations in Earth-Mars relative distance and velocity from one opportunity to the next
  - The entire range of Earth-Mars geometry is encompassed by seven launch opportunities, or about 15 years
  - Before definitive claims of mission characteristics or propulsion system capabilities are made, analysis across the 15-year cycle should be performed

Earth-Mars Orbital Characteristics



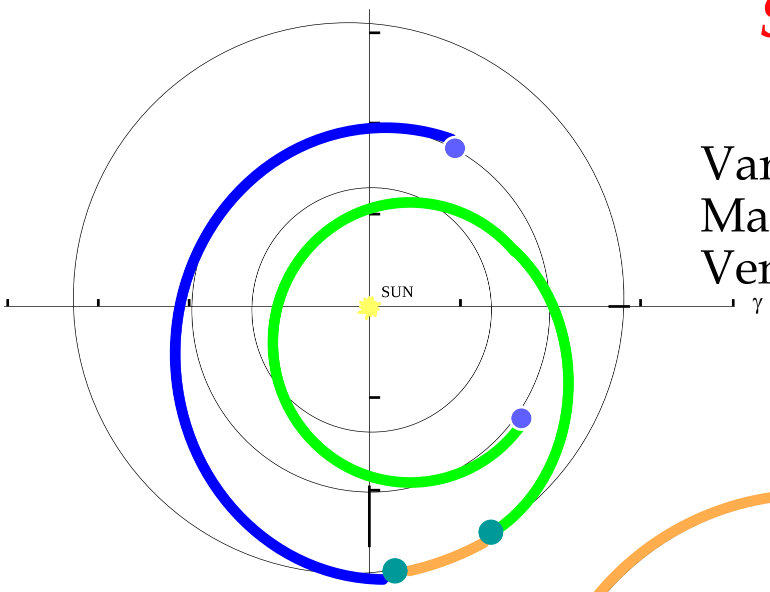
Mars

Perihelion	1.4 AU
Aphelion	1.6 AU
Orbital period	687 days
Mean velocity	24 km/sec
Equatorial radius	3398 km

Earth

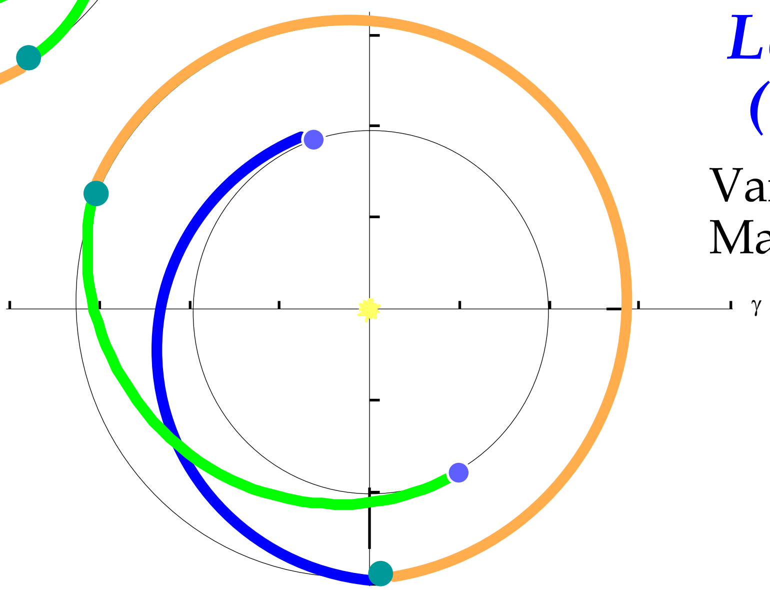
Perihelion	1.0 AU
Aphelion	1.0 AU
Orbital period	365 days
Mean velocity	30 km/sec
Equatorial radius	6378 km

Mars Mission Trajectory Options



Short-Stay Missions (Opposition Class)

Variations of missions with short Mars surface stays and may include Venus swing-by



Long-Stay Missions (Conjunction Class)

Variations of missions with long Mars surface stays.

Outbound
Surface Stay
Inbound

Short-Stay Mission Implications

- *Significant variation of propulsion requirements for the Short-Stay mission across synodic cycle (100%) dictates need for advanced propulsion technology*
  - Nuclear Thermal Propulsion
  - High-Power Electric Propulsion

- *Short stay in the vicinity of Mars can compromise mission return and crew safety*
  - Limited time for gravity-acclimation
  - Limited time for contingencies or dust storms
  - Majority of time spent in deep space (zero-gravity & deep space radiation)

- *Total mission duration for the Short-Stay Mission on the order of 12-22 months*
  - System reliability still critical to mission success and crew safety
  - Short (one-year) missions are possible, but limited to single opportunities over the 15-year synodic cycle

- *Venus swing-by's can reduce propulsive requirement (and thus mission mass)*
  - Pass within 0.72 AU of the sun (increases radiation and thermal load)

Long-Stay Mission Implications

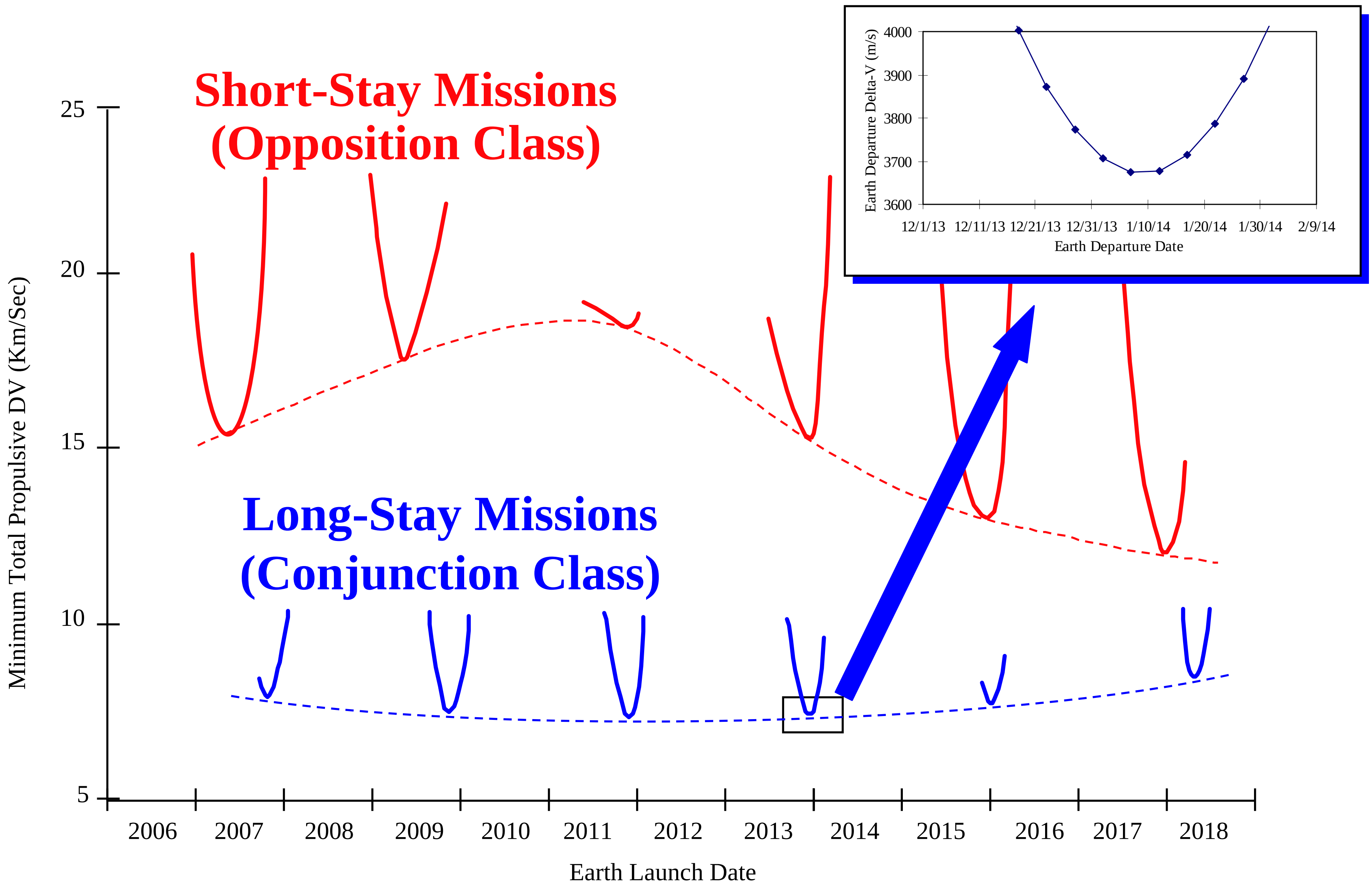
- *Small variation (10%) of propulsion requirement for the Long-Stay mission across the 15-year synodic cycle*
  - Can go any opportunity
  - Vehicles and systems common between opportunities

- *Long-Stay mission trip times can be reduced for minimal impacts, thus reducing life science concerns of deep space travel (radiation and zero-gravity exposure)*

- *Long stay in the vicinity of Mars increases mission return*
  - Sufficient time for gravity-acclimation
  - Sufficient time for dust storms or other contingency situations
  - Majority of time spent on Mars (improved gravity and radiation environment)

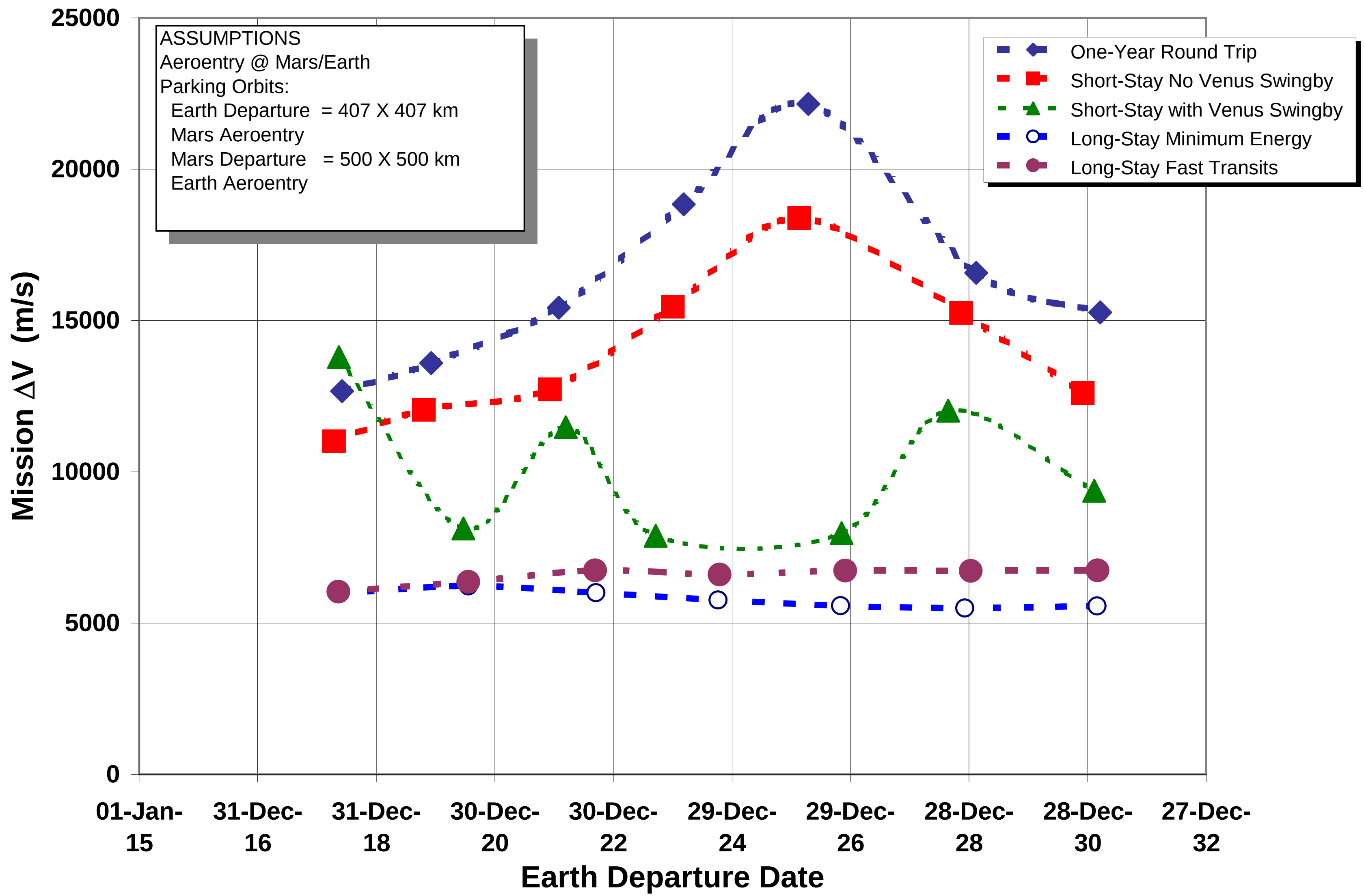
- *Total mission duration on the order of 30 months*
  - System reliability still critical to mission success and crew safety

Delta-V Variations



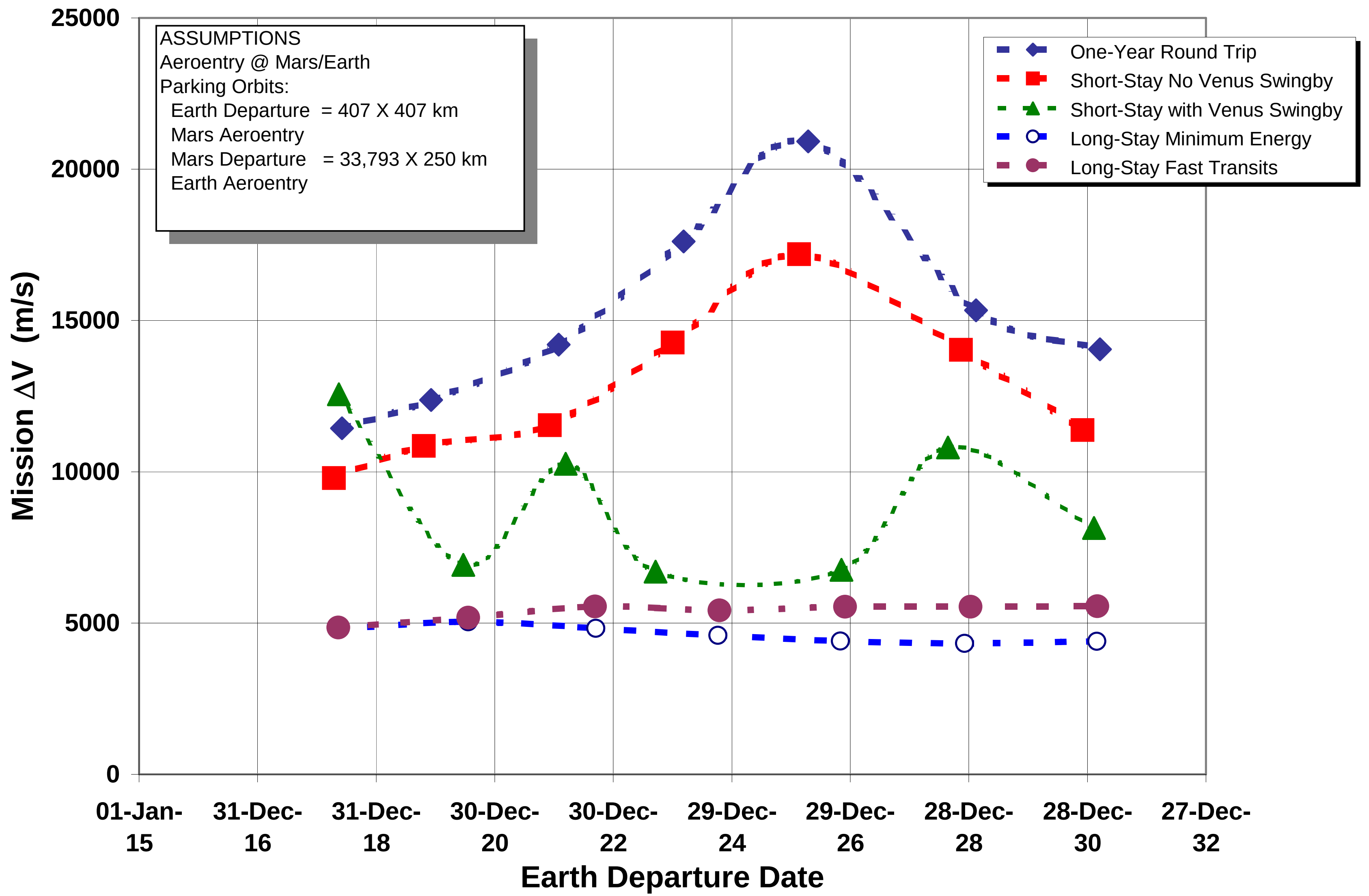
Total Mission ΔV vs Earth Departure Date

Low-Earth Orbit Departure



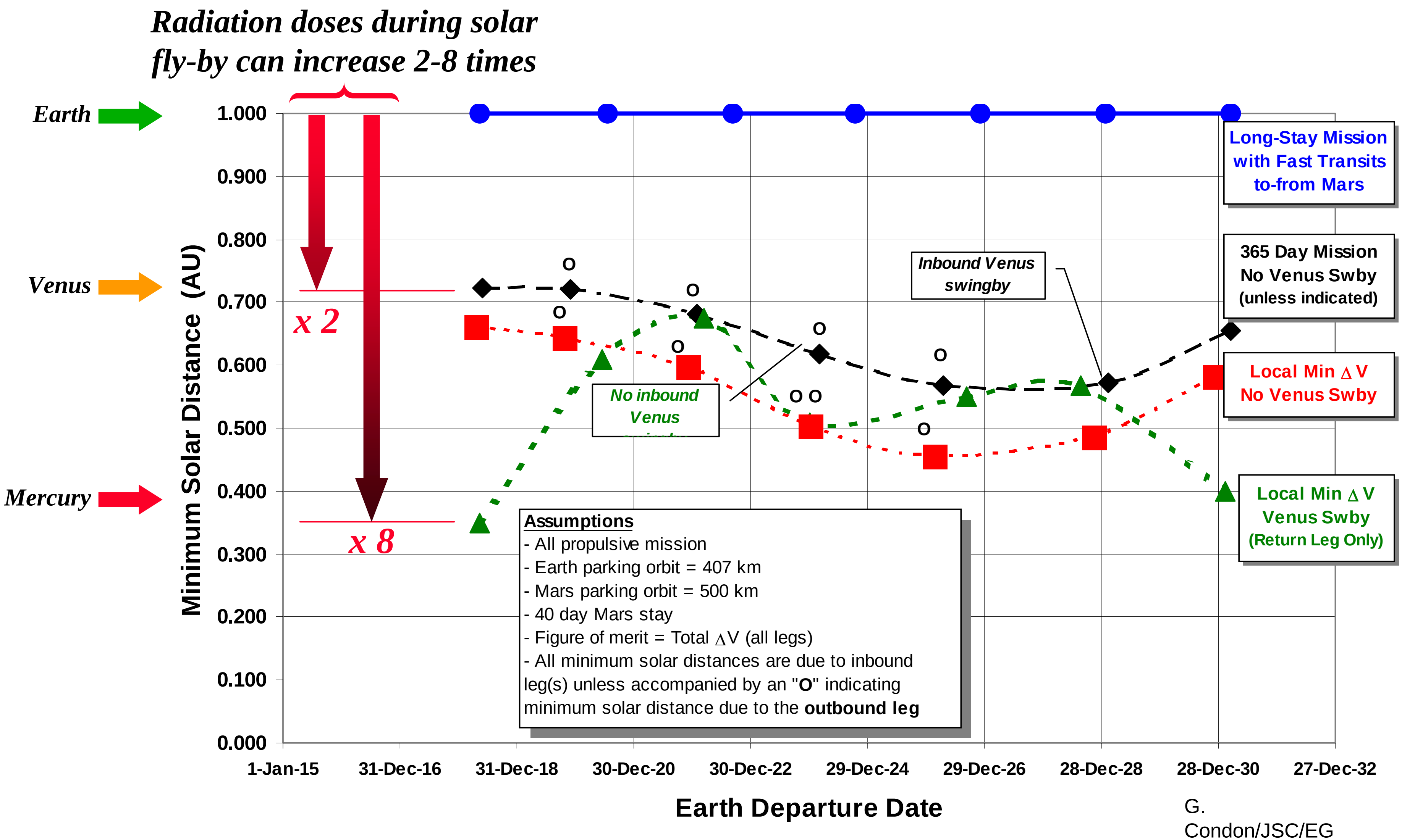
Total Mission ΔV vs Earth Departure Date

High-Earth Orbit Departure



Minimum Solar Distance vs. Mission Opportunity

Short-Stay Mars Missions



Mission Characteristic Comparisons

Parameter	Short-Stay Mission	Long-Stay Mission
Mission Duration (days)	365-661	892-945
Surface Stay	30	501-596
One-Way Transits	104-357	134-210
Total Transit Time	335-631	296-413
Trajectory Characteristics	Venus Swing-by	No Venus Swing-by
Closest Approach to Sun [1]	0.35 – 0.72 AU	1.0 AU
Total Mission Mass (mt)	500-1200 [2]	400-700 [3]
% Vehicles	21% [2]	31% [3]
% Propellant	74% [2]	47% [3]
% Surface Systems	5%	22%

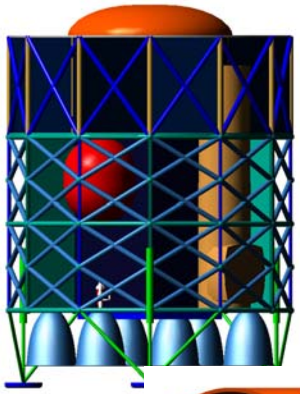
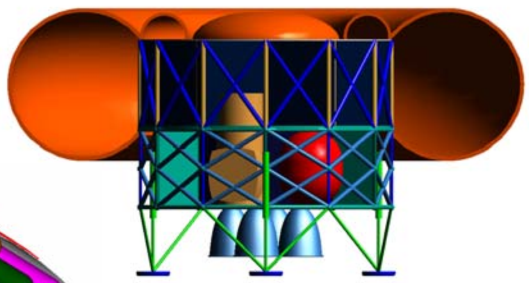
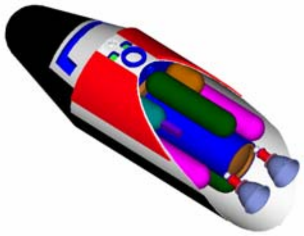
1 Assuming Nuclear Thermal Propulsion (Isp 925 sec)
2 First Piloted Flight - 90 Day Study
3 First Piloted Flight - Mars Design Reference Mission

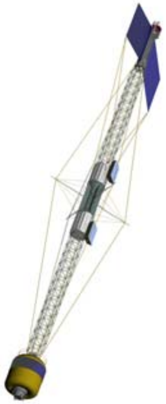
Technology and Mission Implications

	Short-Stay	Long-Stay
Transportation	• Advanced propulsion required for reasonable mass	• Advanced propulsion enhances missions (lower mass or shorter transits)
Earth-to-Orbit	• Large mission mass necessitates high launch rate and/or larger launcher	• Lower mission mass relieves launch requirement and launch rate
Human Health	• Certification process of long zero-g space missions unknown • Crew exposure to surface environment minimized	• Mission transits within US zero-g spaceflight experience • Extended exposure of crew to surface environment
System Reliability	• Similar (12-22 months)	• Similar (30 months)
Mission Focus	• Transportation and propulsion	• Surface and mission return

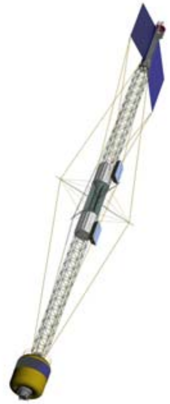
Mars Architecture Key Attributes

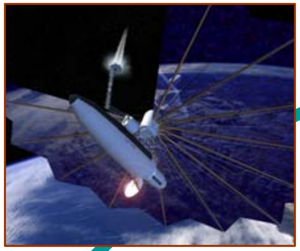
- Crew of 4-6
- Short (30-day) initial visits for focused local science evolving to long (500-day) stays for extensive regional exploration
- Total mission durations range from 365 to 950 days.
- Capability to go to Mars any opportunity
- Maximum use of capabilities developed for Earth's Neighborhood
- Ability to introduce new technologies as they are developed
- Advanced transportation and enhanced launch capacity required to reduce risk and architecture cost

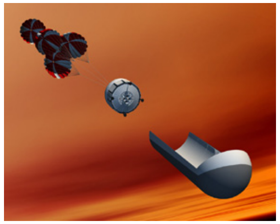


Mars Exploration Transportation Elements



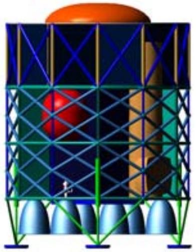


Aeroassist
- Utilization of Mars atmosphere for capture, entry, and descent
- Key Technologies & Options:
  - Advanced Ablators
  - Integrated Launch Shroud / Aeroshell



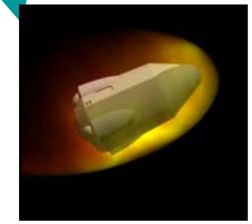
In-Space Transportatoin
- Deep-space propulsion for element delivery and return to Earth
- Key Technologies & Options:
  - Nuclear Electric Propulsion
  - Solar Electric Propulsion
  - Advanced Chemical

Descent / Ascent
- Deep-space propulsion for descent to, and ascent from, the martian surface
- Key Technologies & Options:
  - Advanced Chemical (CH_4/O_2)
  - Long-term Cyro Storage

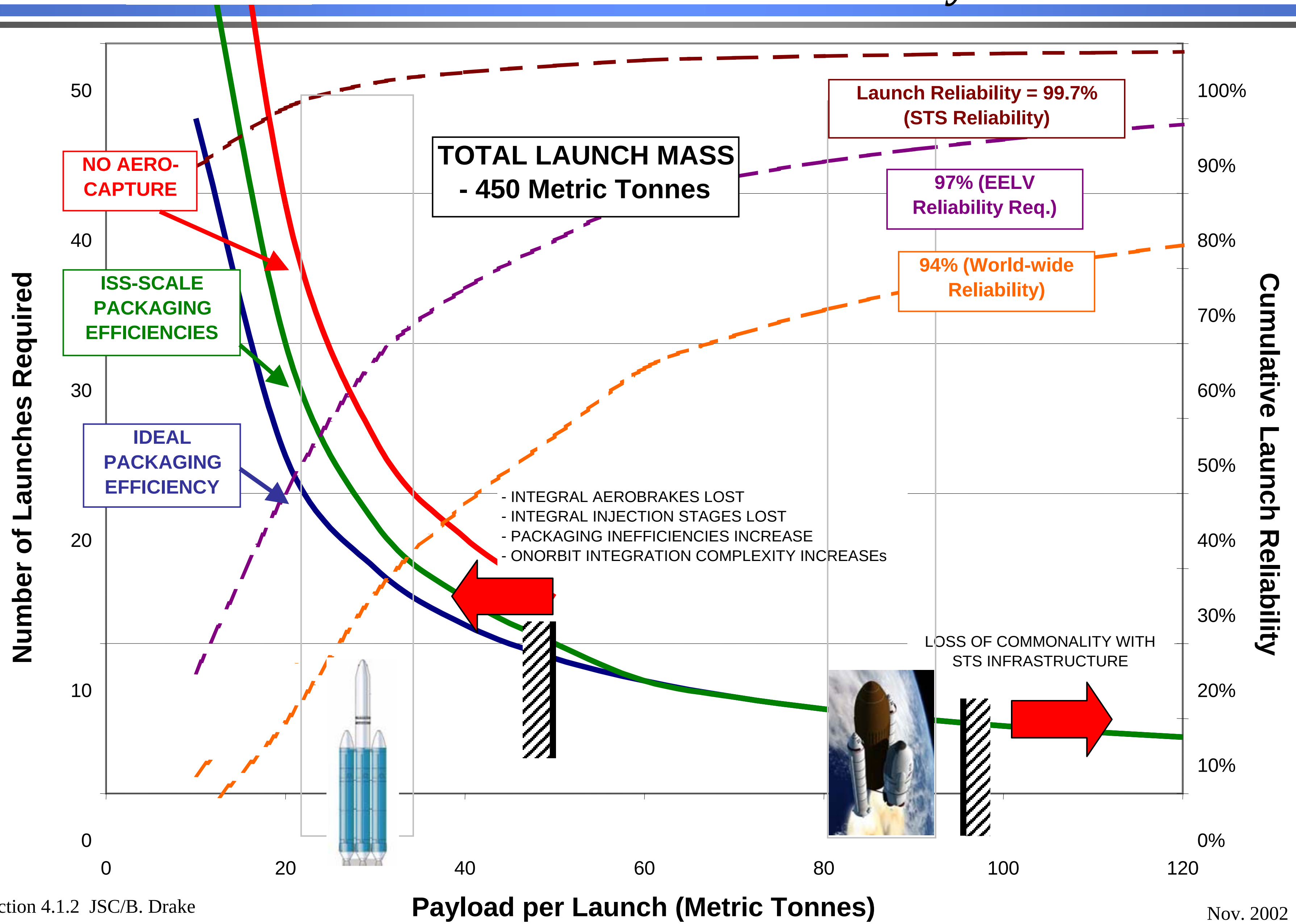


Earth-to-Orbit
- Transports cargo elements and crew from Earth to low-Earth orbit
- Options:
  - Shuttle-derived
  - Clean-sheet approach

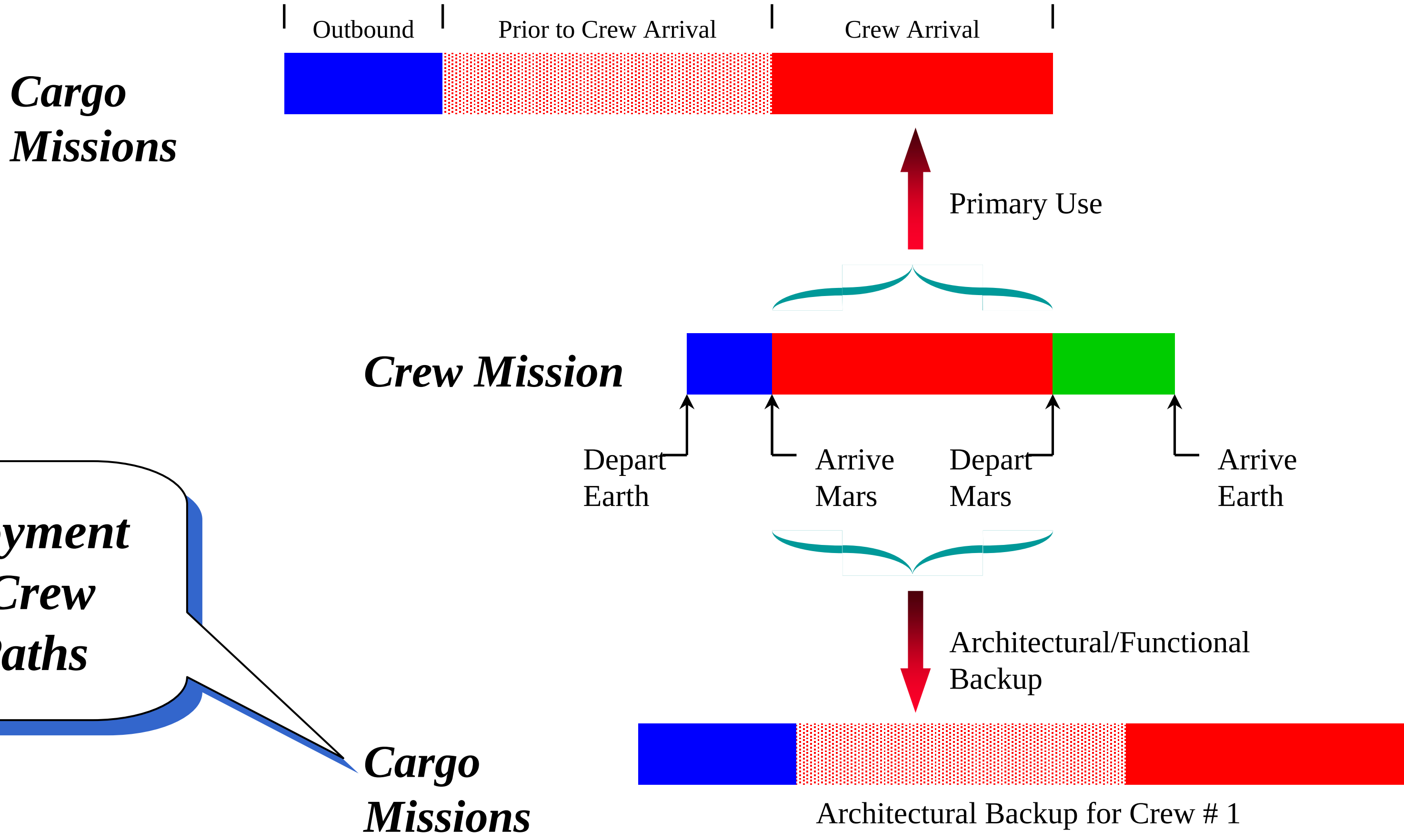
Earth Return
- High-energy aeroassist for orbital capture and entry of Earth's atmosphere
- Key Technologies & Options:
  - Advanced Ablators



Mars Mission Launches Required and Associated Reliability



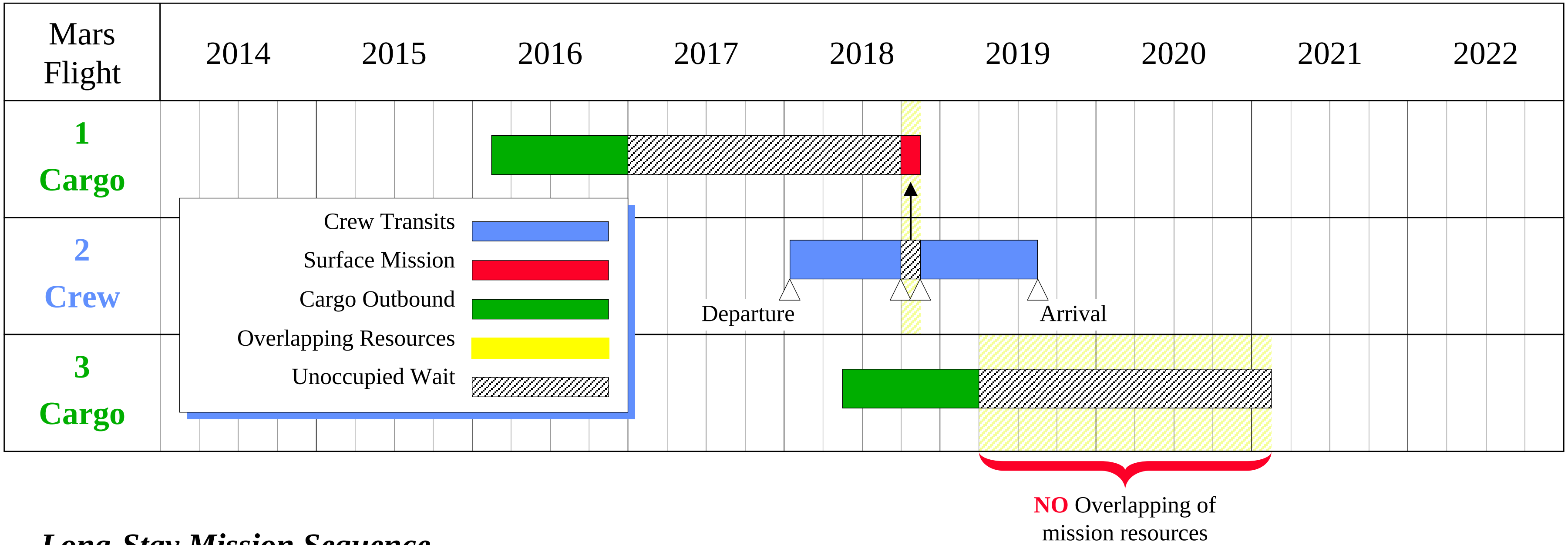
The Forward Deployment Strategy



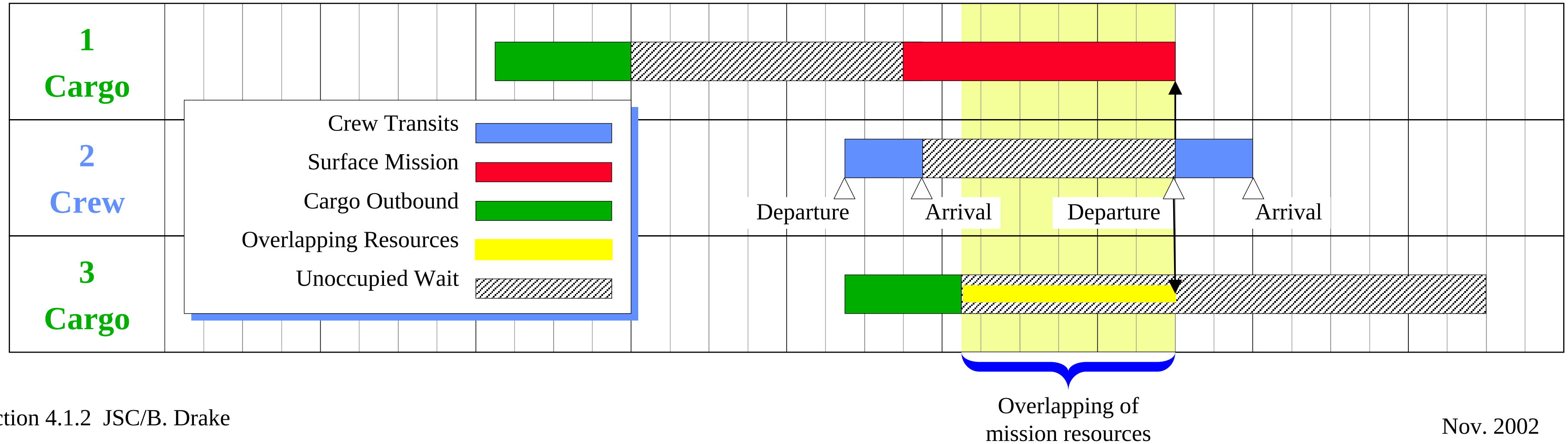
Forward Deployment Provides the Crew Dual Abort Paths

Forward Deployment Sequence

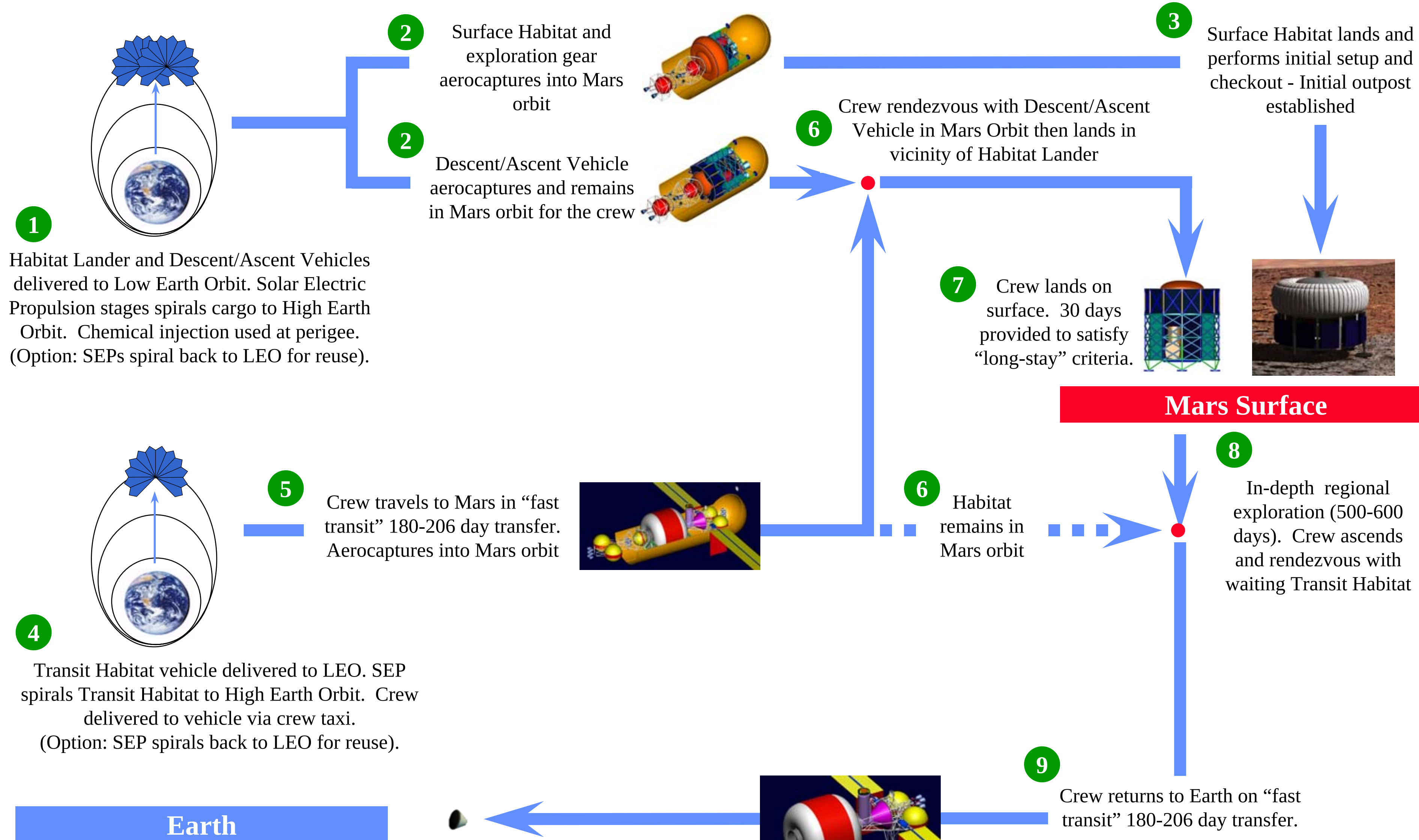
Short-Stay Mission Sequence



Long-Stay Mission Sequence



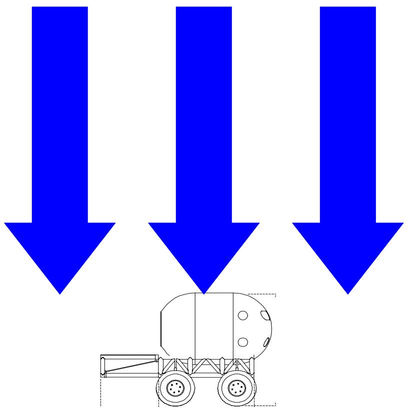
Mars Long-Stay Mission Overview Option
(Solar Electric Propulsion Option)



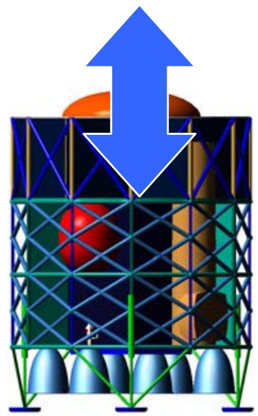
Total mission duration: 892-945 days
Time on Mars surface: 500-600 days

Surface Architecture

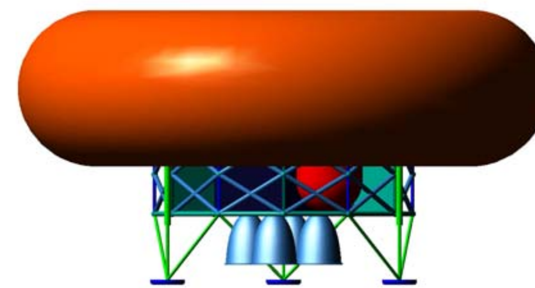
Outpost Missions
(Bite Size Chunks)



Basic Survivability
(30 Days)



Full Mission Capability
(18 Months)



- **Full Mission and augmented systems**
  - Rovers
  - Power (nuke)
  - Science (drills)
  - etc.

- **Short-stay capability (30 days)**
  - Ascent vehicle and propellant (abort-to-orbit)
  - Contingency science
  - Common lander design

- **Full surface mission support systems**
  - Power
  - Life Support
  - Maintenance
  - Thermal
  - Crew accommodations
  - Science
  - Common lander design

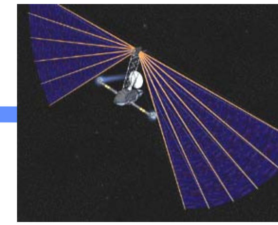
Mission Sequence
High Earth Orbit Boost Phase

UNPILOTED VEHICLES

"Shuttle Class" 2
SEP launched to low Earth orbit

"Shuttle Class" 3
Descent/Ascent vehicle, aerobrake, and TMI stage launched LEO

"Shuttle Class" 4
Surface Habitat Lander, aerobrake, and TMI stage launched LEO



SEP vehicles boost Descent/Ascent and Surface Hab landers to High Earth Orbit

STS 4 / Taxi
Servicing mission in High Earth Orbit

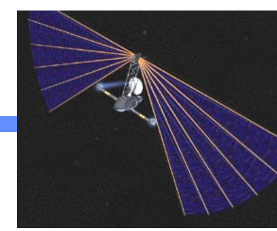
PILOTED VEHICLES

"Shuttle Class" 1
Transit Habitat launched to low Earth orbit

STS 1 & 2
Transit Habitat outfitting missions

"Shuttle Class" 5
Transit Habitat SEP vehicle launched to low Earth orbit

"Shuttle Class" 6
Transit Habitat propulsion stages launched to low Earth orbit

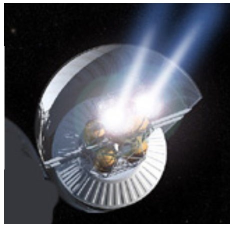


SEP vehicle boosts Transit Habitat to High Earth Orbit

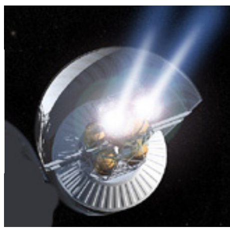
STS 3 / Taxi
Transit Habitat servicing mission in High Earth Orbit

Mission Sequence
Trans-Mars Injection / Mars Arrival Phase

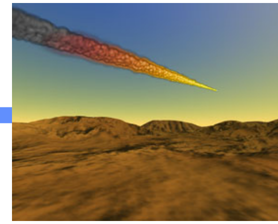
Surface Habitat Lander

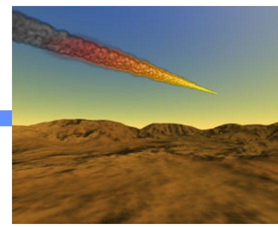


Descent/ Ascent Vehicle

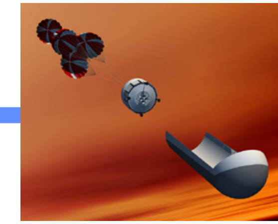


Unpiloted Vehicles injected toward Mars on near minimum energy transfers

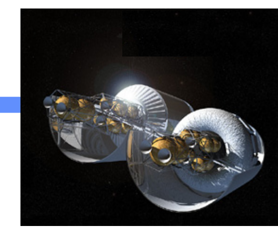




Unpiloted vehicles aerocapture into Mars orbit prior to the crew



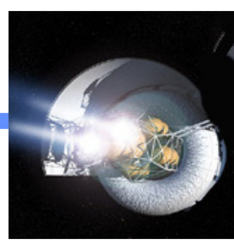
Surface Habitat performs deorbit, entry, descent, and precision landing on Mars



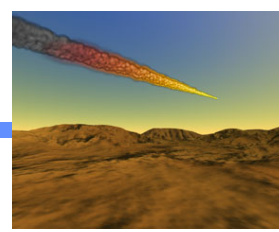
Transit Habitat performs rendezvous with Descent/ Ascent vehicle in Low Mars Orbit.

Crew transfers to Descent/ Ascent Vehicle

<u>STS 5 / Taxi</u> Flight Crew Delivery to Transit Habitat

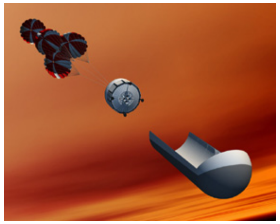


Transit Habitat Trans-Mars Injection (180-206 day transfers)

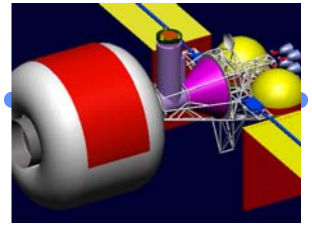


Transit habitat aerocaptures into Mars orbit

Mission Sequence
Surface Mission / Mars Ascent / Return Phases



Crew performs deorbit, entry, descent, and precision landing on Mars in Descent / Ascent Vehicle

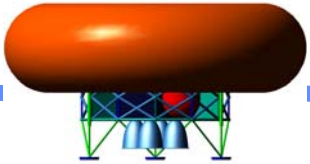


Low-Mars Orbit Wait
Transit Habitat remains in low-Mars Orbit during surface mission (unmanned)

Ascent & Rendezvous
Ascent from Mars surface and rendezvous with Transit Habitat in low-Mars orbit

Earth Return
Direct Earth entry at end of mission

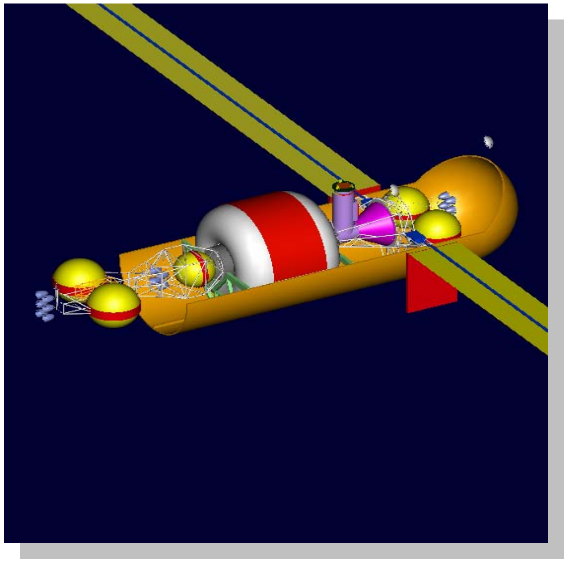
Initial Operations
30 days for systems checkout and crew acclimation.
Contingency abort-to-orbit capability

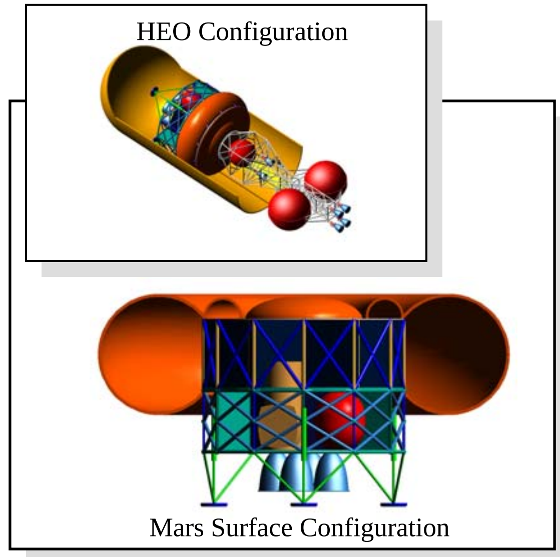


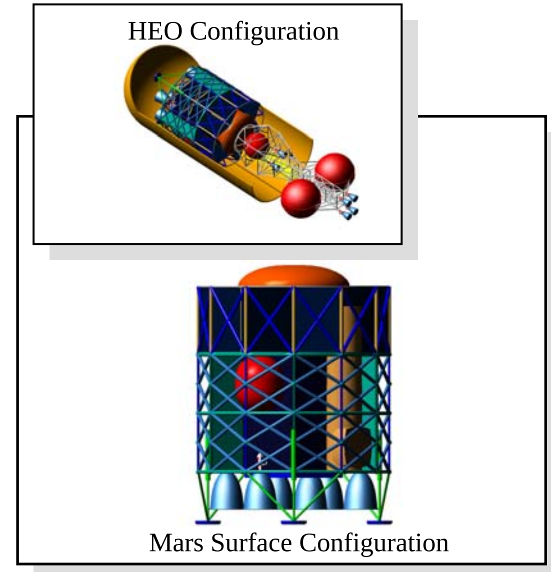
Initial Habitat Operations
Safe vehicle, habitat inflation, power system deployment, habitat outfitting and systems checkout.

Surface Exploration
Concentrates on the search for life, drilling, geology, and microbiology investigations (up to 18 months long)

Mars Mission Vehicle Concepts







Mars Transit Vehicle

- Supports mission crew of six for up to 200-day transits to and from Mars
- Return propulsion stage integrated with transit system
- Provides return-to Earth abort capability for up to 30 hours post-TMI
- Total Vehicle Mass in High-Earth Orbit = 188 mt

Mars Surface Habitat

- Vehicle supports mission crew of six for up to 18 months on the surface of Mars
- Provides robust exploration and science capabilities
- Descent vehicle capable of landing 36,000 kg
- Total Vehicle Mass in High-Earth Orbit = 99 mt

Descent/Ascent Vehicle

- Transports six crew from Mars orbit to the surface and back to orbit
- Provides contingency abort-to-orbit capability
- Supports six crew for 30-days
- Vehicle capable of utilizing locally produced propellants
- Total Vehicle Mass in High-Earth Orbit = 103 mt

Low-Earth Orbit Rendezvous and Docking

- **Utilizing a large volume, large mass launch vehicle requires only automated rendezvous and docking**

- **Both Earth surface and LEO based navigation and control infrastructure utilized to enable LEO operations**

- **Dual launch sequence:**
  - Mars payload launched first to LEO
  - Injection stage launched second
  - Mars payload acts as primary control vehicle during rendezvous and docking maneuver

- **Vehicles remotely checked out in LEO prior to initiating Trans-Mars Injection maneuver**

Solar Electric Vehicle Transportation Concept

2016 | **2018** | **2020**

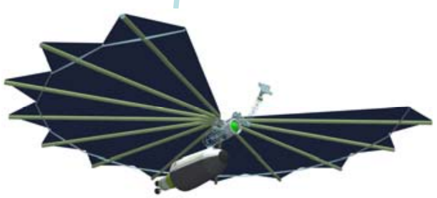
Cargo Boost

SEP-1 vehicle boosts cargo vehicles to high Earth departure orbit

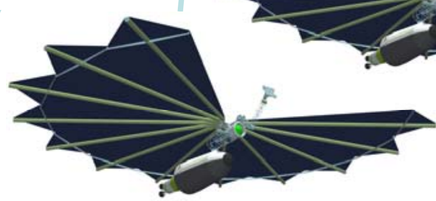
Piloted/Cargo Boost

Both cargo and piloted vehicles are boosted to high Earth departure orbit

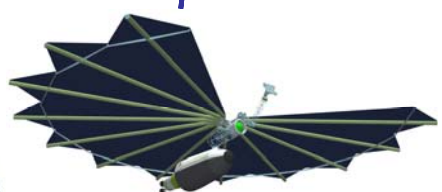
1



1



2



2

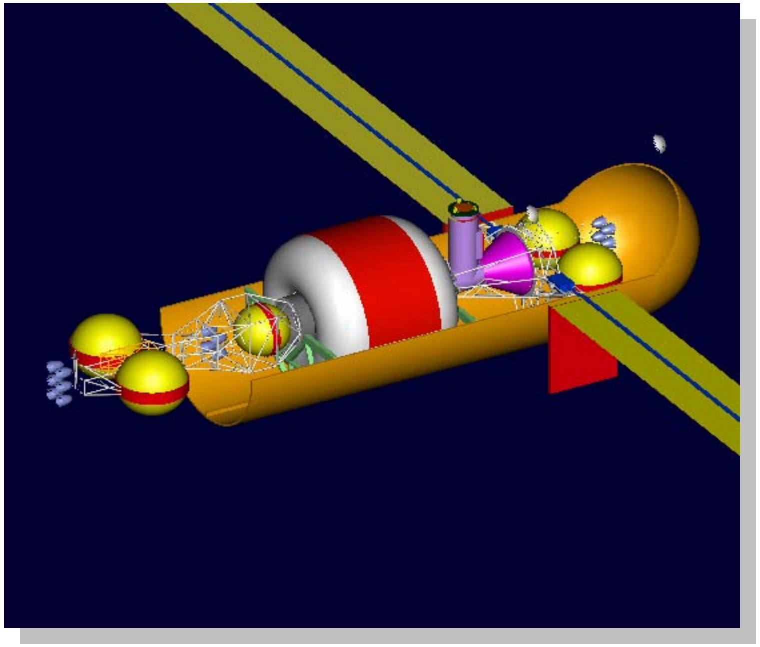
Return

SEP-2 vehicle returns to LEO for new propulsion module and mission payload

Return

SEP-1 vehicle returns to LEO for new propulsion module and mission payload

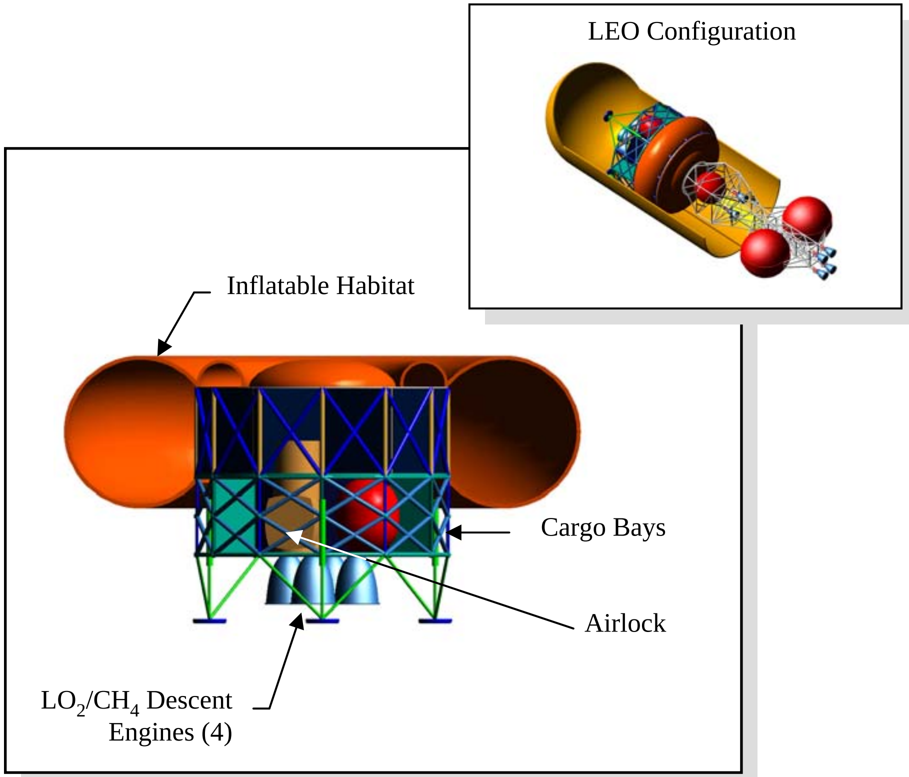
Mars Transit Habitat



- Supports mission crew of six for up to 200-day transits to and from Mars
- Provides zero-g countermeasures and deep-space radiation protection
- Return propulsion stage integrated with transit system
- Provides return-to Earth abort capability for up to 30 hours post-TMI

	TRANSIT HABITAT Mass (kg)	Stowed Vol. (M3)
1.0 Power System	5834.6	0.000
2.0 Avionics	287.0	0.140
3.0 Environmental Control & Life Support	3948.9	19.133
4.0 Thermal Management System	1257.3	5.260
5.0 Crew Accommodations	4309.9	30.719
6.0 EVA Systems	868.7	2.922
7.0 Structure	896.9	0.000
Margin (15%)	2475.9	8.726
Crew	558.0	- - - - -
Food (Return Trip)	2436.0	8.473
Food (Outbound Trip)	2436.0	8.473
Food (Contingency)	7320.0	25.461
Total Transit Habitat Mass	**32629.1**	**109.306**
Crew Taxi/Earth Return Capsule	**3246.5**	**0.000**
Circ Stage	**14770.6**	**0.000**
Stage	567.7	0.000
Propulsion	1301.6	0.000
Propellants	12901.3	0.000
Aerobrake	**4848.5**	**0.000**
TEI Stage	**51429.8**	**0.000**
Stage	1286.0	0.000
Propulsion	2363.1	0.000
Propellants	47780.7	0.000
TMI Stage	**66583.9**	**0.000**
Stage	1455.1	0.000
Propulsion	2518.5	0.000
Propellants	62610.3	0.000
INITIAL MASS IN HIGH EARTH ORBIT	**173508.4**	

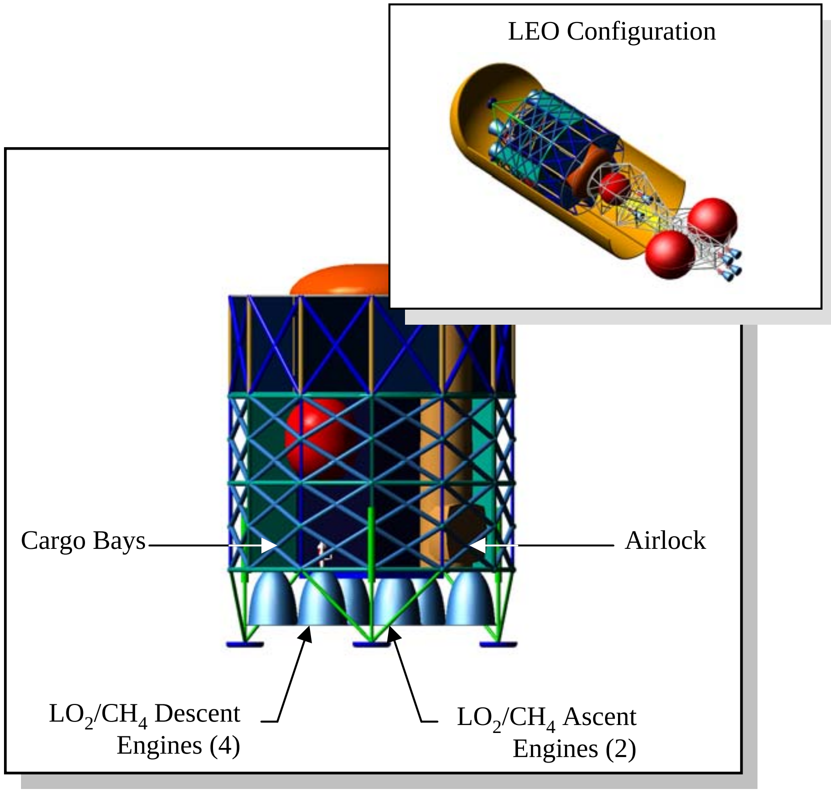
Mars Habitat Lander



- Vehicle supports mission crew of six for up to 18 months on the surface of Mars
- Provides robust exploration and science capabilities
- Descent vehicle capable of landing 36,000 kg

	HABITAT LANDER	
	Mass (kg)	Stowed Vol. (M^3)
Payloads and Systems	**30325.2**	**99.996**
1.0 Power System	5988.0	0.000
2.0 Avionics	153.0	0.279
3.0 Environmental Control & Life Support	3948.9	19.133
4.0 Thermal Management System	2912.1	9.020
5.0 Crew Accommodations	3502.9	26.369
6.0 EVA Systems	1174.4	10.124
7.0 In-Situ Resource Utilization	165.0	0.227
8.0 Mobility	0.0	0.000
9.0 Science	829.9	4.215
10.0 Structure	1861.3	0.000
Margin (15%)	1775.1	6.837
Food	6840.0	23.791
Crew	0.0	- - - - -
Ascent Stage	**243.1**	**0.000**
Crew Module	110.0	0.000
Stage	133.1	0.000
Propulsion	0.0	0.000
Propellants	0.0	0.000
Descent Stage	**12636.3**	**0.000**
(Payload Down)	*30568.3*	- - - - -
Stage	1002.1	0.000
Propulsion	3436.0	0.000
Propellants	8198.2	0.000
Aerobrake	**4656.2**	**0.000**
Circ/Deorbit Stage	**9494.0**	**0.000**
Stage	365.0	0.000
Propulsion	1339.5	0.000
Propellants	7789.5	0.000
TMI Stage	**24357.3**	**0.000**
(TMI Payload)	*57354.8*	- - - - -
Stage	686.4	0.000
Propulsion	2045.9	0.000
Propellants	21625.1	0.000
INITIAL MASS IN HIGH EARTH ORBIT	**81712.1**	

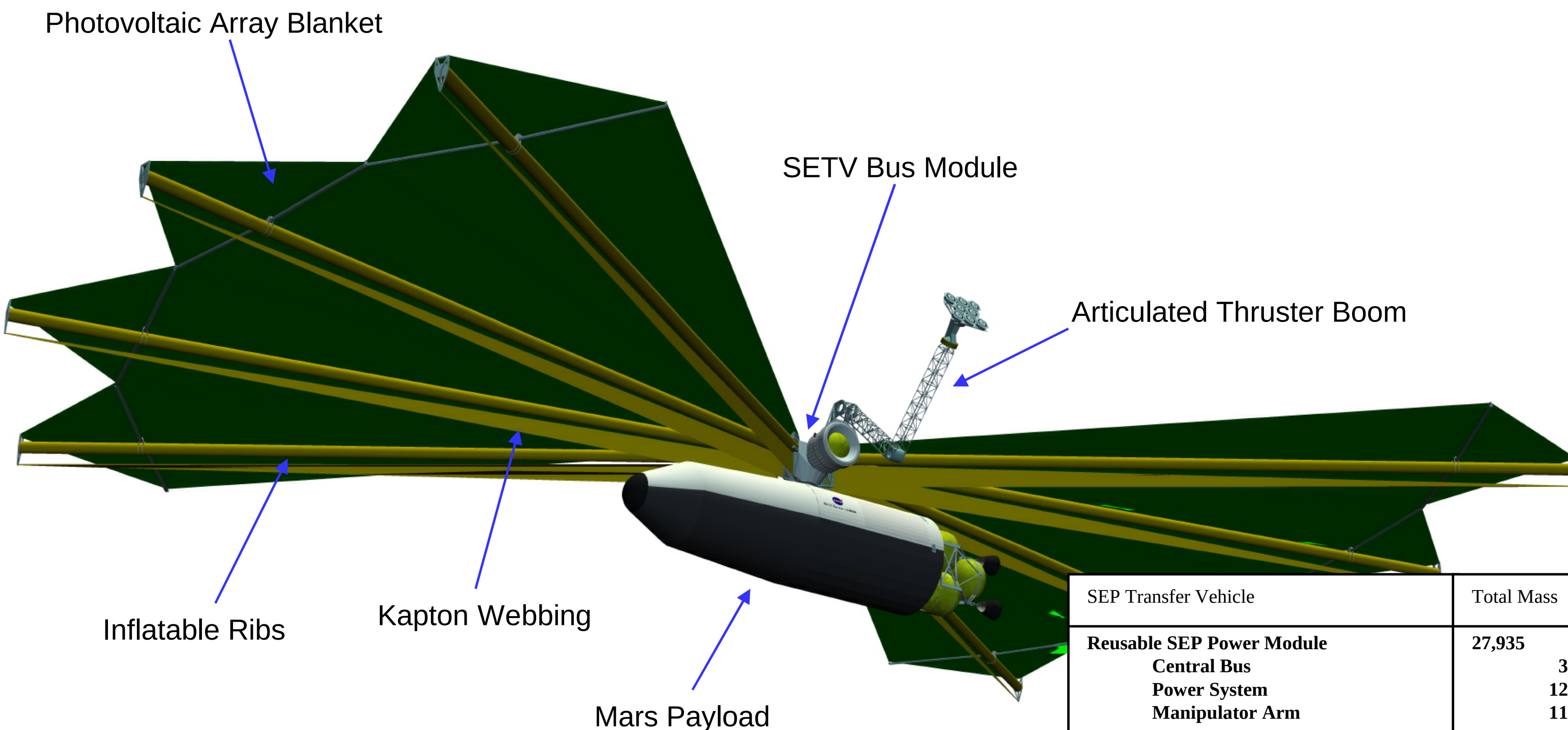
Mars Descent / Ascent Vehicle



- Transports six crew from Mars orbit to the surface and return to Mars orbit
- Provides contingency abort-to-orbit capability
- Vehicle supports crew for 30-days
- Vehicle capable of utilizing locally produced propellants

	DESCENT/ASCENT LANDER	
	Mass (kg)	**Stowed Vol. (M^3)**
Payloads and Systems	**13467.2**	**30.095**
1.0 Power System	4762.0	0.000
2.0 Avionics	153.0	0.279
3.0 Environmental Control & Life Support	1037.6	3.983
4.0 Thermal Management System	527.4	2.350
5.0 Crew Accommodations	727.7	5.776
6.0 EVA Systems	1085.0	3.084
7.0 In-Situ Resource Utilization	0.0	0.000
8.0 Mobility	1200.4	8.171
9.0 Science	301.2	1.600
10.0 Structure	1339.8	0.000
Margin (15%)	1415.1	3.599
Food	360.0	1.252
Crew	558.0	- - - - -
Ascent Stage	**17779.2**	**1.000**
Crew Module	1617.5	1.000
Stage	471.3	0.000
Propulsion	2121.1	0.000
Propellants	13569.3	0.000
Descent Stage	**12876.5**	**0.000**
(Payload Down)	*31246.3*	- - - - -
Stage	1242.3	0.000
Propulsion	3436.0	0.000
Propellants	8198.2	0.000
Aerobrake	**4656.2**	**0.000**
Circ/Deorbit Stage	**9494.0**	**0.000**
Stage	365.0	0.000
Propulsion	1339.5	0.000
Propellants	7789.5	0.000
TMI Stage	**24357.3**	**0.000**
(TMI Payload)	*58273.1*	- - - - -
Stage	686.4	0.000
Propulsion	2045.9	0.000
Propellants	21625.1	0.000
INITIAL MASS IN HIGH EARTH ORBIT	**82630.4**	

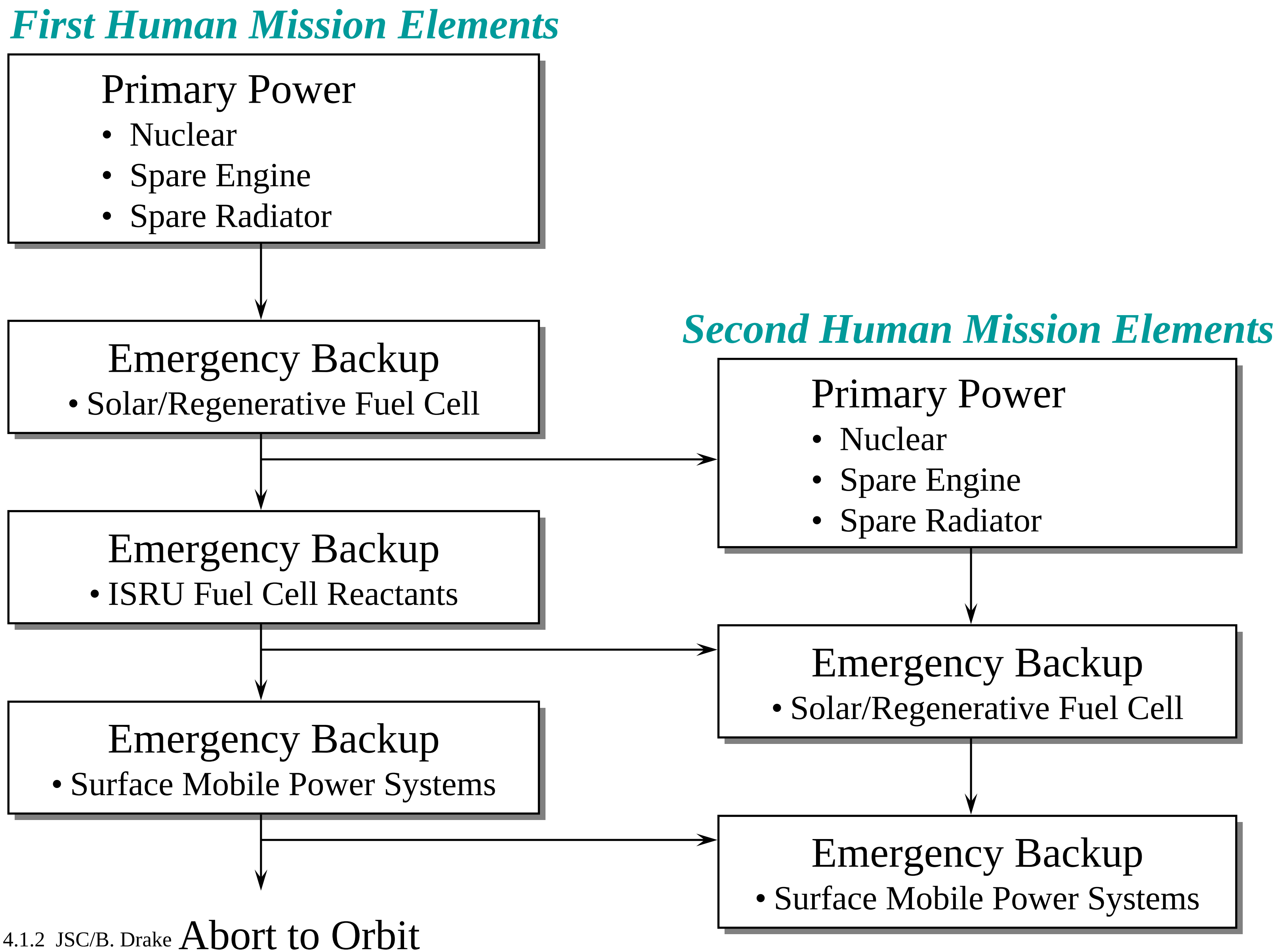
Solar Electric Propulsion Vehicle



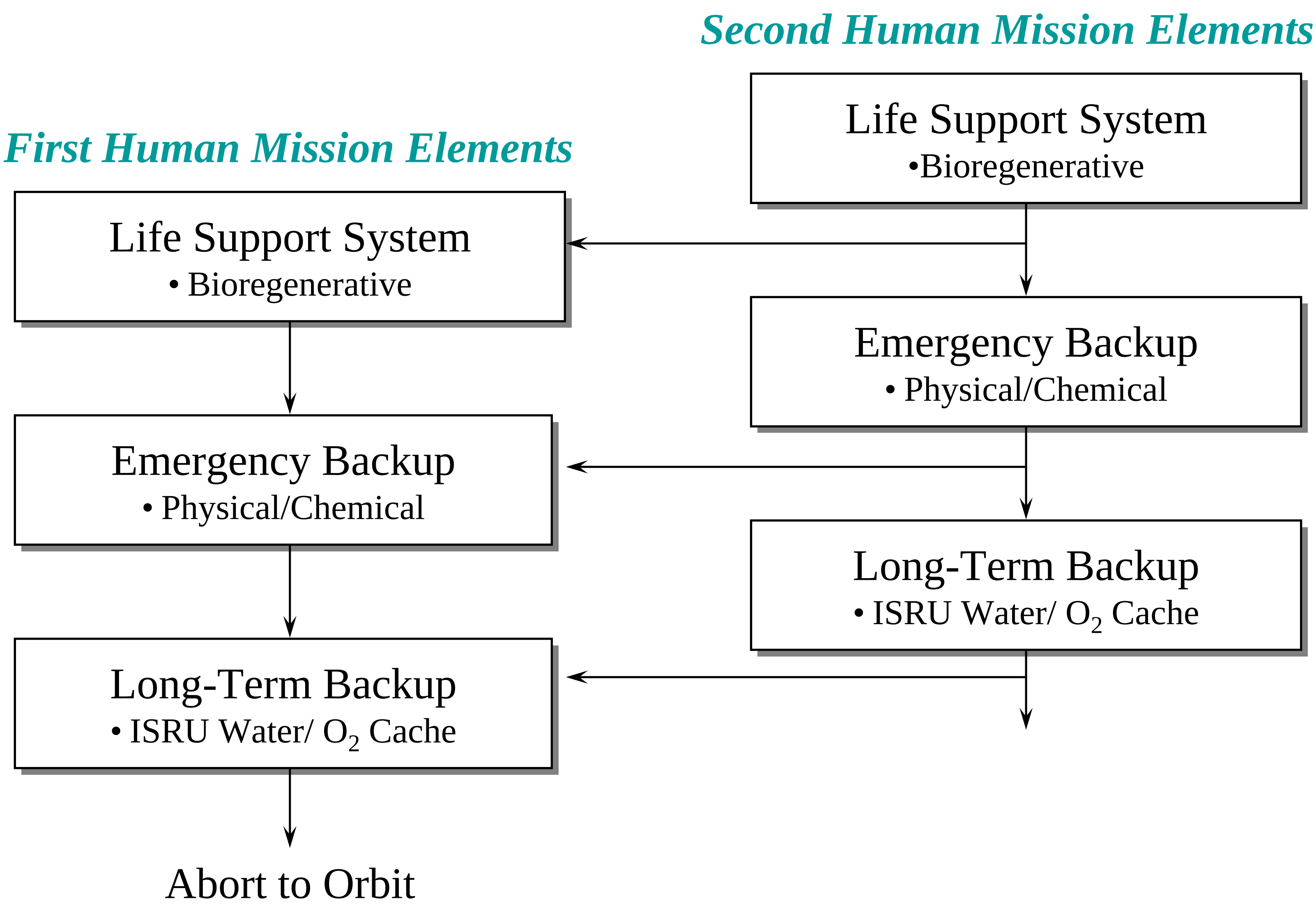
SEP Transfer Vehicle	Total Mass (kg)
Reusable SEP Power Module	**27,935**
Central Bus	**3,770**
Power System	**12,370**
Manipulator Arm	**11,795**
SEP Propulsion Module	**7,730**
Propulsion Platform	**3,900**
Propellant Feed System	**3,830**
Maximum Propellant Load	**64,335**

Ref. Glenn Research Center

Example Power System Redundancy

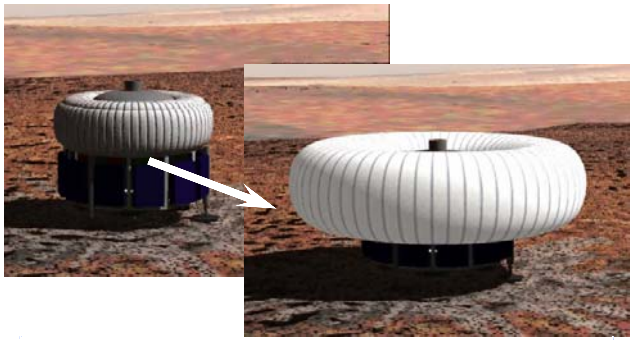


Example Life Support System Redundancy



Mars Vicinity Abort Options

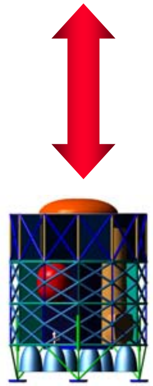
System Pre-Deployment



Habitat Pre-Deployment

- Surface habitat pre-deployed prior to crew landing.
- Initial habitat safing, checkout, and verification
- Risk to crew is reduced since crew does not commit to the landing phase until all habitat systems are operational.

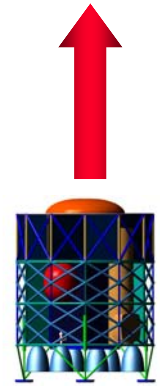
Initial Operations (30 days)



First 30 Days

- Crew lands in separate vehicle
- 30-day initial operations for crew acclimation, initial science
- Once acclimated, crew performs habitat system initialization, checkout and verification.
- Contingency abort-to-orbit capability provided

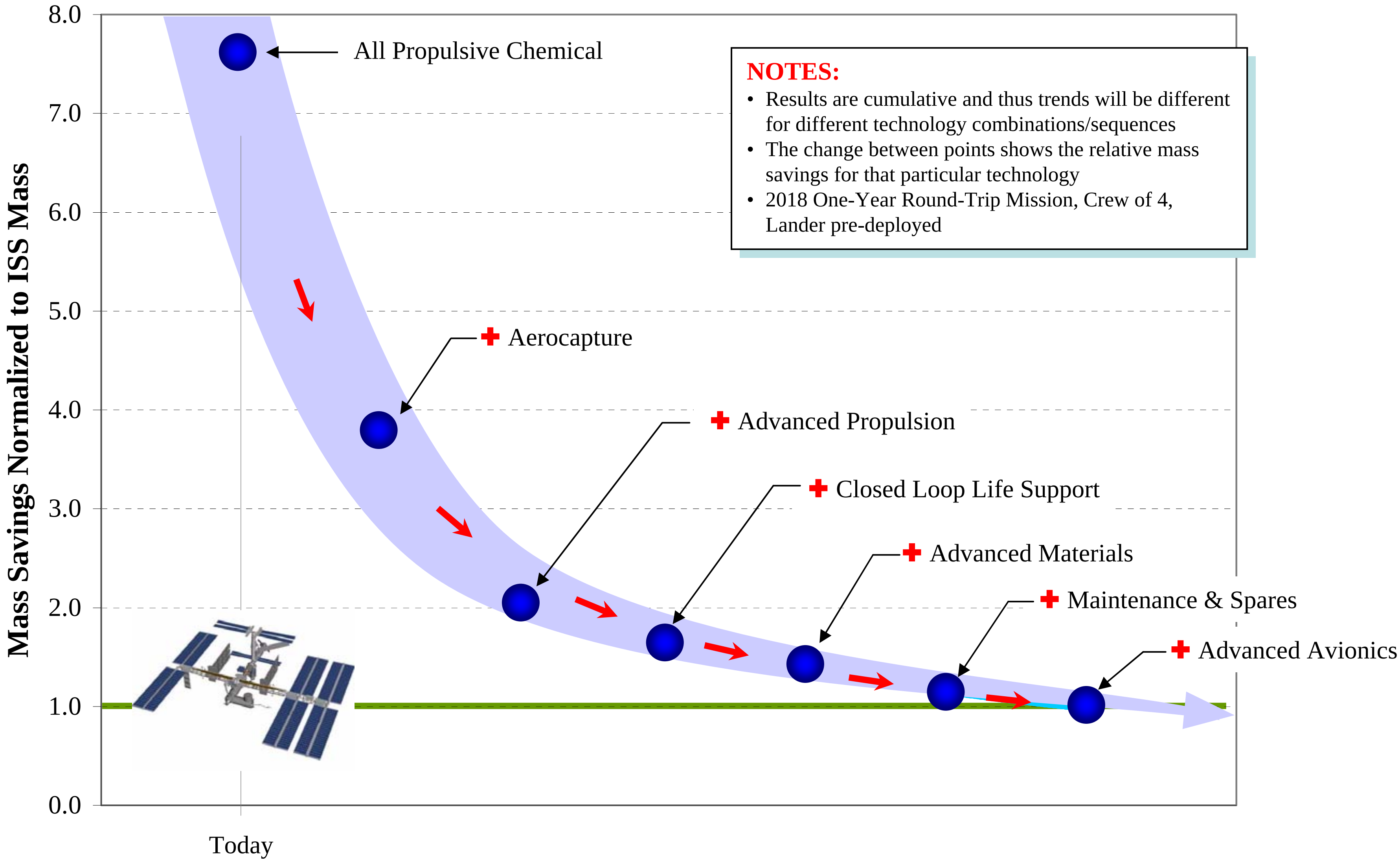
Full Surface Mission (600 days)



600-Day Surface Mission

- Crew transition to surface habitat complete
- Long-stay criteria met
- Ascent Vehicle placed in stand-by mode
- Contingency abort-to-orbit in Ascent Vehicle if required. Must wait in Mars orbit until Trans-Earth Injection window opens.

The Value of Technology Investments
Mars Mission Example



Architecture Unique Technology Needs
Long-Stay Mars Mission

- *Human Support*
  - Advanced health care systems for long periods away from Earth (30 months)
  - Advanced surface mobility and EVA: suitable for robust surface exploration (dexterity, mobility, maintainability)

- *Advanced Space Transportation*
  - Advanced interplanetary propulsion: Primary options include:
    - Nuclear Electric Propulsion (30005 sec Isp, 6 MWe)
    - Solar Electric Propulsion / Chemical / Aerobrake (1.7 Mwe, 18 % efficiency thin film solar)
  - Large volume / large mass Earth-to-Orbit transportation
  - Aeroassist technologies for Mars aerocapture and Earth return
  - In-situ consumable production for EVA system breathing oxygen and ECLSS backup
  - Automated rendezvous and docking of exploration payloads (2) in Earth orbit

- *Advanced Space Power*
  - Nuclear power reactor 30 kWe for crew support and science investigations

- *Miscellaneous*
  - Integrated vehicle health maintenance for vehicles unattended for long periods (22-42 months)
  - Advanced reliability for long vehicle operations (up to 32-51 months)

Example "Assumed" Technology Advancements

- *Human Support*
  - **Closed-loop Life Support:** capable of operating for long periods (up to 3 years)
  - **Advanced Habitation:** Advanced habitat concepts that provide large volume with low mass
  - **Radiation Protection:** Adequate radiation protection for prolonged exposure to deep-space radiation (both galactic cosmic rays and solar proton events)
  - **Advanced Health Care:** Advanced health countermeasure systems and protocols to mitigate the long duration exposure to the deep-space environment (zero and partial gravity)
  - **Medical Care:** Advanced medical care and environmental health monitoring
  - **Advanced Surface Mobility and EVA:** suitable for robust surface exploration (dexterity, mobility, maintainability)

- *Advanced Space Transportation*
  - **Advanced Interplanetary Propulsion:** Concepts which reduce mission mass and risk: Options include Nuclear Thermal, Nuclear Electric, Solar Electric, and Advanced Chemical
  - **Aeroassist:** High energy aerocapture for orbital insertion, guided entry, precision landing and hazard detection/avoidance on planetary bodies
  - **In-situ Consumable Production:** Concepts to produce useful products (breathing oxygen, power system reactants, propellants) out of planetary resources
  - **Low-Cost Launch:** Low-cost transportation of exploration payloads
  - **Automated Rendezvous and Docking:** of exploration payloads in Earth orbit
  - **Cryogenic Fluid Management:** Long-term storage and maintenance of cryogenic propellants both in space and on planetary surfaces. Cryogenic propellant options include hydrogen, oxygen, methane, xenon, krypton

Example “Assumed” Technology Advancements

- *Advanced Space Power*
  - **Power Generation:** Advanced lightweight, highly reliable power systems for both stationary and mobile systems. Options include both solar and nuclear systems.
  - **Photovoltaic:** Advanced lightweight thin film solar photovoltaic power generation.
  - **Energy Storage:** High capacity regenerative fuel cell and lightweight batteries for long-term energy storage
  - **Dust Mitigation:** Advanced dust mitigation (95%) efficiency for Mars surface solar photovoltaic applications
  - **PMAD:** Lightweight, high efficiency power management and distribution systems

- *Information and Automation*
  - **Autonomy:** Advanced vehicle and systems health management and autonomous operations
  - **Communication:** Robust, high bandwidth communications at exploration destinations (the space internet)
  - **Operations:** Autonomous systems operation, independent of direct-earth based control, at remote exploration destinations

- *Sensors and Instruments*
  - **Wireless:** Wireless instruments and vehicle systems
  - **Sensors:** Advanced system, medical, and health monitoring

Key In-Space Transportation Technology Options & Needs

Earth-to-Orbit Launch

Application: Affordable delivery of cargo elements and crew from Earth to LEO.

Needs: 80-100 mt with payload volumes up to 10 m x 30 m.

Key Options: Shuttle derived or clean sheet approaches

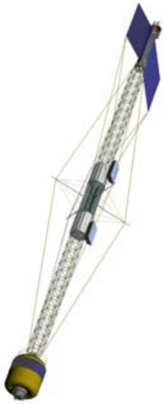
Advanced Chemical Propulsion

Application: High energy injection stages for transportation of elements in near-Earth space. Advanced chemical engines for descent and ascent at planetary destinations.

Needs: 5-6 klbf throttleable engines which are compatible with utilization of local resources.

Key Options: O2/Methane, O2/Hydrogen

Electric Propulsion

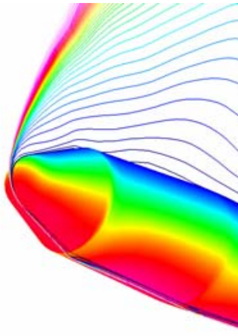


Application: High-efficiency propulsion for delivery of cargo and crew elements from Earth vicinity to planetary destinations and return.

Key Options: 6-20 MWe nuclear electric.

1-3 MWe solar electric (combined with chemical injection stages and aeroassist at Mars).

Key In-Space Transportation Technology Options & Needs



Aeroassist

Application: Utilization of planetary atmospheres (Mars and Earth return) for orbital capture, entry, descent, and landing.

Needs: Arrival speeds of 7.4 km/s (Mars) and 11.0 – 13.5 km/s (Earth return).

Key Options: Advanced ablators. Integrated aeroshell/payload shroud concepts.

Cryogenic Fluid Management

Application: Long-term storage of cryogenic fluids in space and on planetary surfaces.

Needs: Storage of cryogenic fluids (H_2, O_2, CH_4) for up to 1200 days.

Key Options: Combination of passive and active systems.

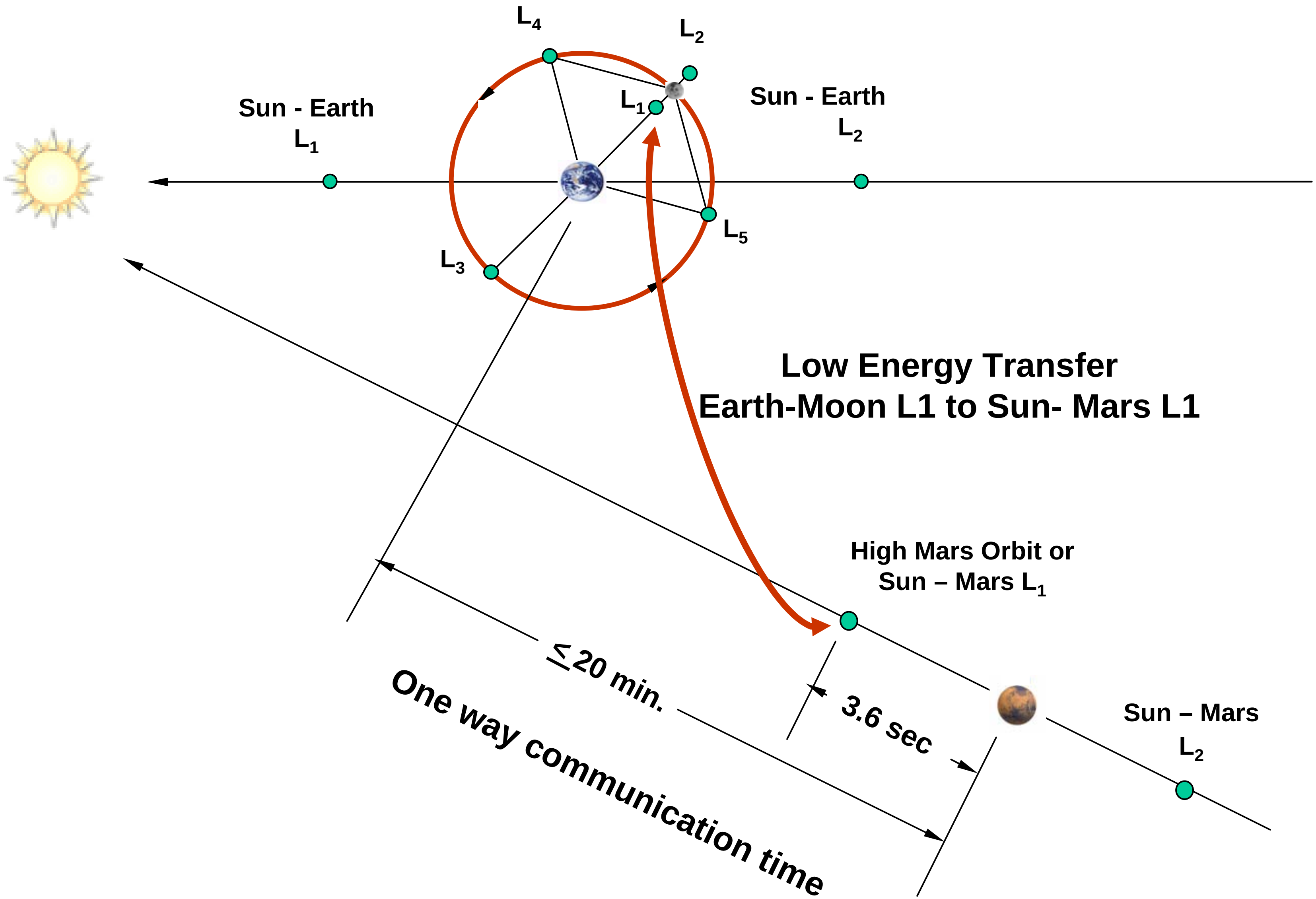
An Emerging Architecture

Artificial-Gravity Nuclear Electric Propulsion Option

New Approach
Mars Lagrange Point Staging Location

- **Low energy transfers between Earth-moon L_1 and Mars L_{1-2}**
- **Move Mars tele-operation from Earth to High Mars Orbit**
  – Deploy and operate micro-missions
  – Short light time (<7 sec. Round-trip)
- **Reduce mass and cost**
  – Stay out of Mars gravity well -aerocapture for transit vehicle not needed
  – Enables reuse of transit vehicles
- **Fuel depots at Moon and Mars gateways:**
  – Potential fuel sources: Earth, Moon, Mars
- **Safe locations to operate nuclear electric propulsion if needed**
- **Equivalent access to all of Mars surface**
- **Use existing or planned launch vehicles??**
- **Stepping stone for humans to Mars with incremental investments**

New Options



L_4
L_2
Sun - Earth L_1
L_1
Sun - Earth L_2
L_5
L_3
Low Energy Transfer
Earth-Moon L1 to Sun- Mars L1
High Mars Orbit or
Sun – Mars L_1
$\leq$ 20 min.
3.6 sec
Sun – Mars L_2
One way communication time

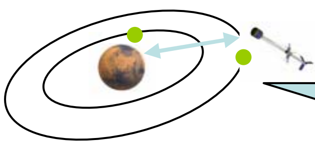
Potential Mars System Human Destinations

Martian Surface

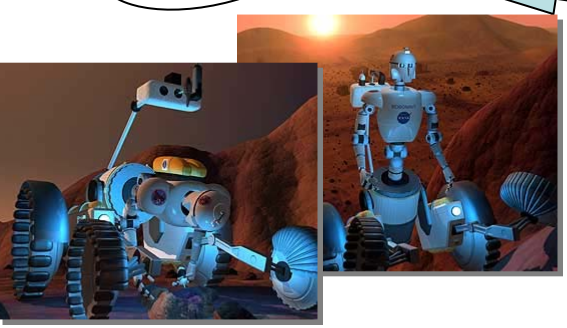
- Automated / teleoperated robots
- Direct Human Exploration
- Access to Mars Resources
  - Propellant
  - Life Support Consumables

Phobos/Deimos

- Accelerated and amplified robotic surface exploration through telepresence
- Round-trip light time delay <0.2 second

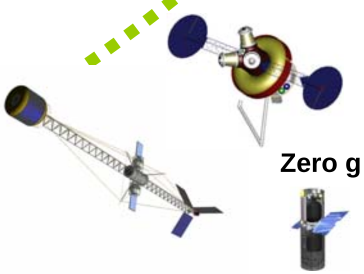


Teleoperation



High Mars Orbit / Lagrange Point

- Accelerated and amplified robotic surface exploration through telepresence
- Round-trip light time delay <7 seconds
- Reduction of cost and risk associated with human landing
- Vehicle(s) never enter gravity "well" (reduced propellant requirements)

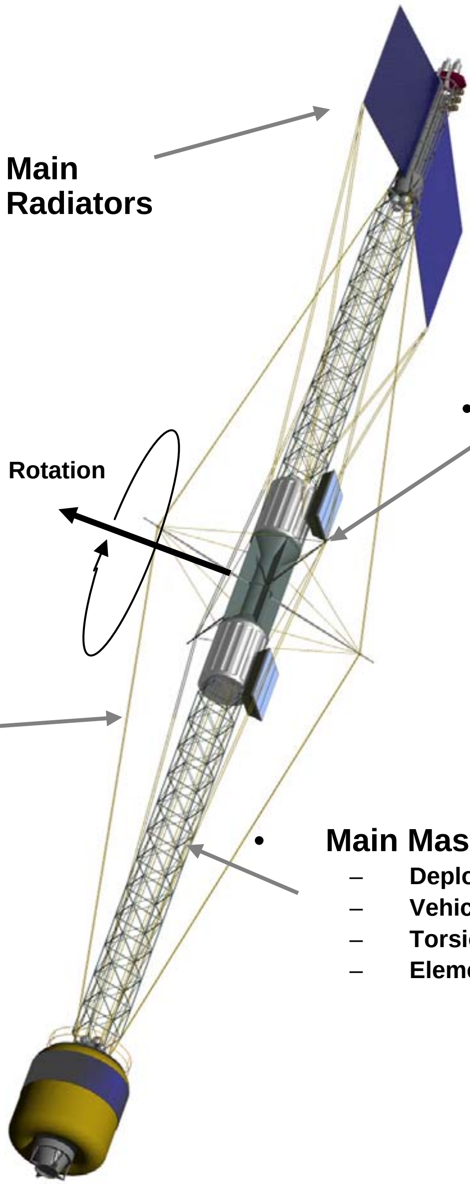


Zero g option

Artificial g option

Mars "Sphere of Influence"

Artificial Gravity Concept



- **Main Radiators**

- **Main Power**
  - Redundant Reactors
  - Redundant Power Conversion
  - Reactor Radiation Shielding

- **Propulsion Modules**
  - Propellant Tankage
  - Electric Propulsion

- **Guy Cables**
  - Rotational acceleration/deceleration loads

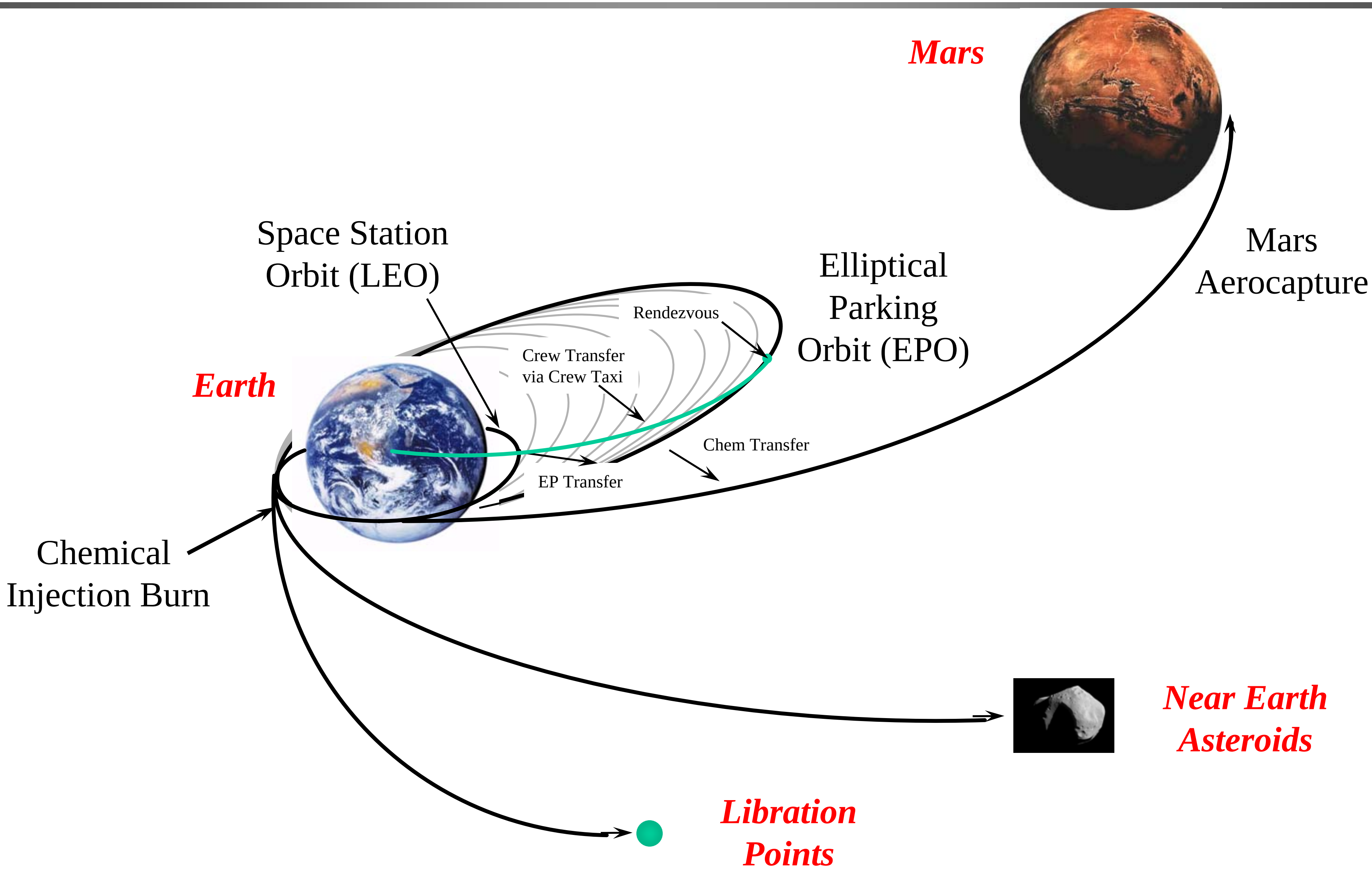
- **Crew Module**
  - Inflatable Pressure Shell
  - Radiation Shielding
  - Micrometeoroid Protection
  - Life Support
  - EVA Support
  - Auxiliary Power
  - Rotational RCS (chemical/arcjet)
  - Body-Mounted Radiator

- **Main Masts**
  - Deployable
  - Vehicle tension loading
  - Torsion Loads
  - Element zero-g positional control

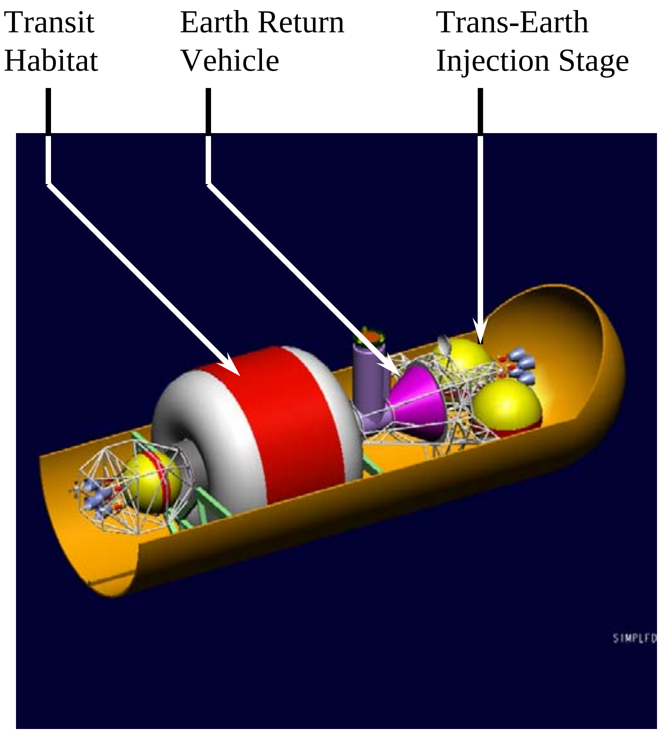
Mars Architecture Analysis

Backup

High Earth Orbit Staging Mission Scenarios



Earth Vicinity Abort Scenarios (SEP Architecture)



Post-Trans-Mars Injection Aborts: **Trans-Earth Injection stage can be used to return the crew from an off-nominal TMI burn**

Post-Trans-Mars Injection Abort Options

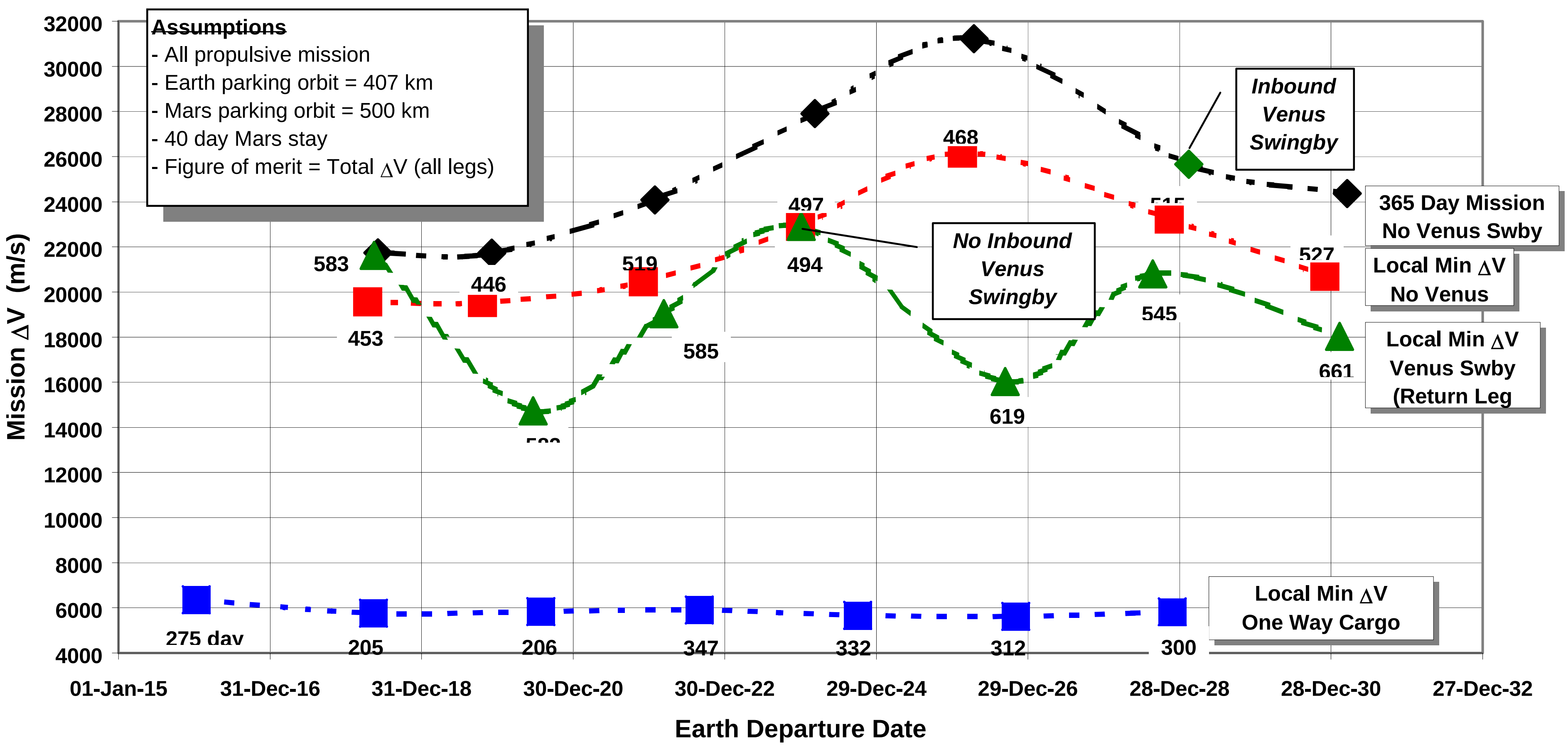
① Long Return Option (within 8 hrs of TMI)
- Crew lives in Transit Habitat after abort declaration
- Crew returned to Earth in the Earth Return Vehicle up to 30 days later

② Quick Return Option (within 30 hrs of TMI)
- Crew returned in the Earth Return Vehicle
- Return transit time 1-2 days

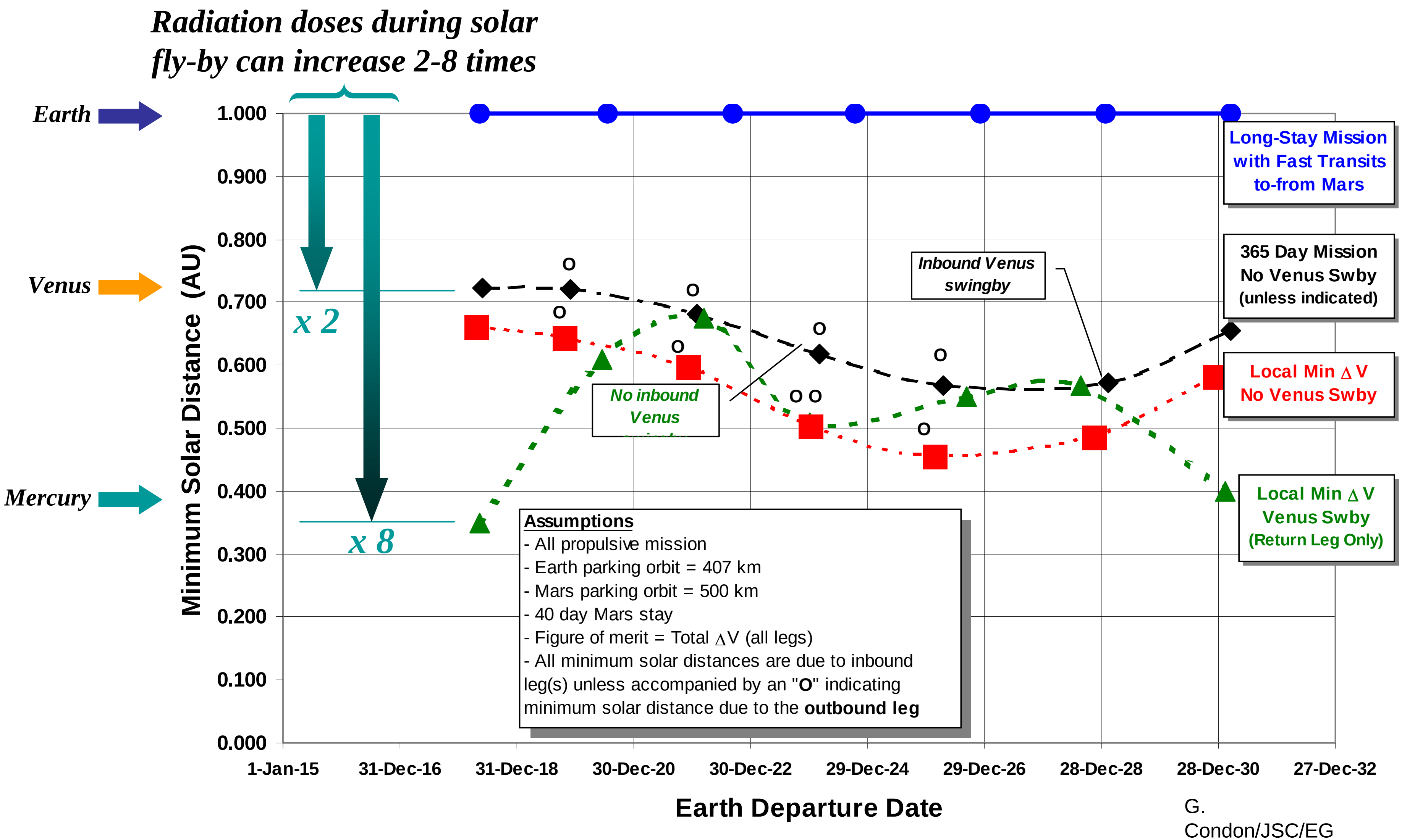
③ Heliocentric Aborts (1-2 months after TMI)
- Return transit times range from 360-570 days
- Crew lives in the Transit Habitat during return - direct Earth entry via Earth Return Vehicle
- Can perform this abort only for some (3 of 7) opportunities (2014, 2016, 2018) with the current TEI size (33% increase to cover all opportunities)

Total Mission ΔV vs Earth Departure Date
Short-Stay Mars Missions

Total Mission ΔV vs Earth Departure Date



Minimum Solar Distance vs. Mission Opportunity Short-Stay Mars Missions



Human Expedition to Mars

Objective

- Establishment of early leadership in human exploration of the solar system

Key Features

- 3 human expeditions to Mars
- Chemical/aerobrake propulsion
- Split/sprint mission profile
- Aerocapture at earth return
- Vehicle assembly in low-earth orbit (SSF)
- 8 crewmembers per expedition (2006, 2009, 2011)
- 440-500 day round trip (20 days on Mars surface)
- Total Mission mass = 1628 mt

1988

Principal Results

- Short-stay missions are energy intensive, thus requiring large transfer vehicles
- Advanced propulsion technologies (aerocapture and nuclear thermal rocket) can significantly reduce mass requirement (57-72%)
- On-orbit assembly, storage of cryogenic propellants, and vehicle checkout increase mission complexity
- Large mass in LEO requires a heavy-lift launch capability and potentially on-orbit assembly capability

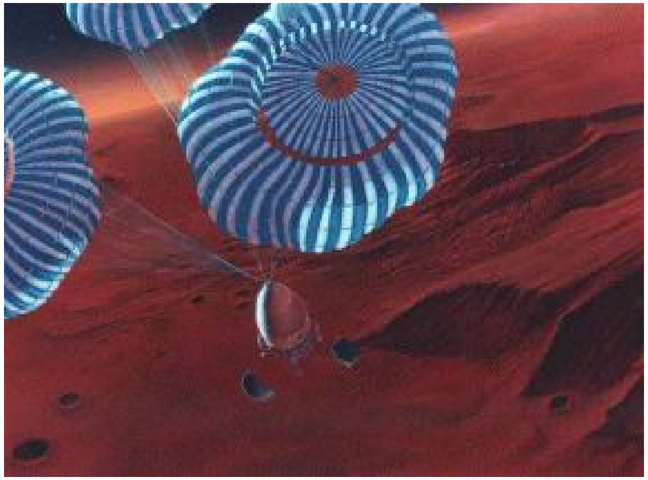
Mars Evolution

Objective

- Emplace a permanent, largely self-sufficient outpost on the surface of Mars

Key Features

- First human flight in 2007 (4 growing to 7 crew)
- Vehicles assembled in LEO (free-flyer platform)
- Chemical/aerobraking propulsion
- Propellant production at Phobos
- Artificial-gravity spacecraft
- Surface stay initially 30-days growing to 500



1989

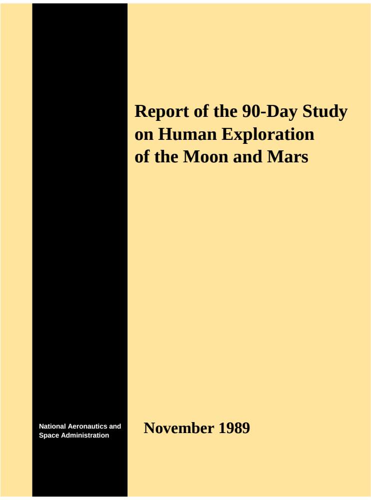
Principal Results

- Heavy-Lift launch vehicle (140 t to LEO) required to support mass and flight rate requirements
- Even with HLLV, extensive on-orbit assembly and check-out required in low-earth orbit
- Use of nuclear thermal rocket, in addition to aerobraking, would increase payload capability and reduce flight times to and from Mars
- Advanced EVA systems are required to support the extensive surface operations required
- Significant research and development of in-situ resource utilization processes are required
- Architecture requires delivery of approximately 500t to low earth orbit per year

NASA 90-Day Study

Objective

- To provide a database for the National Space Council to refer to as it considered strategic planning issues
- Agency-wide study commissioned by Admiral Truly after the President’s July 20, 1989 speech



November 1989

Key Features

- Five reference approaches (generally similar)
- Robotic - Moon - Mars pathway
- Extensive use of:
  - Space Station Freedom for assembly and checkout operations
  - Reusable transportation vehicles (initially expendable)
  - In-Situ Resource Utilization (oxygen from the lunar regolith)
  - Chemical/aerobrake propulsion

Key Trades

- Launch Vehicle Size (80 - 140 mt)
- In-space assembly or direct to the surface
- Freedom, new spaceport, or direct assembly
- Chemical, electric, nuclear, or unconventional
- Aerobraking or all-propulsive
- Expendable or reusable spacecraft
- Propellant or tank transfer
- Open or closed life support
- Zero-gravity or artificial-gravity Mars vehicle
- In situ or Earth-supplied resources

Principal Results

- Premature discussion/disclosure of cost results can have unwanted effects, difficult to characterize long-term initiatives
- Use of local planetary resources can greatly enhance capabilities and reduce the cost of exploration
- Aerobraking reduces vehicle mass by as much as 50% as compared to all chemical systems
- Nuclear thermal propulsion provides a great deal of promise for Mars missions (40% mass reduction)

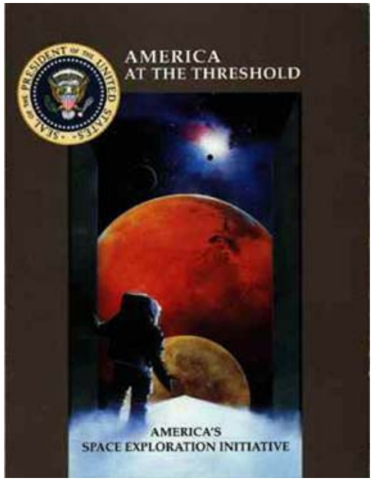
The White House Synthesis Group
America At The Threshold

Charter

- Chartered by the National Space Council to develop several alternatives of exploration, future acquisition of scientific knowledge, and future space leadership.
- Chaired by Tom Stafford, Lieutenant General, U.S. Air Force (ret.)

Four Candidate Architectures

- Mars Exploration
- Science Emphasis for the Moon and Mars
- The Moon to Stay and Mars Exploration
- Space Resource Utilization



May 1991

Principal Results

- Several supporting technologies identified as key for future exploration:
  - Heavy Lift Launch Vehicle (150-250 mt)
  - Nuclear Thermal Propulsion
  - Nuclear electric surface power
  - Extravehicular activity suit
  - Cryogenic transfer and long-term storage
  - Automated rendezvous and docking
  - Zero-g countermeasures
  - Telerobotics
  - Radiation effects and shielding
  - Closed loop life support systems
  - Human factors for long duration space missions
  - Lightweight structural materials and fabrication
  - Nuclear electric propulsion for follow-on cargo deliv.
  - In situ resource evaluation and processing

Mars Exploration Mission Studies
Design Reference Mission 1.0

Objective

- Develop a “Reference Mission” based on previous studies and data.
- Reference Mission serves as a basis for comparing different approaches and criteria from future studies

Approach

- Limit the time that the crew is exposed to the harsh space environment by employing fast transits to and from Mars and abort to the surface strategy
- Utilize local resources to reduce mission mass
- Split Mission Strategy: Pre-deploy mission hardware to reduce mass and minimize risk to the crew of 6
- Examine three human missions to Mars beginning in 2009
- Utilize advanced space propulsion (Nuclear Thermal Propulsion) for in-space transportation
- Payloads sent directly to Mars using a large launch vehicle (200+ mt to LEO)
- Nuclear surface power for robust continuous power

1994

Principal Results

- Total mission mass approximately 900 mt for the first crew (3 cargo vehicles, 1 piloted vehicle)
- Development of the large launch vehicle is a long-lead and expensive system. Approaches using smaller launch vehicles should be investigated.

Mars Exploration Mission Studies
Design Reference Mission 3.0

Objective

- Refine DRM 1.0 to improve identified weaknesses
- Provide further refinement of systems design and concepts

Approach

- Refine launch strategy to eliminate the need for the large (200+ mt) launch vehicle. Dual launch (80 mt) strategy utilized.
- Repackage payload elements to reduce the physical size of the aerobrake used for Mars aerocapture and entry
- Investigate the need for the redundant surface habitat
- Incorporate emerging technologies and system concepts to reduce architectural mass

1997

Principal Results

- Reduced system masses allowed for the elimination of redundant surface habitat, thus eliminating one Mars cargo vehicle
- Incorporation of TransHab concept in conjunction with other systems improvements (ECLSS, power, etc) resulted in a mass savings of ~30% at Mars entry.
- System mass improvements and revision of mission strategy resulted in over 50% payload mass savings
- Emerging systems concepts including Solar Electric Propulsion and Bi-Modal NTR shown to be viable alternative concepts
- Total mission mass estimates:
    - Nuclear Thermal Propulsion: 418 mt
    - Solar Electric Propulsion: 409 mt (early estimate)

Mars Exploration Mission Studies
Design Reference Mission 4.0

Objective

- Refine DRM 3.0 to improve identified weaknesses
- Provide further refinement of systems design and concepts
- Improve risk abatement strategy

1998

Approach

- Modify mission strategy to incorporate a round-trip crew transfer vehicle instead of pre-deploying the crew return habitat
- Place further emphasis on Solar Electric Propulsion concept (NTR and Chemical/Aerobrake investigated as options)
- Further refinement of In-situ resource utilization concept
- Shuttle derived launch vehicle (80 mt) used for LEO transportation

Principal Results

- Incorporation of a round-trip crew transfer vehicle reduces system reliability requirement from five to three years, but requires an additional rendezvous in Mars orbit
- End-to-end Solar Electric Propulsion vehicle mission concept is shown to be a viable concept, but vehicle packaging and size remain tall-poles
- Total mission mass estimates:
    - Solar Electric Propulsion: 467 mt
    - Nuclear Thermal Propulsion: 436 mt
    - Chemical/Aerobrake: 657 mt *

* similar but not same mission concept

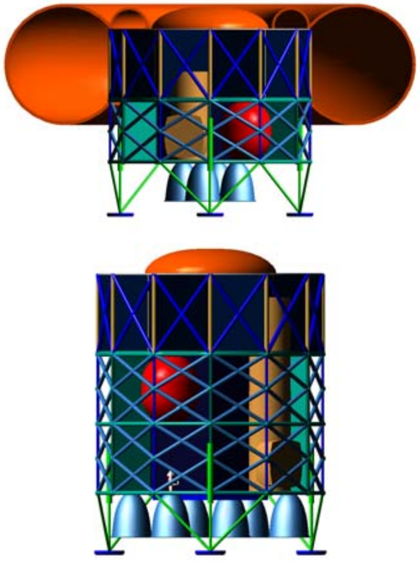
Mars Exploration Mission Studies
Dual Landers

Objective

- Refine Combo Lander approach to eliminate potential long-poles by separating the crew lander functions between two vehicles

Approach

- Long-duration stay mission with fast transits to and from Mars
- Aerobraking at Mars
- Descent/Ascent vehicle for crew transport from orbit, to surface, and back to Mars orbit
- Inflatable habitats for transit and surface vehicles
- CH_4/O_2 propellants brought with the crew of 6
- Solar surface power
- Solar Electric Propulsion used for interplanetary propulsion
- Magnum launch vehicle used for ETO transportation (100 mt to LEO)



1999

Principal Results

- Six 100-mt launches required
- Significant improvement in aeroassist and parachute deployment conditions (as compared to Combo Lander II)
- Surface system reusability is enabled
- Greater improvement in Earth vicinity abort scenarios developed
- Total mission mass estimates:
    - Solar Electric Propulsion: 585 mt

Decadal Planning Team / NASA Exploration Team Mars Missions

Objective

- Develop a Mars mission approach embodying the philosophy:
  - Go Anywhere, anytime
  - Avoid political obstacles - No HLLV
  - Limit the total mission duration (goal of one-year)

Approach

- Include both short-stay and long-stay mission options
- Investigated both EELV-Exploration Class and 100-mt launch vehicles
- Solar Electric Propulsion and Nuclear Thermal Propulsion options
- Crew size of 6
- Understand trajectory sensitivities for all opportunities and various trip times

1999-2002

Principal Results

- Short-stay missions are very demanding missions
  - One-year round-trip missions occur infrequently (1 out of 7 opportunities)
  - Mission mass varies widely across launch opportunities (400-1600 mt)
  - Short-stay missions provide little time at Mars for contingencies
  - Round-trip mission times for short-stay missions range from 365 to 600 days
- Long-stay missions reduce mission complexity, but require longer overall mission
  - Mission mass constant across launch opportunities (30% variation)
  - Total mission times range from 892-945 days with surface stay times ranging from 501-596 days
- Utilizing EELV-Exploration Class launch vehicle impractical (excessive number of launches and complex orbital assembly and checkout)
- Estimated radiation exposure for long-stay missions is lower than short-stay missions

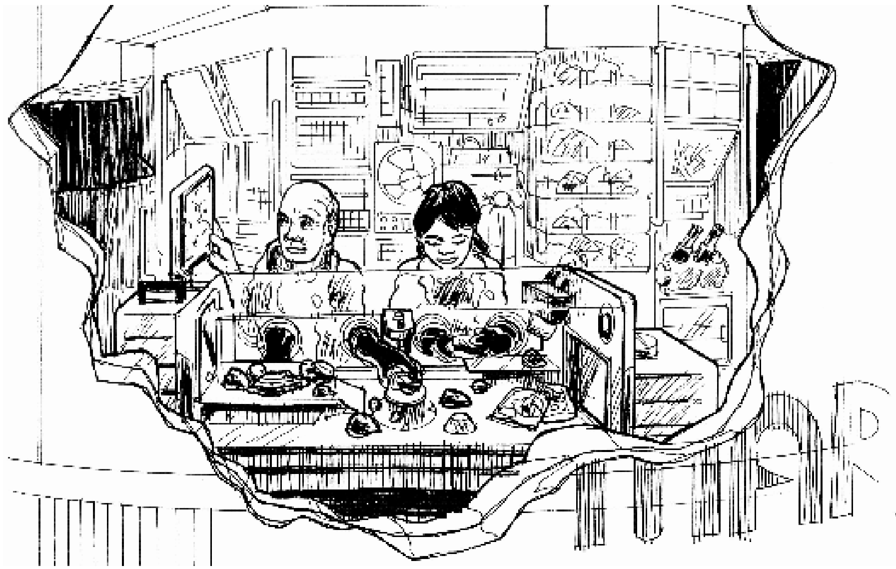
Mars Surface Science Objectives

- **To explore Mars and learn how Mars is similar to, and how it is different from, our home planet**
  - whether life evolved on Mars and, if so, whether and how such life may have become extinct
  - whether Mars is still a geologically live planet
  - how the early history of Mars and the history of volatiles on Mars may illuminate the history of Earth

- **Strategy Components**
  - Fossil-Life Search
  - Atmospheric Evolution and Climate History
  - Geoscience and Geologic History

Science Functions

- **Exploring in person**
  - Cleaving rocks
  - Auguring holes
  - Trenching
  - Raking and sieving
  - Drilling
  - Documenting
  - Observing (human eye)
- **Exploring via Telepresence**
  - As above through remote control
- **Surveying**
- **Sounding**
- **Deploying Instruments**



- **Planning**
- **Documenting**
- **Preparing Samples for Analysis**
- **Sample Curation**
- **Laboratory Analysis, Synthesis, and Computer Modeling**
- **Consulting Colleagues on Earth**

Science Tools and Equipment

For EVA Exploration

- Drills
- Geologists field tool kit
- Portable chem/mineral analysis
- Cameras / imaging
- Portable workstation
- Navigation aids and communications
- Electronic field notebook
- Life detection

Laboratory Analysis

- Elemental analyzer
- Mineralogical analyzer
- Stable isotope analyzer
- Petrographic Microscope
- Life detection and characterization equipment

Science Collaboration

- High quality voice and imagery communications for collaboration with colleagues on Earth

Telepresence Exploration

- Predeployed rovers
- High bandwidth telecommunications
- Displays
- Controls
- Imaging and remote manipulation
- Virtual environment graphics
- Geological, chemical, and biological sensors

Library

- Mission critical information on-board in digital form
- Remote access to information on Earth

	HABITAT LANDER System Mass (kg)	DESCENT / ASCENT LANDER System Mass (kg)
Payloads and Systems	**33677.9**	**15368.4**
9.0 Science	829.9	301.2
Field Geology Package	0.0	301.2
Geoscience Laboratory Eq.	98.0	0.0
Exobiology Laboratory	40.8	0.0
Geophysical/Meteriology Inst.	61.0	0.0
Teleoperated Science Rovers	0.0	0.0
Traverse Geophysical Inst.	221.0	0.0
Drill Equipment	209.1	0.0
Meterology Balloons	200.0	0.0

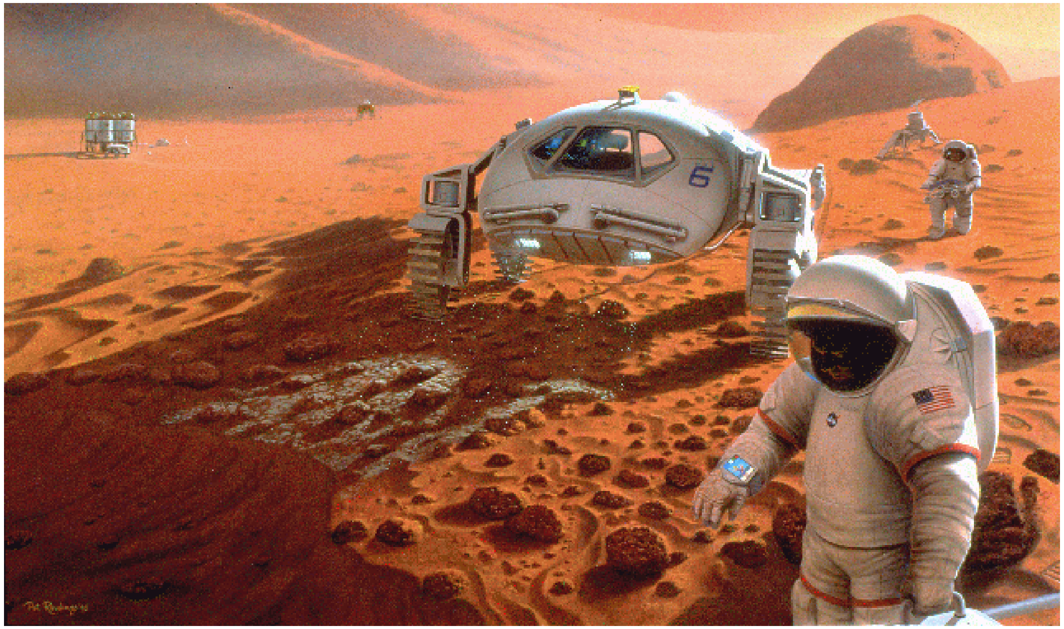
Exploration Field Work

- **Field work is a primary objective**
- **The landing site is probably not the most interesting site**

- **A "field camp" could be used to minimize commuting time**

Mobility is Key for Exploring the Surface

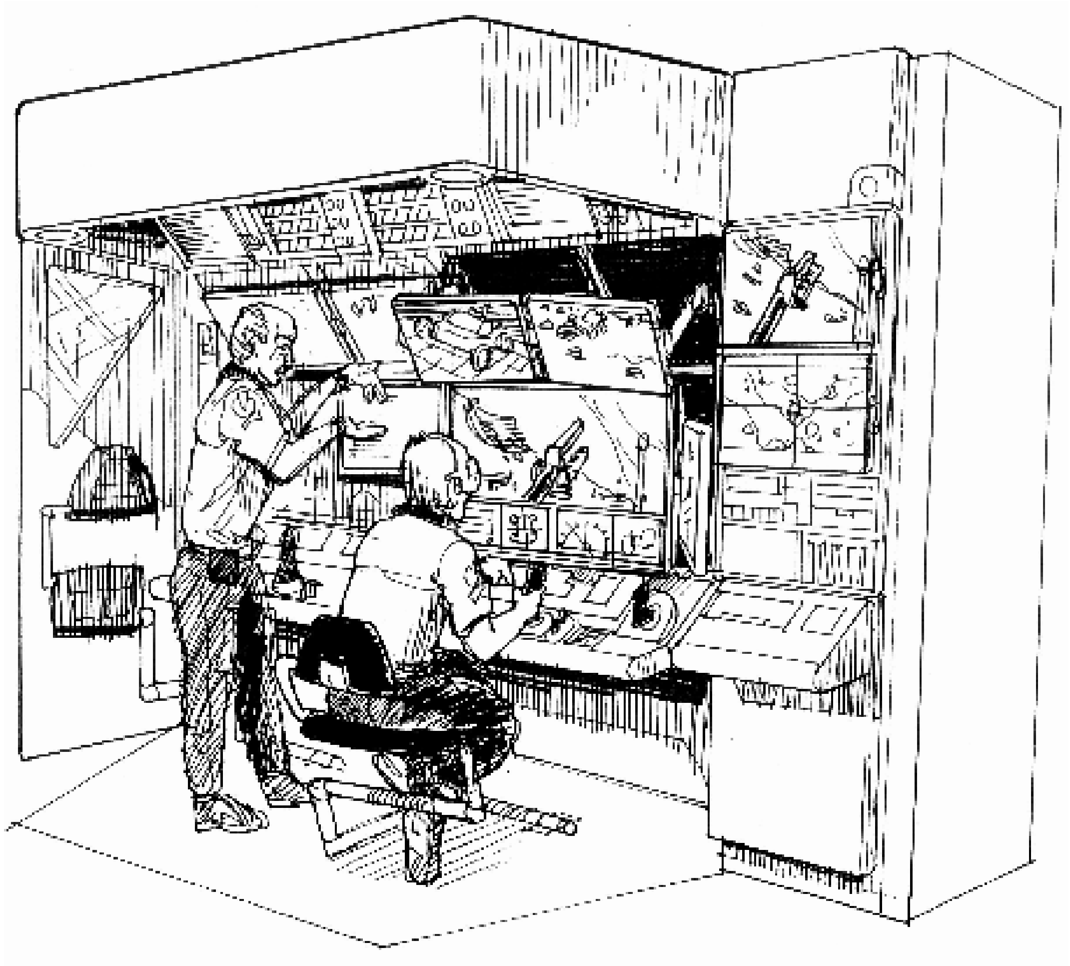
- **EVA suits**
  - 4 - 8 hour duration
- **Unpressurized rovers**
  - similar duration as EVA suit



- **Pressurized rovers**
  - several days duration

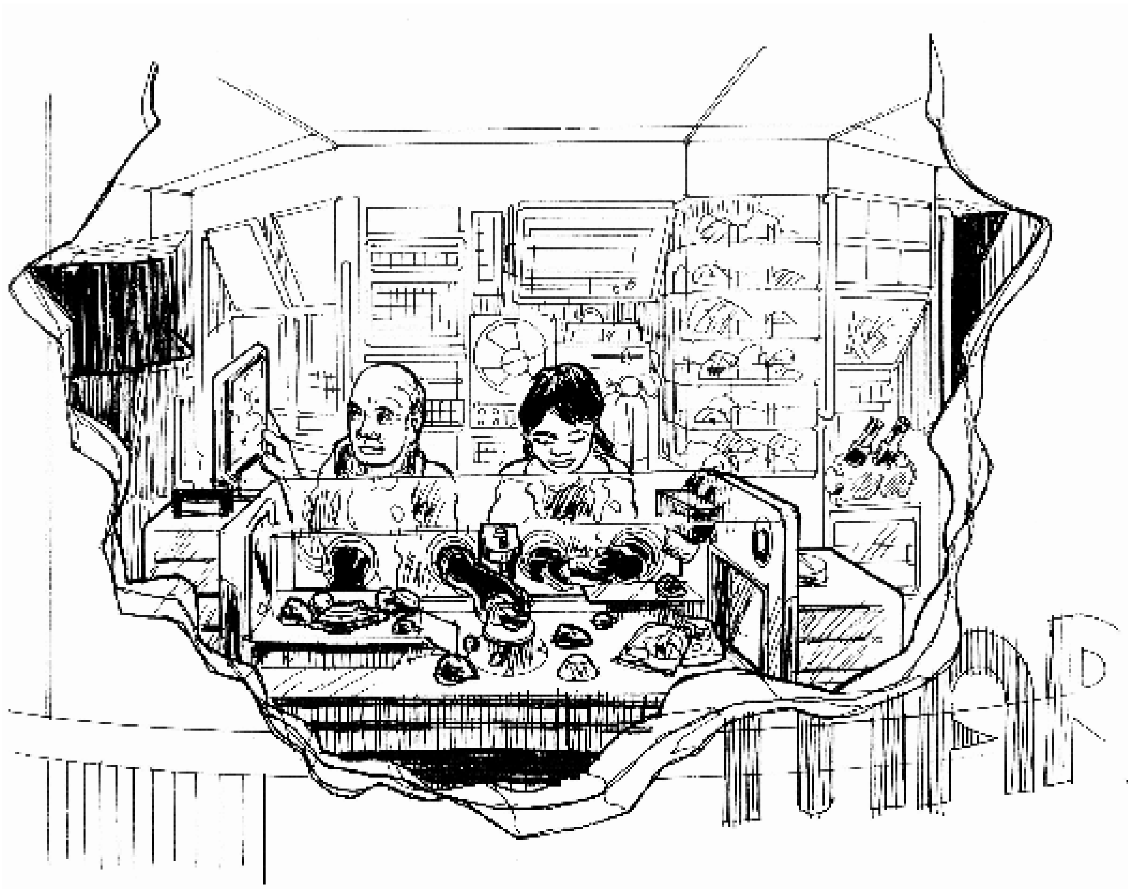
Rover Teleoperations

- Explore beyond the range of EVAs
- Early reconnaissance
- Follow-up visits
- Maintenance



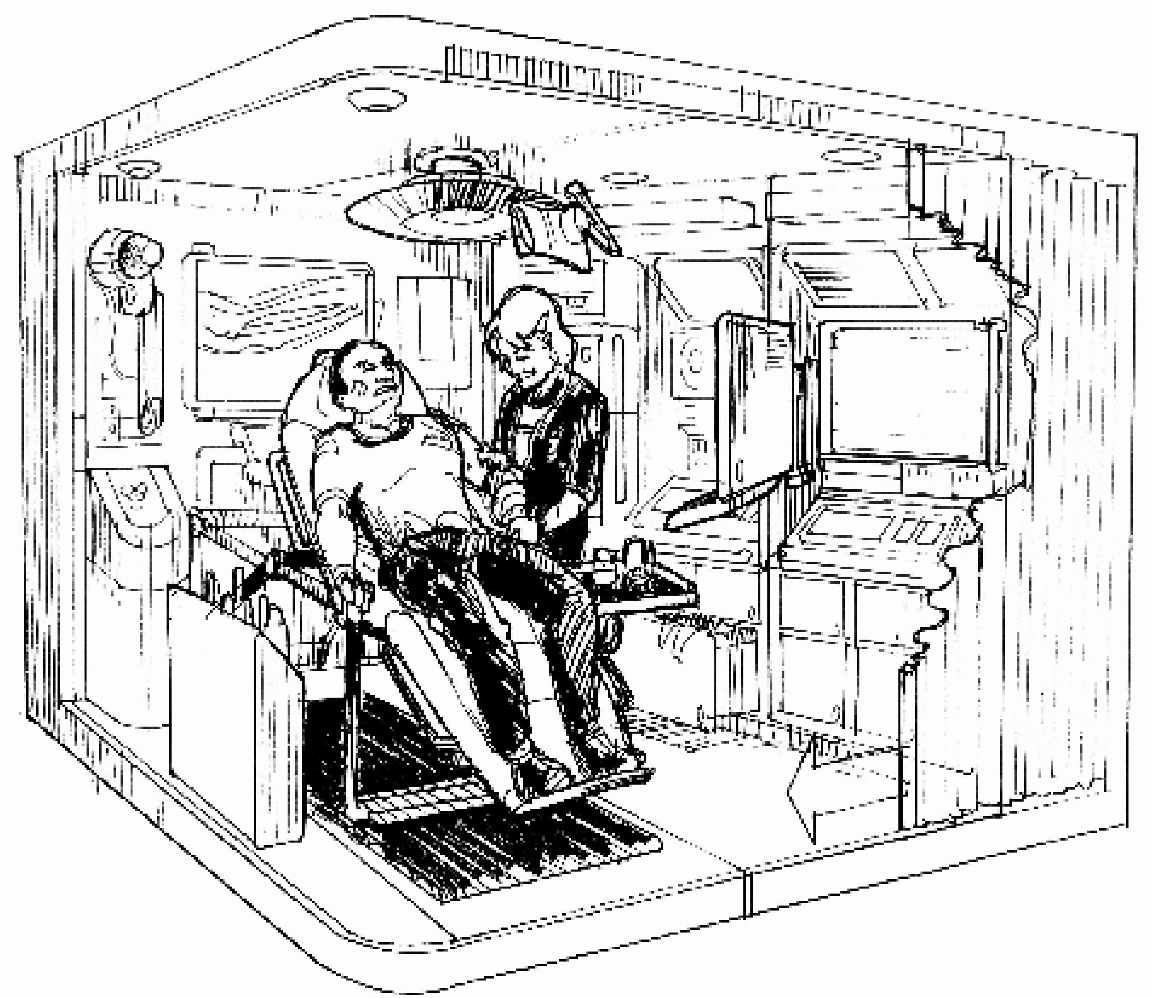
Habitat Laboratory

- **Search for life**
- **Test hypotheses**
- **High-grade samples**



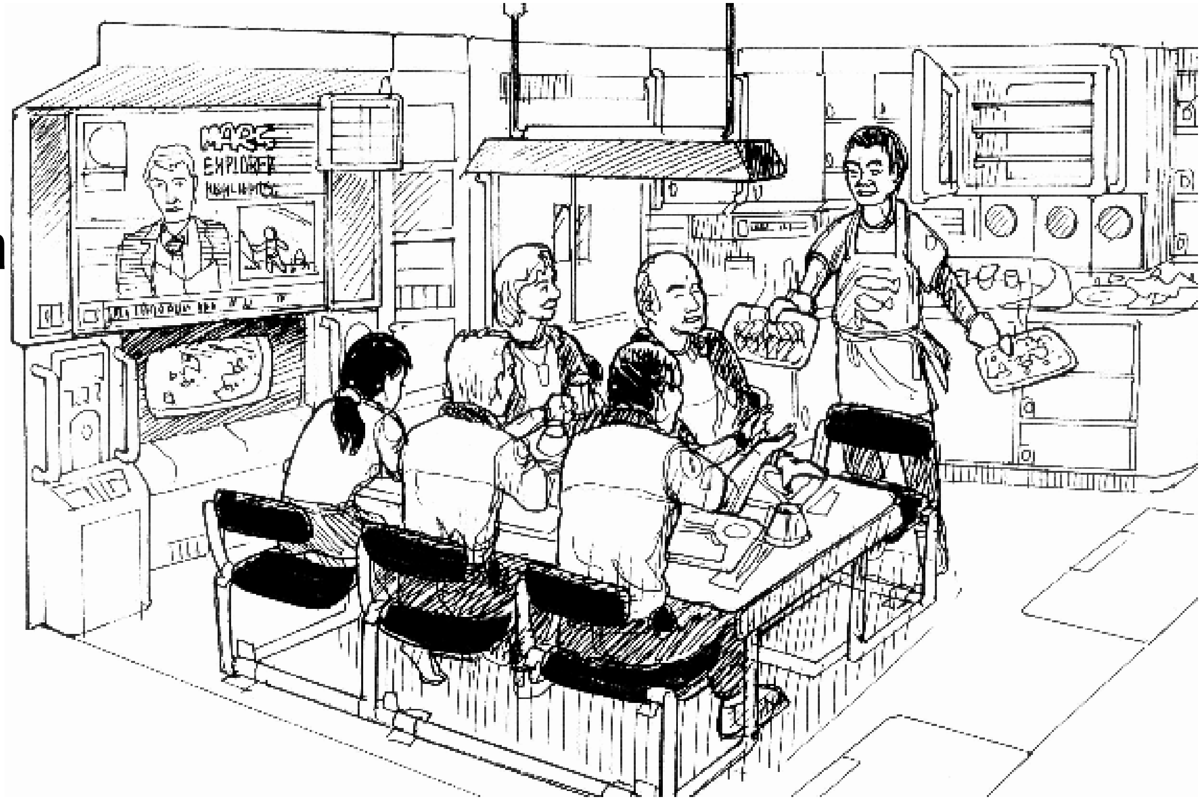
Medical Facilities

- **Monitor crew health**
- **Available for emergencies**



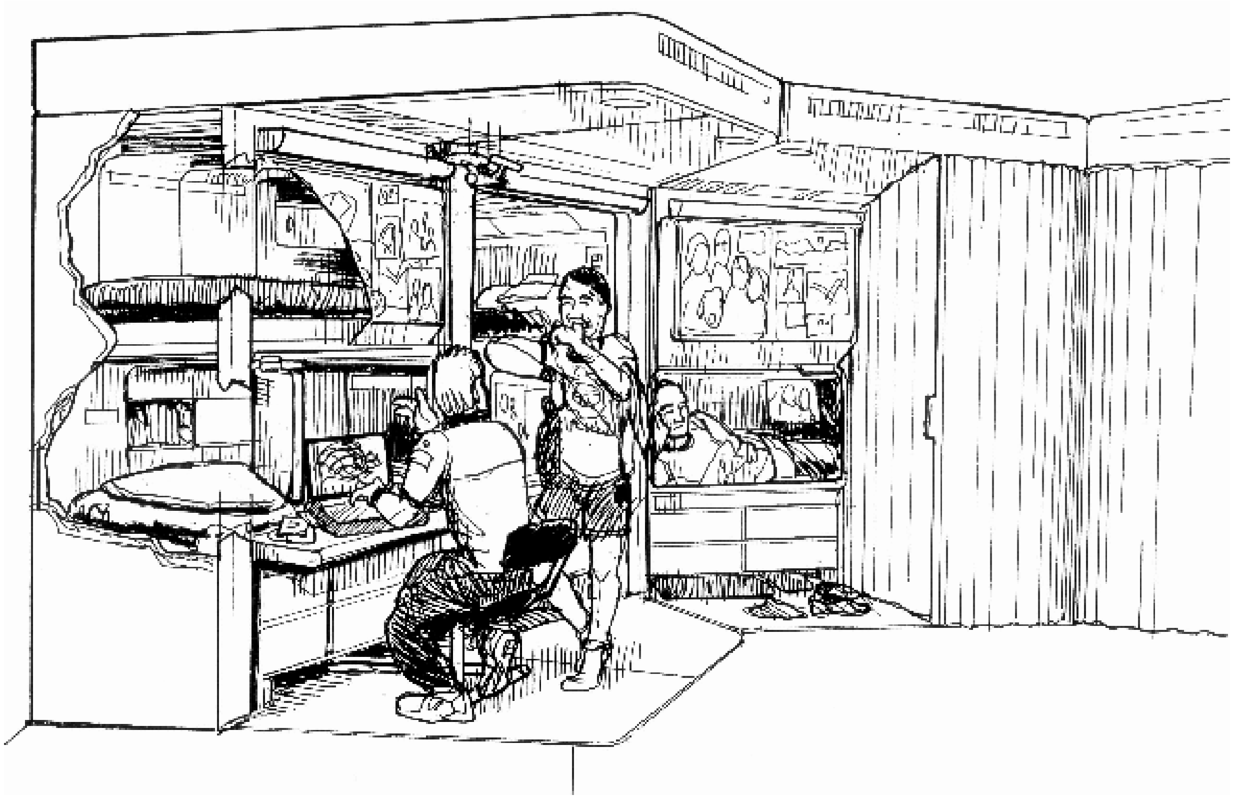
Wardroom

- Community meals
- Meeting room
- Social area
- "Information Wall"



Crew Quarters

- Privacy
- Buddy system
- Personal space

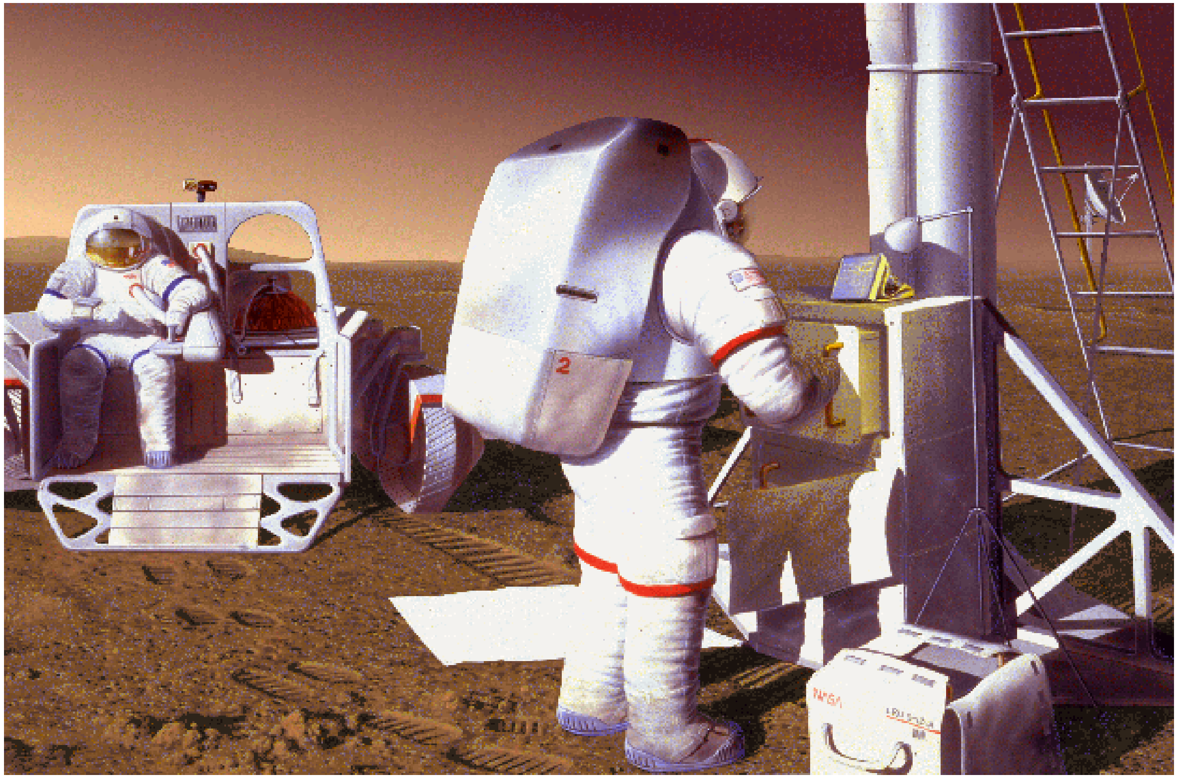


- **Robots to assist crew**
  - autonomous
  - supervised
  - teleoperated
- **Local navigation aids**
  - space-based
  - surface-based

- **Information storage and retrieval**

External Maintenance and Repair

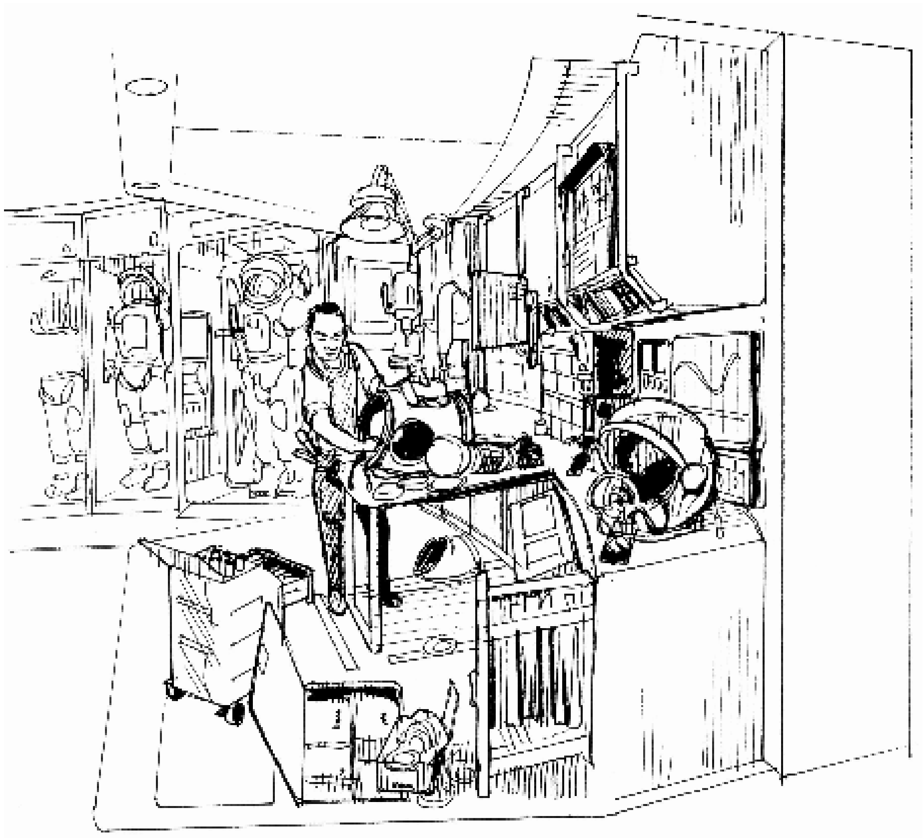
- **Emphasize reliability to minimize spares and maintenance activities**



- **Repairable systems EVA and robotic compatible**

Maintenance and Repair Workstation

- **Capability to repair at the piece-part level**
- **Manufacture simple parts**
- **Common parts/modules to minimize the number of spares**



Advanced Concept Analysis in Support of the Integrated Space Plan

Section 4.1.3

Exploration Architecture Analysis
Human Missions to the Sun-Earth Libration Point (L2)

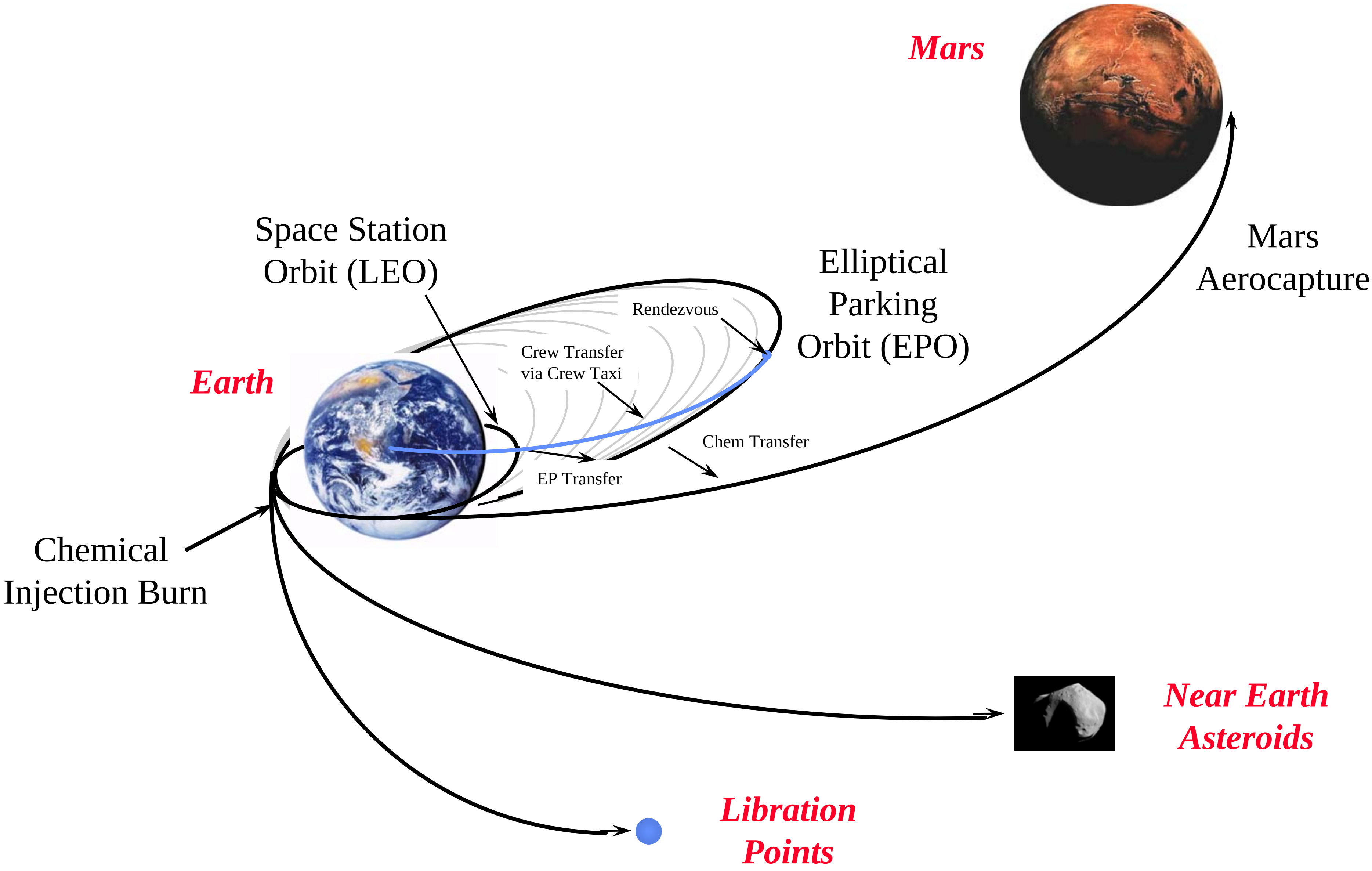
November 2002

Primary Objectives

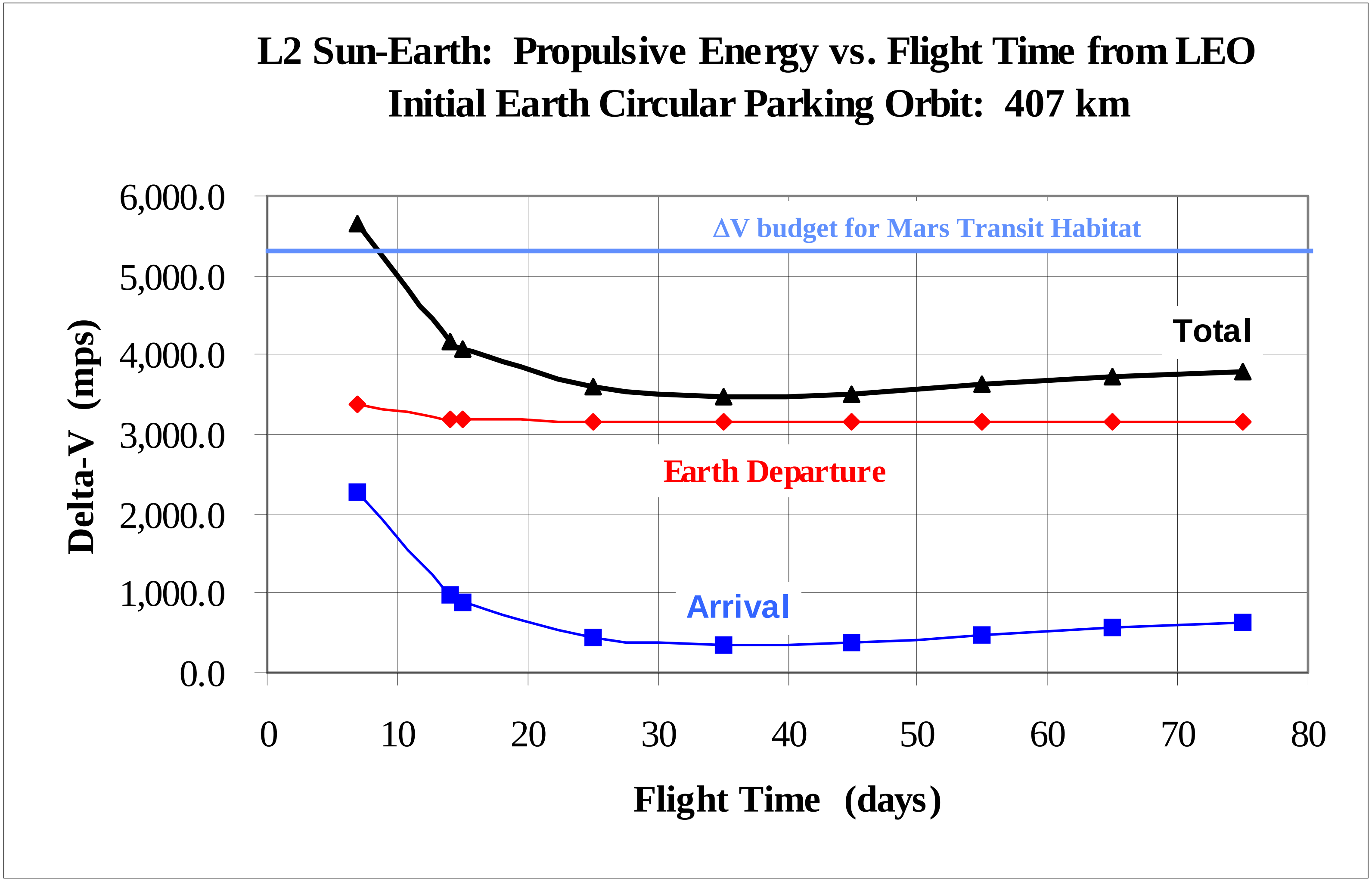
- ***Can provide an inexpensive and early validation of:***
  - ***Core exploration capabilities and technologies***
    - Transit Habitat (subscale)
    - High Performance Chemical Propulsion Stage (trans-Mars injection stage)
    - Aeroassist (at Earth return)
    - Advanced space power systems
    - Launch vehicle
  - ***Development and demonstration of interplanetary cruise hardware***
  - ***Deep-space operational experience***
    - Begin to bridge the operational experience gap between LEO missions and long-duration deep space missions

- ***Does not make sense to use Sun-Earth libration points as a staging location for Mars missions***
  - ***Requires more energy (~700 m/s)***
  - ***Adds more trip time (~ 2 months)***

High Earth Orbit Staging Mission Scenarios

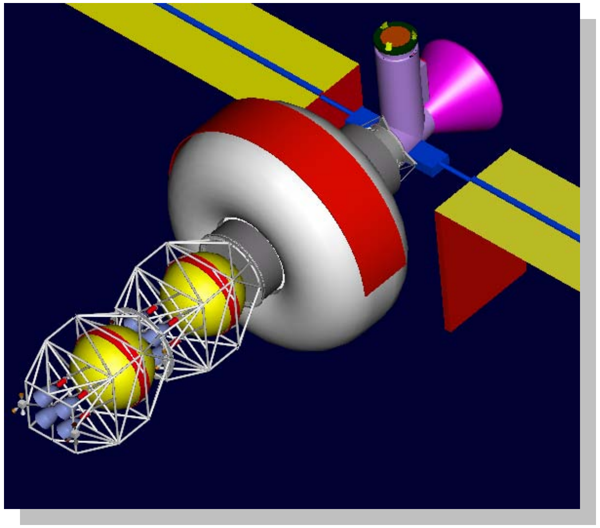


Earth-Sun Libration Point Trajectories



Earth-Sun Libration Point Vehicle Configuration

HEO Departure



- "Mini-TransHab" design based on current TransHab approach
- Supports mission crew of 4 for up to 100-day round-trip mission
- 400 kWe SEP spirals vehicle to HEO (7 months), crew taxi used to deliver flight crew to HEO
- Return propulsion stage integrated with transit system
- Earth Return Vehicle for crew return

Mass Statement for round-trip Earth-Sun (L2) mission

Sun-Earth L_2 Mission Mass Breakdown	Mass (kg)	Stowed Vol. (M3)
1.0 Power System	3339	0.000
2.0 Avionics	287	0.140
3.0 Environmental Control & Life Support	2797	19.133
4.0 Thermal Management System	1163	5.260
5.0 Crew Accommodations	2153	15.685
6.0 EVA Systems	738	1.782
7.0 Structure	822	0.000
Margin (15%)	1695	6.300
Crew	372	- - - - -
Food (Return Trip)	200	0.696
Food (Stay time)	400	0.835
Food (Outbound Trip)	200	0.696
Food (Contingency)	0	0.000
Total Transit Habitat Mass	**14540**	**50.525**
Earth Return Vehicle	**4271**	**0.000**
Total Transit Habitat Mass plus ERV	**18810**	
Aerobrake	**0**	**0.000**
Primary Structure	3184.0	- - - - -
Thermal Protection System	3012.0	- - - - -
Margin	0.0	0.000
Total Transit Habitat plus Aerobrake	**18810**	
Propulsion Stage	**14164**	**0.000**
Stage	1149	0.000
Propulsion	1792	0.000
Propellants	11223	0.000
Total with Stage	**32975**	
SEP Vehicle	**33000**	
Power System	9709	
Propulsion System	3142	
Propellant	20149	
INITIAL MASS IN LOW EARTH ORBIT	**65975**	

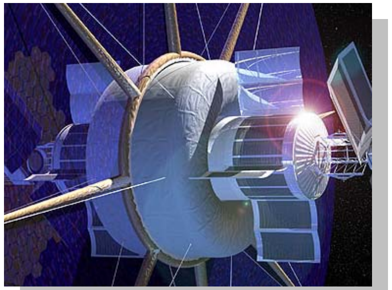
Human Libration Point Missions
Common Capabilities

Earth to Orbit Transportation

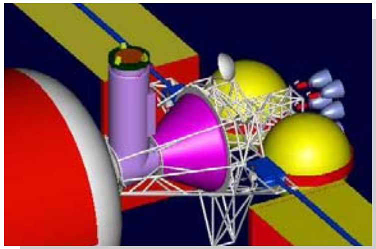
Cost effective delivery of large exploration payloads to low-Earth orbit

Interplanetary Habitation

Long duration (100 days) support of multiple mission crews



High Performance Chemical Propulsion Stage



Performs all major propulsive maneuvers including injection, capture, and return

Solar Electric Propulsion Vehicle

Transports mission payloads from low-Earth orbit to high-Earth staging orbits

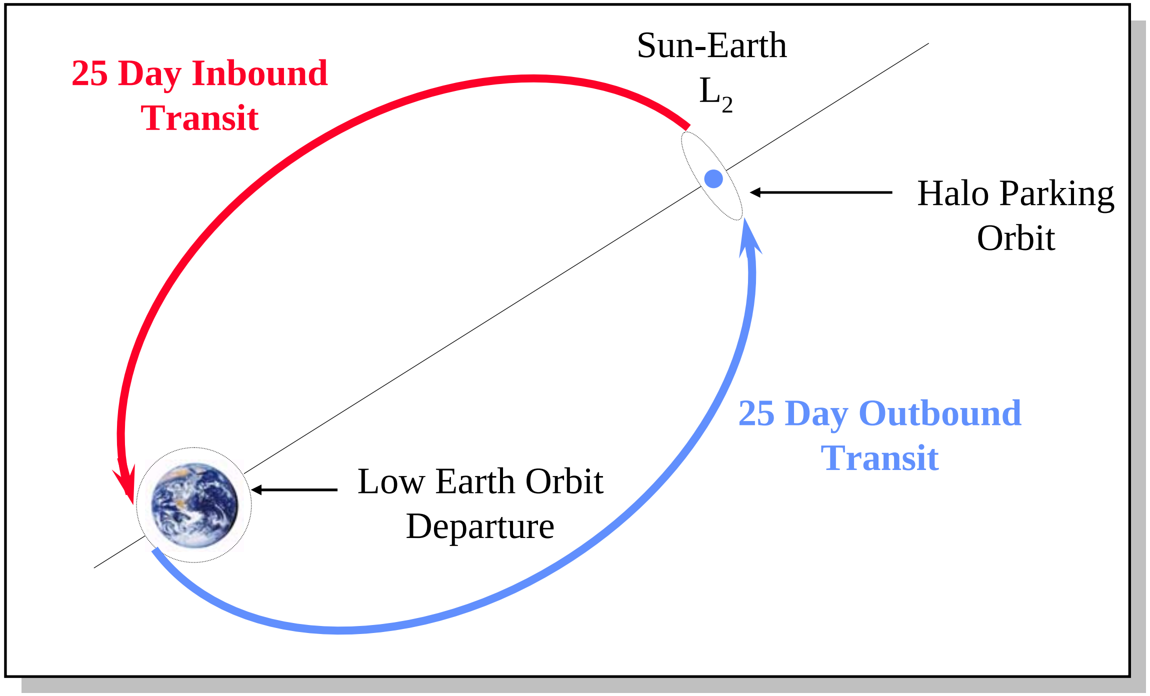
Crew Taxi

Transports mission crew from low-Earth orbit to high-Earth staging orbits

Backup

Sun-Earth Libration Point Mission Profile

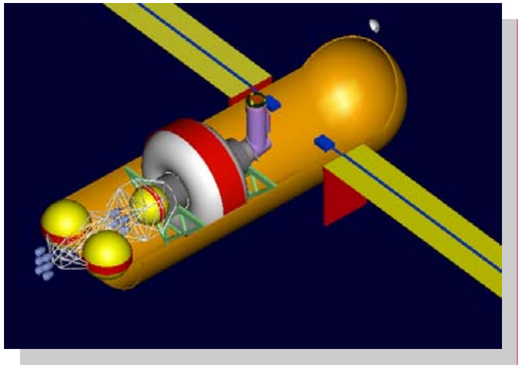
- "100-day" Class Mission
- 25-day transits to and from libration point
- 50-days in libration point halo orbit



Sun-Earth Libration Point

LEO Departure Options

Option A



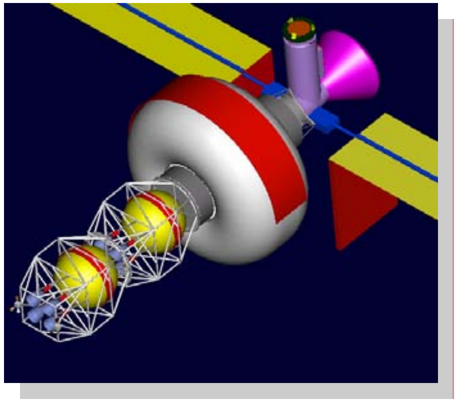
- Magnum used for delivery of hardware, STS delivers crew
- Stage A performs departure burn. Stage B performs all other burns.
- Aerobraking at Earth return - habitat reused.

Magnum
- Stage A
- Stage B
- TransHab
- Aerobrake
(91,600 kg)

STS
- TransHab outfitting

STS
- TransHab checkout
- Crew delivery

Option B



- Delta-IV H and STS used for delivery to LEO
- Stage A performs partial departure burn. Stage B finishes departure burn and performs all other maneuvers.
- Direct entry at Earth return - no reuse

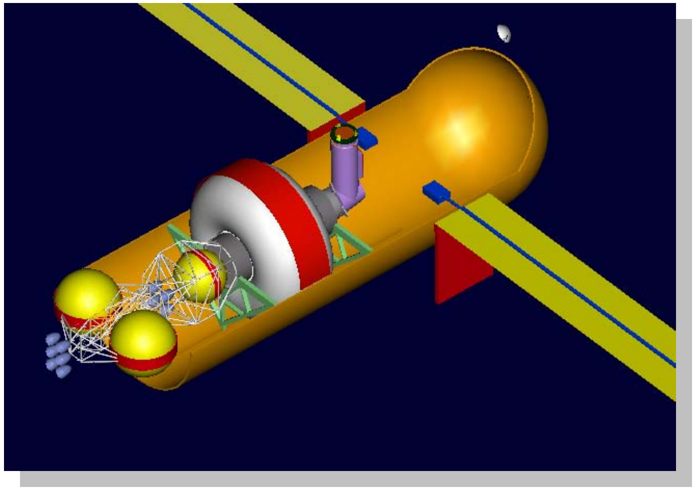
Delta IV-H
- Stage A
(32,000 kg)

Delta IV-H
- Stage B
(34,000 kg)

STS
- TransHab outfitting
- ERV
(18,800 kg)

STS
- TransHab checkout
- Crew delivery

Earth-Sun Libration Point Vehicle Configuration
LEO Departure Option A



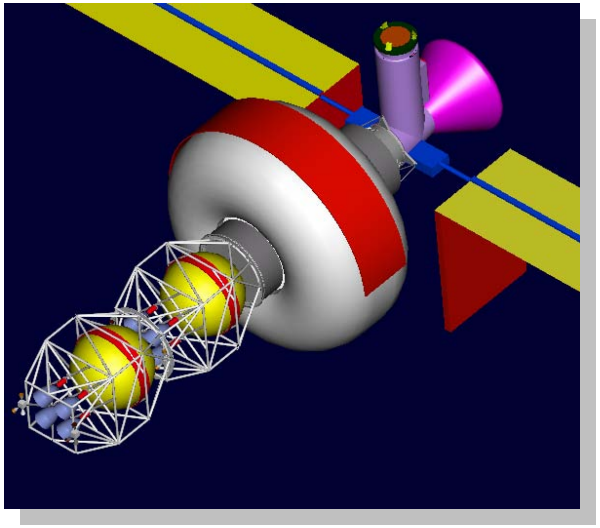
- "Mini-TransHab" design based on current TransHab approach
- Supports mission crew of 4 for up to 100-day round-trip mission
- Provides zero-g and deep-space radiation protection
- Return propulsion stage integrated with transit system
- Habitation system returned to Low-Earth Orbit for reuse

Mass Statement for round-trip Earth-Sun (L2) mission

Sun-Earth L_2 Mission Mass Breakdown	Mass (kg)	Stowed Vol. (M3)
1.0 Power System	3339	0.000
2.0 Avionics	287	0.140
3.0 Environmental Control & Life Support	2797	19.133
4.0 Thermal Management System	1163	5.260
5.0 Crew Accommodations	2153	15.685
6.0 EVA Systems	738	1.782
7.0 Structure	822	0.000
Margin (15%)	1695	6.300
Crew	372	- - - - -
Food (Return Trip)	200	0.696
Food (Stay time)	400	0.835
Food (Outbound Trip)	200	0.696
Food (Contingency)	0	0.000
Total Transit Habitat Mass	**14540**	**50.525**
Aerobrake	**6196**	**0.000**
Primary Structure	3184	- - - - -
Thermal Protection System	3012	- - - - -
Margin	0	0.000
Total Transit Habitat plus Aerobrake	**20736**	
Stage A	**30276**	**0.000**
Stage	2150	0.000
Propulsion	2092	0.000
Propellants	26034	0.000
Total with Stage A	**51012**	
Stage B	**40613**	**0.000**
Stage	2758	0.000
Propulsion	2092	0.000
Propellants	35762	0.000
INITIAL MASS IN LOW EARTH ORBIT	**91624**	

Earth-Sun Libration Point Vehicle Configuration

LEO Departure Option B



- "Mini-TransHab" design based on current TransHab approach
- Supports mission crew of 4 for up to 100-day round-trip mission
- Provides zero-g and deep-space radiation protection
- Return propulsion stage integrated with transit system
- Earth Return Vehicle for crew return; Transit Habitat abandoned.

Mass Statement for round-trip Earth-Sun (L2) mission

Sun-Earth L_2 Mission Mass Breakdown	**Mass (kg)**	**Stowed Vol. (M3)**
1.0 Power System	3339	0.000
2.0 Avionics	287	0.140
3.0 Environmental Control & Life Support	2797	19.133
4.0 Thermal Management System	1163	5.260
5.0 Crew Accommodations	2153	15.685
6.0 EVA Systems	738	1.782
7.0 Structure	822	0.000
Margin (15%)	1695	6.300
Crew	372	- - - - -
Food (Return Trip)	200	0.696
Food (Stay time)	400	0.835
Food (Outbound Trip)	200	0.696
Food (Contingency)	0	0.000
Total Transit Habitat Mass	**14540**	**50.525**
Earth Return Vehicle	**4271**	**0.000**
Total Transit Habitat Mass plus ERV	**18810**	
Stage A	**31825**	**0.000**
Stage	2241	0.000
Propulsion	2092	0.000
Propellants	27492	0.000
Total with Stage A	**50635**	
Stage B	**34394**	**0.000**
Stage	2392	0.000
Propulsion	2092	0.000
Propellants	29909	0.000
INITIAL MASS IN LOW EARTH ORBIT	**85029**	

Earth to Orbit Transportation

Functions

- Cost effective delivery of large exploration payloads to low-Earth orbit

Sizing Parameters

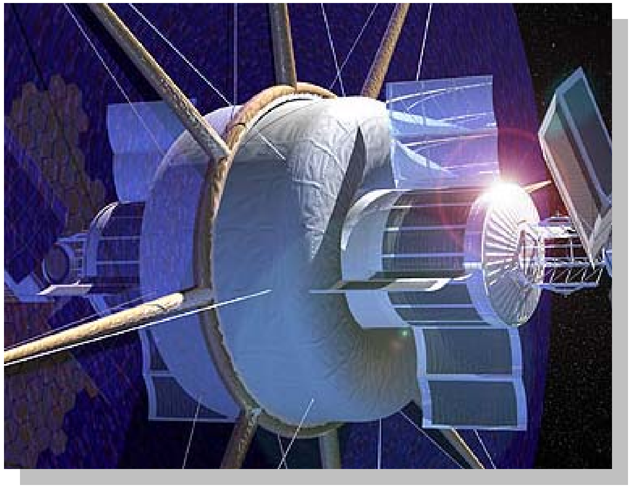
Payload Capability:	80-90 mt
Orbit Altitude:	407 x 407 km
Orbit Inclination:	28.5-51.6 deg
Payload Length:	15 m
Payload Diameter:	7.5-8 m

Technologies

- Lightweight composites for fuel tanks and payload shrouds
- Automated rendezvous and docking
- Low-cost engine concepts
- Advanced light-weight sensors

Destination Commonality

- Moon
- Asteroids
- Libration Points
- Mars



Interplanetary Habitation

(Identical habitation system as Lunar scenario)

Technologies

- High volume-to-weight structures
- Deep-space radiation protection
- Advanced life support system closure (100% air and water)
- Zero/low-gravity research and countermeasures

Destination Commonality

- Moon
- Asteroids
- Libration Points
- Mars

Functions

- Provides habitation for *four* crew for up to 100 days in deep space

Sizing Parameters

	Mass (kg)
Power:	3,350
Avionics:	290
Life Support System:	2,800
Thermal Management:	1,150
Crew Accommodations:	2,150
Structure:	850
Margin	1,700
Total	**12,290***

* No crew consumables

Solar Electric Propulsion Vehicle

Technologies

- Advanced light-weight inflatable structures
- Advance high-performance thin film $CuInS_2$ solar cells
- High-power (100 kWe) electric thrusters (option include Hall, VASIMR, Ion)
- Radiation hardened electronic systems

Destination Commonality

- Moon
- Asteroids
- Libration Points
- Mars

Functions

- Transports mission payloads from low-Earth orbit to high-Earth staging orbits

Sizing Parameters

Specific Impulse:	2,500 sec
Propellant:	X_e or K_r
Power Module Mass:	28,000 kg
Propulsion Module Mass:	7,730 kg
Max Propellant Load:	64,270 kg
Spiral Time:	< 360 days
Payload Mass:	180-200 mt
Final Orbit	800 x 120,550 km

Crew Taxi

Functions

- Transports mission mission crew from low-Earth orbit to high-earth staging orbits

Technologies

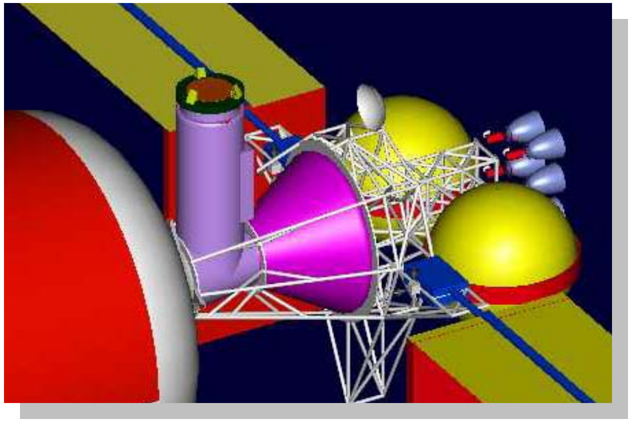
- Advanced thermal protection
- Lightweight structures, systems, sensors and avionics
- High energy aerocapture and thermal protection
- Automated rendezvous and docking

Destination Commonality

- Moon
- Asteroids
- Libration Points
- Mars

Sizing Parameters

Crew size:	6
Dry Mass:	7,480 kg
Propellant:	11,810 kg
ASE:	1,627 kg
Mission Duration:	2.7 days
Final orbit:	120,550 x 800 km



High Performance Chemical Transfer Stage

(Identical to the Trans-Mars Injection stage)

Functions

- Injects mission payloads from High-Earth orbit toward the Sun-Earth Libration Point

Technologies

- Advanced, high performance, space engine
  - Multi-start, space start
  - LO_2/CH_4 for ISRU compatibility
  - 20,000 lb_f thrust
  - Highly reliable and operationally simple
- Long-term cryogenic fluid management and storage

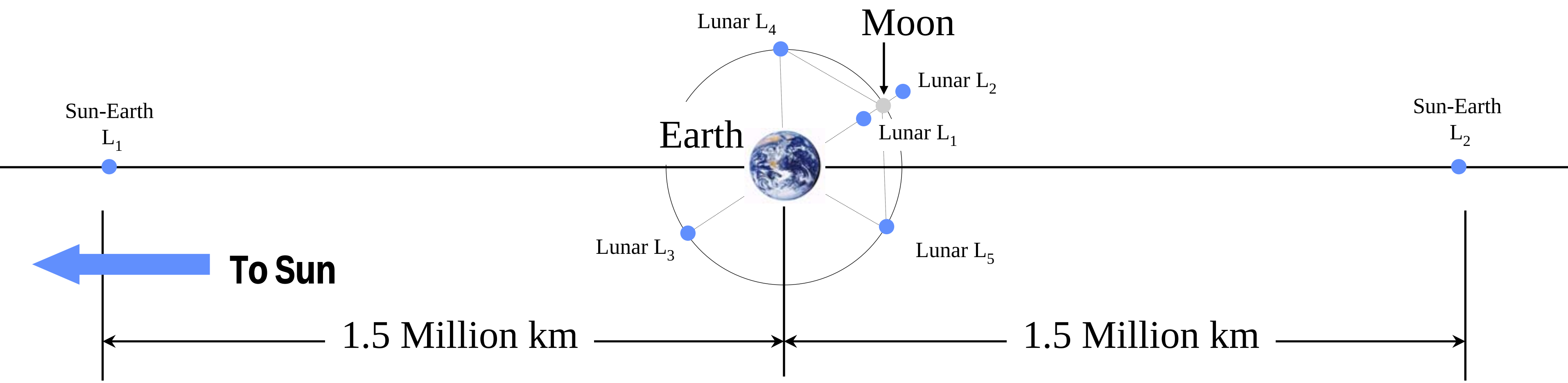
Sizing Parameters

Specific Impulse:	379 sec
Propellant:	LO_2/CH_4
Total Thrust:	120 klb_f
# Engine out capability	1
Dry Mass:	3,821 kg
Max Propellant Load:	62,610 kg

Destination Commonality

- Asteroids
- Libration Points
- Mars
- Moon

Sun-Earth Libration Point Geometry



Advanced Concept Analysis in Support of the Integrated Space Plan

Section 4.1.4

Human Exploration of Mars
Opposition Class (Short-Stay)/Conjunction Class (Long-Stay) Mission Comparison

November 2002

Mars Mission Planning

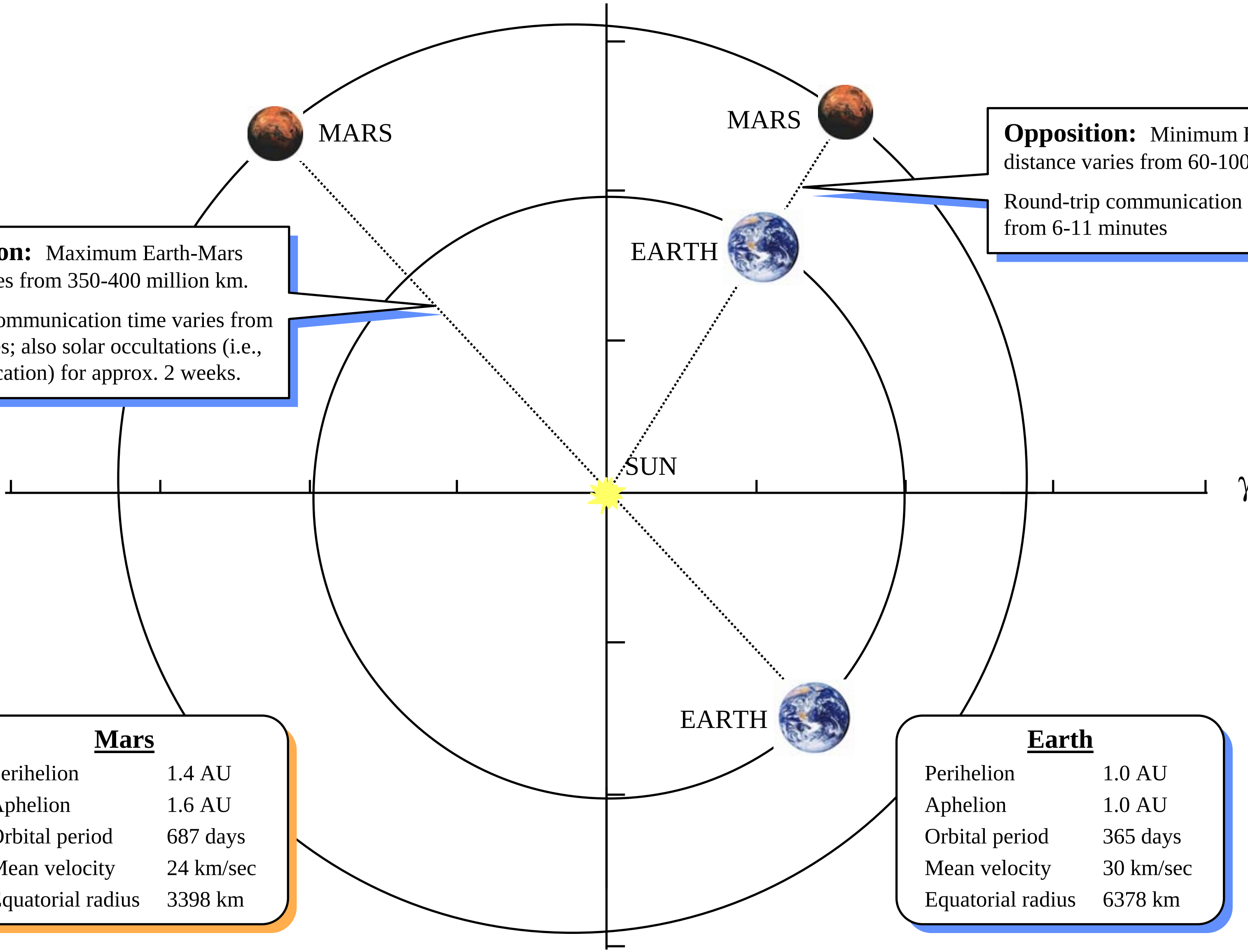
Earth-Mars Mission Planning

- Trips to Mars and back are, in effect, a double rendezvous problem
- First rendezvous outbound must be developed considering influence of the rendezvous inbound
- Practical considerations dictate favorable (and different) planetary alignments relative to the sun for both transfers

Synodic Period

- Is the period of time necessary for the phase angle between Earth and Mars to repeat itself
- Repetition rate for identical Earth-Mars phasing, and therefore launch opportunities for similar mission classes, is ~26 months
- The eccentricity of Mars' orbit causes significant variations in Earth-Mars relative distance and velocity from one opportunity to the next
- The entire range of Earth-Mars geometry is encompassed by seven launch opportunities, or about 15 years
- Before definitive claims of mission characteristics or propulsion system capabilities are made, analysis across the 15-year cycle should be performed

Earth-Mars Orbital Characteristics



Mars

Perihelion	1.4 AU
Aphelion	1.6 AU
Orbital period	687 days
Mean velocity	24 km/sec
Equatorial radius	3398 km

Earth

Perihelion	1.0 AU
Aphelion	1.0 AU
Orbital period	365 days
Mean velocity	30 km/sec
Equatorial radius	6378 km

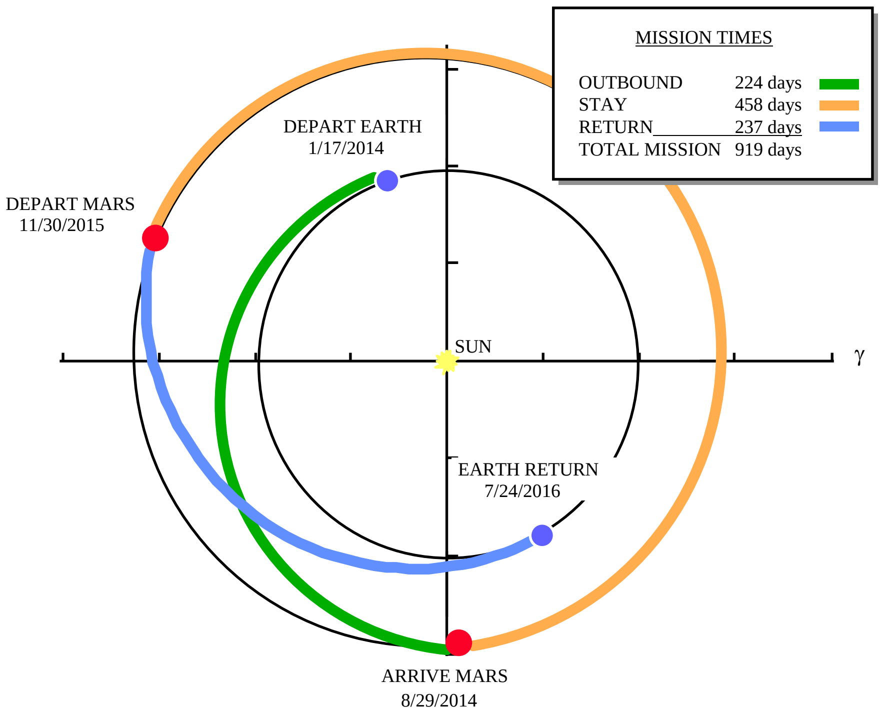
Mars Trajectory Classes

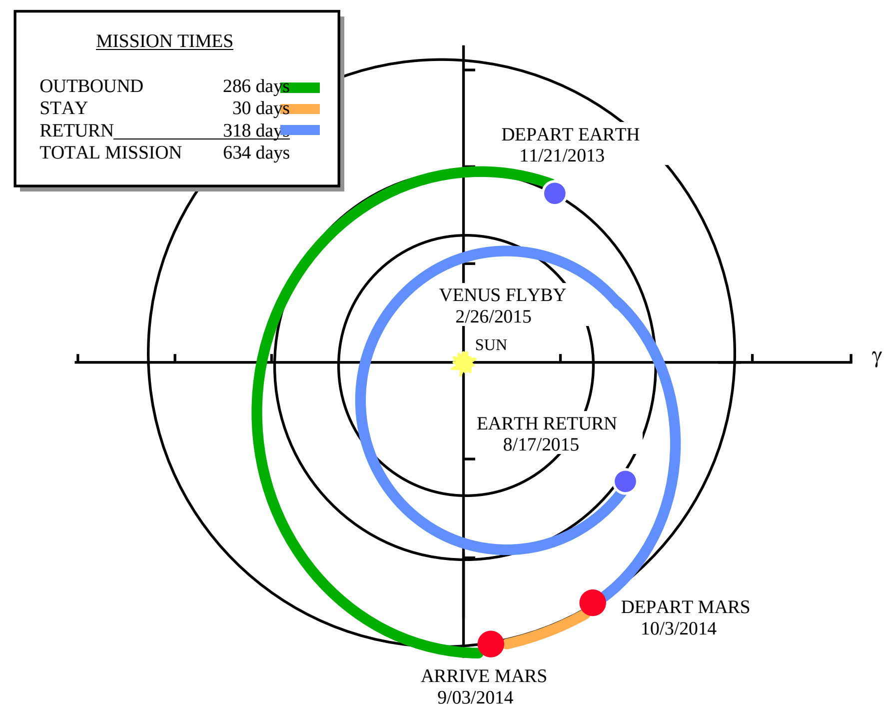
Long-Stay Missions

- Variations about the minimum energy mission
- Often referred to as Conjunction Class missions

Short-Stay Missions

- Variations of missions with short Mars surface stays and may include Venus swing-by
- Often referred to as Opposition Class missions

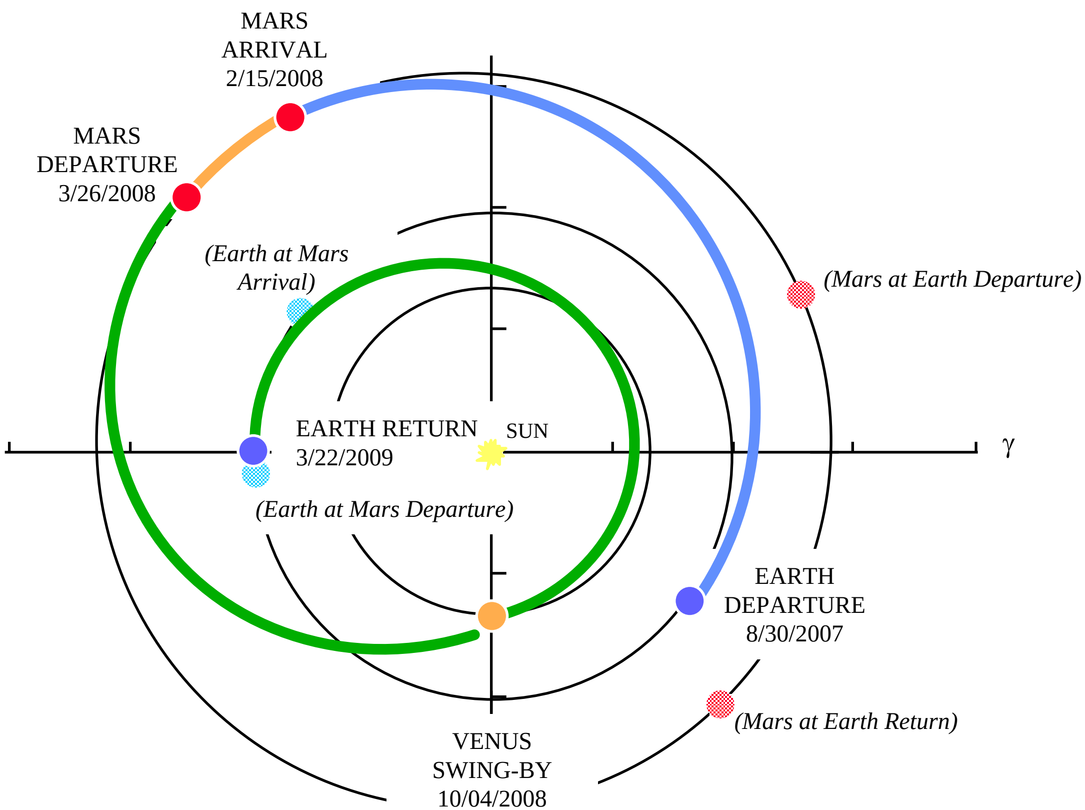




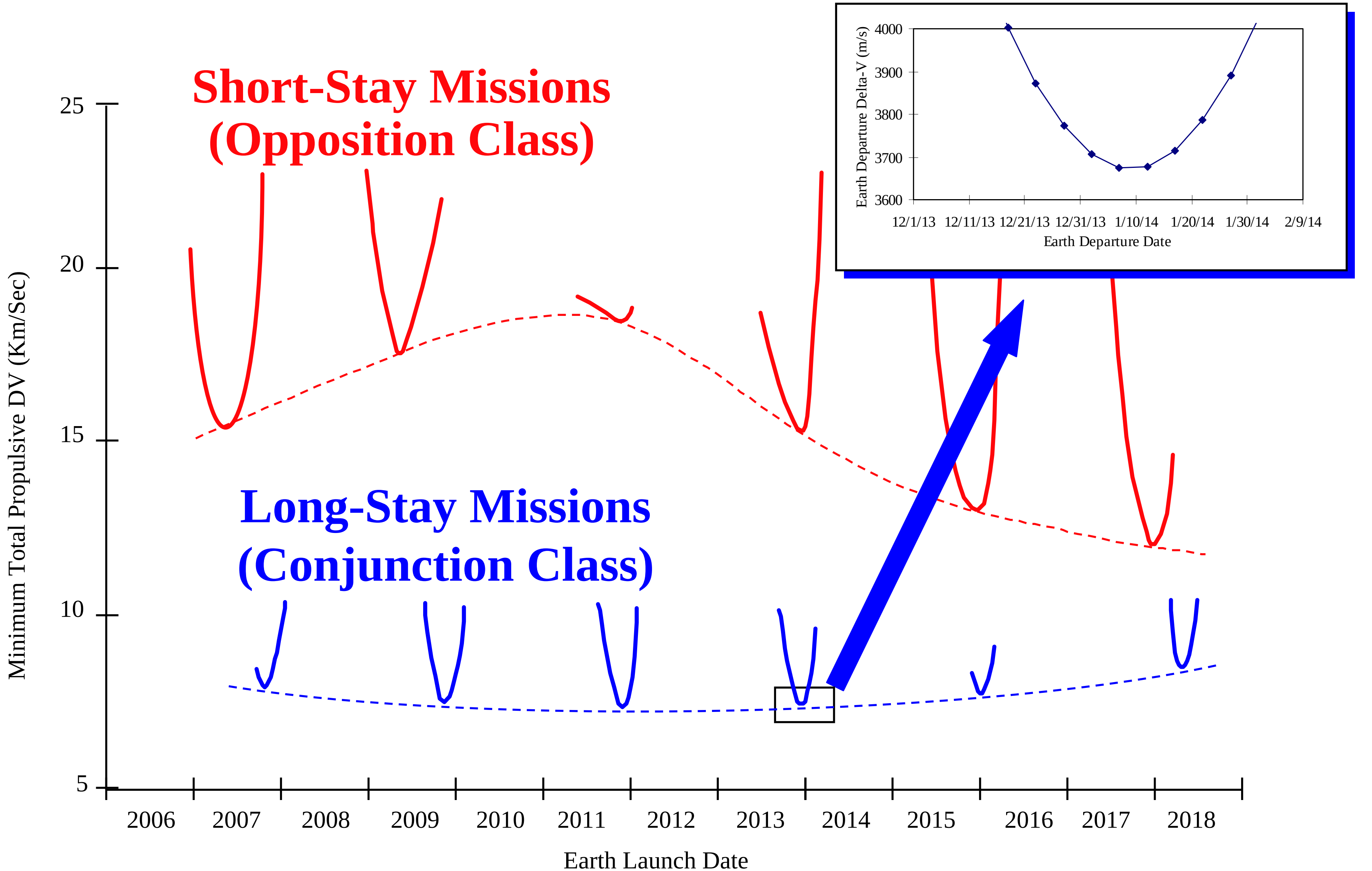
Opposition Class Missions

Venus Swing-by Strategy

- ***Either an outbound or inbound transfer which passes in the vicinity of Venus can have the same result as a deep-space maneuver***
  - More propulsively efficient than the three-impulse strategy
  - Requires that Venus be in a specific relative geometry with Earth and Mars



Delta-V Variations



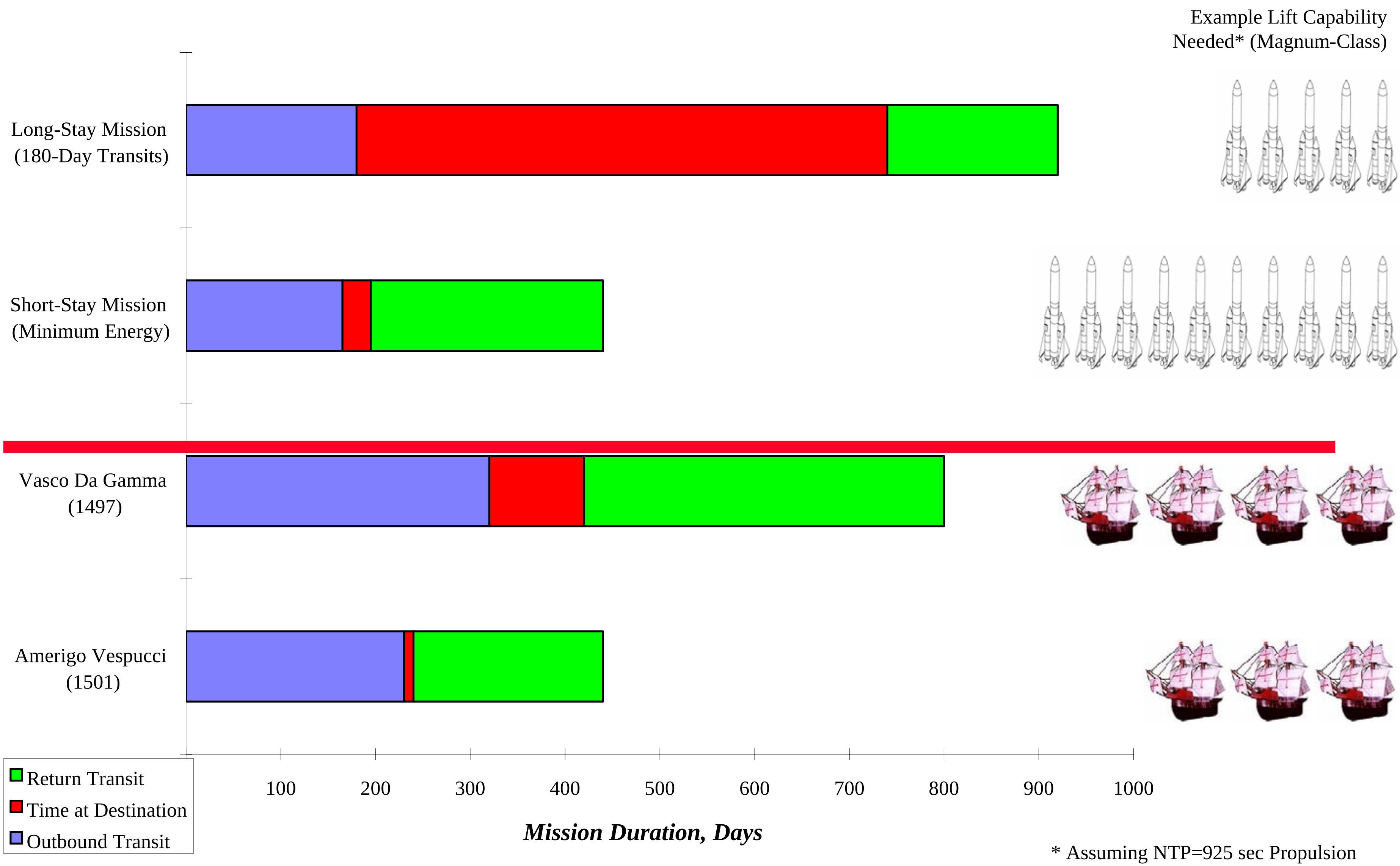
Short-Stay Mission Implications

- Significant variation of propulsion requirements for the Short-Stay mission across synodic cycle (100%) dictates need for advanced propulsion technology
  - Nuclear Thermal Propulsion
  - High-Power Electric Propulsion
- Short stay in the vicinity of Mars compromises mission return and crew safety
  - Limited time for gravity-acclimation
  - Limited time for contingencies or dust storms
  - Majority of time spent in deep space (zero-gravity & deep space radiation)
- Total mission duration for the Short-Stay Mission on the order of 15-25 months
  - System reliability still critical to success
  - Life support system reliability
  - Short (one-year) missions are possible, but limited to single opportunities over the 15-year synodic cycle
- Venus swing-by’s can reduce propulsive requirement (and thus mission mass)
  - Pass within 0.72 AU of the sun (increases radiation and thermal load)

Long-Stay Mission Implications

- Small variation (10%) of propulsion requirement for the Long-Stay mission across the 15-year synodic cycle
  - Can go any opportunity
  - Vehicles and systems common between opportunities
- Long-Stay mission trip times can be reduced for minimal impacts, thus reducing life science concerns of deep space travel (radiation and zero-gravity exposure)
- Long stay in the vicinity of Mars increases mission return and crew safety
  - Sufficient time for gravity-acclimation
  - Sufficient time for dust storms or other contingency situations
  - Majority of time spent on Mars (improved gravity and radiation environment)
- Total mission duration on the order of 30 months
  - System reliability still critical to success
  - Life support system reliability
- Surface of Mars is the “Second” safest place in the solar system
  - Planetary surface and atmosphere for increased radiation protection
  - Hypogravity environment ($3/8^{th}$ -g)
  - Stable environment (things don’t happen fast on the surface)

Mars Mission Duration Comparison



Mission Characteristic Comparisons

Parameter	Short-Stay Mission	Long-Stay Mission
Mission Duration (days)	590-740	850-950
Surface Stay	30-90	490-640
One-Way Transits	190-370	120-200
Total Transit Time	540-700	240-400
Trajectory Characteristics	Venus Swing-by	No Venus Swing-by
Total Mission Mass (mt) [1]	500-1200	400-700
% Vehicles	21% [2]	31% [3]
% Propellant	74% [2]	47% [3]
% Surface Systems	5% [2]	22% [3]

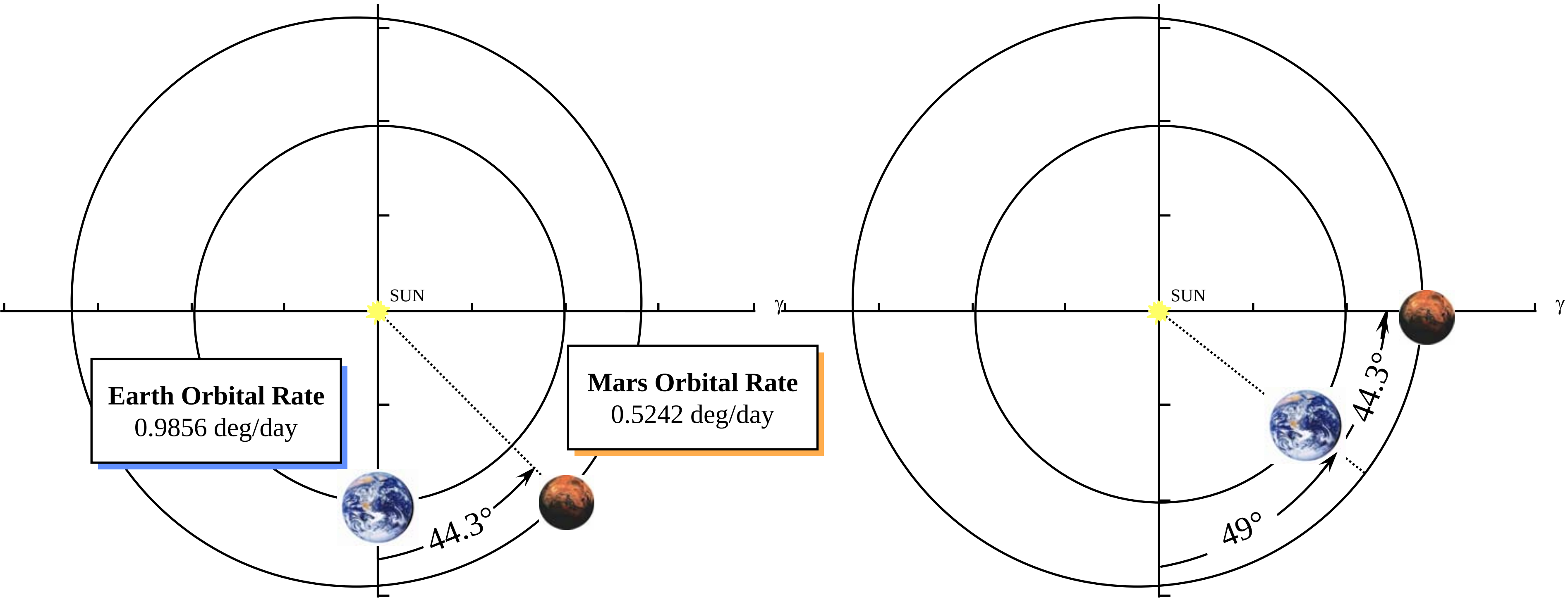
1 Assuming Nuclear Thermal Propulsion (Isp 925 sec)
2 First Piloted Flight - 90 Day Study
3 First Piloted Flight - Mars Design Reference Mission

Technology and Mission Implications

	Short-Stay	**Long-Stay**
Transportation	• Advanced propulsion <u>required</u> for reasonable mass	• Advanced propulsion enhances missions (lower mass or shorter transits)
Earth-to-Orbit	• Large mission mass necessitates high flight rate and/or larger launcher	• Lower mission mass relieves launch requirement and launch rate
Human Health	• Certification process of long zero-g space missions unknown	• Mission transits within US zero-g spaceflight experience on MIR
System Reliability	• Similar (15-25 months)	• Similar (30 months)
Mission Focus	• Transportation and propulsion	• Surface and mission return

Backup Data

Repetitive Phasing



First Opportunity ***Second Opportunity***

- Repetition rate for identical phasing = $\dfrac{\text{360 degrees}}{\text{0.9858 deg/day - 0.5242 deg/day}}$ = 780 days ~ 26 months
- Number of opportunities for full progression around sun = $\dfrac{\text{360 degrees}}{\text{49 deg per opportunity}}$ ~ 7 opportunities

Example Earth-Mars Long-Stay Missions

(Minimum Energy)

Launch Date	$\Delta V_{(1)}$ TMI	Outbound (Days)	$\Delta V_{(2)}$ MOI	Mars Stay-Time (Days)	$\Delta V_{(2)}$ TEI	Inbound (Days)	Total Mission Duration (Days)	$\Delta V_{(3)}$ Total
4/03/01	3639	200	2532	545	2108	205	950	8278
6/08/03	3574	204	2095	547	2647	192	943	8316
8/20/05	3963	217	2038	492	2703	214	923	8704
10/06/07	4199	248	2032	437	2278	262	947	8509
11/08/09	4035	278	1988	374	2064	270	922	8087
11/28/11	3672	252	2532	418	1989	259	929	8193
1/17/14	3832	224	2794	458	1941	237	919	8567
3/11/16	3739	204	2677	529	1983	212	945	8399
5/11/18	3530	204	2230	553	2466	190	946	8227
7/27/20	3807	207	2031	517	2746	203	927	8584

(1) Launch from ISS altitude orbit (407 km)
(2) 500 km circular orbit at Mars
(3) Assumes direct entry upon Earth return
All velocities in meters/second

TMI Trans-Mars Injection
MOI Mars Orbit Capture
TEI Trans-Earth Injection

Example Earth-Mars Short-Stay Missions
(with Venus Swingby)

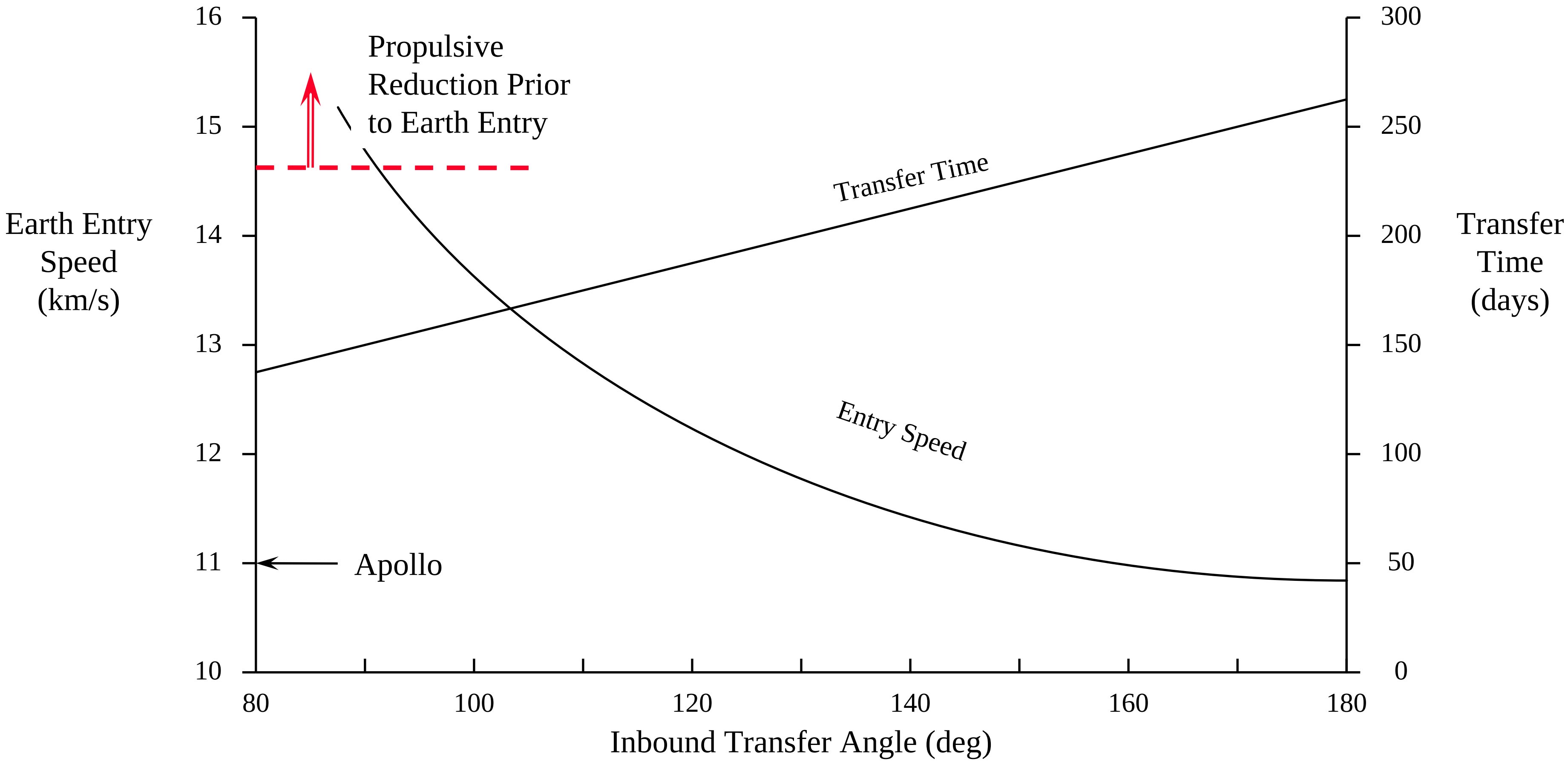
Launch Date	Venus Swingby	$\Delta V_{(1)}$ TMI	Outbound (Days)	$\Delta V_{(2)}$ MOI	Mars Stay-Time (Days)	$\Delta V_{(2)}$ TEI	Inbound (Days)	Total Mission Duration (Days)	$\Delta V_{(3)}$ Total
4/01/01	Inbound	3635	201	2538	40	4248	345	586	10422
8/22/02	Outbound	3820	302	4744	40	3134	261	603	11704
3/09/04	Outbound	4131	344	4429	40	2639	271	655	11198
8/27/07	Inbound	4600	188	4341	40	4030	340	568	12972
1/17/09	In & Out	4208	330	3339	40	3367	367	737	11342
11/28/10	Outbound	4426	330	3502	40	2494	303	673	10422
11/21/13	Inbound	3692	281	2464	40	4419	311	632	10575
10/26/15	Inbound	4865	279	3136	40	4810	261	580	12811
4/06/17	Outbound	4181	359	3780	40	2531	245	645	10502
6/09/20	Inbound	4164	190	2707	40	3961	364	594	10832

(1) Launch from ISS altitude orbit (407 km)
(2) 500 km circular orbit at Mars
(3) Assumes direct entry upon Earth return
All velocities in meters/second

TMI Trans-Mars Injection
MOI Mars Orbit Capture
TEI Trans-Earth Injection

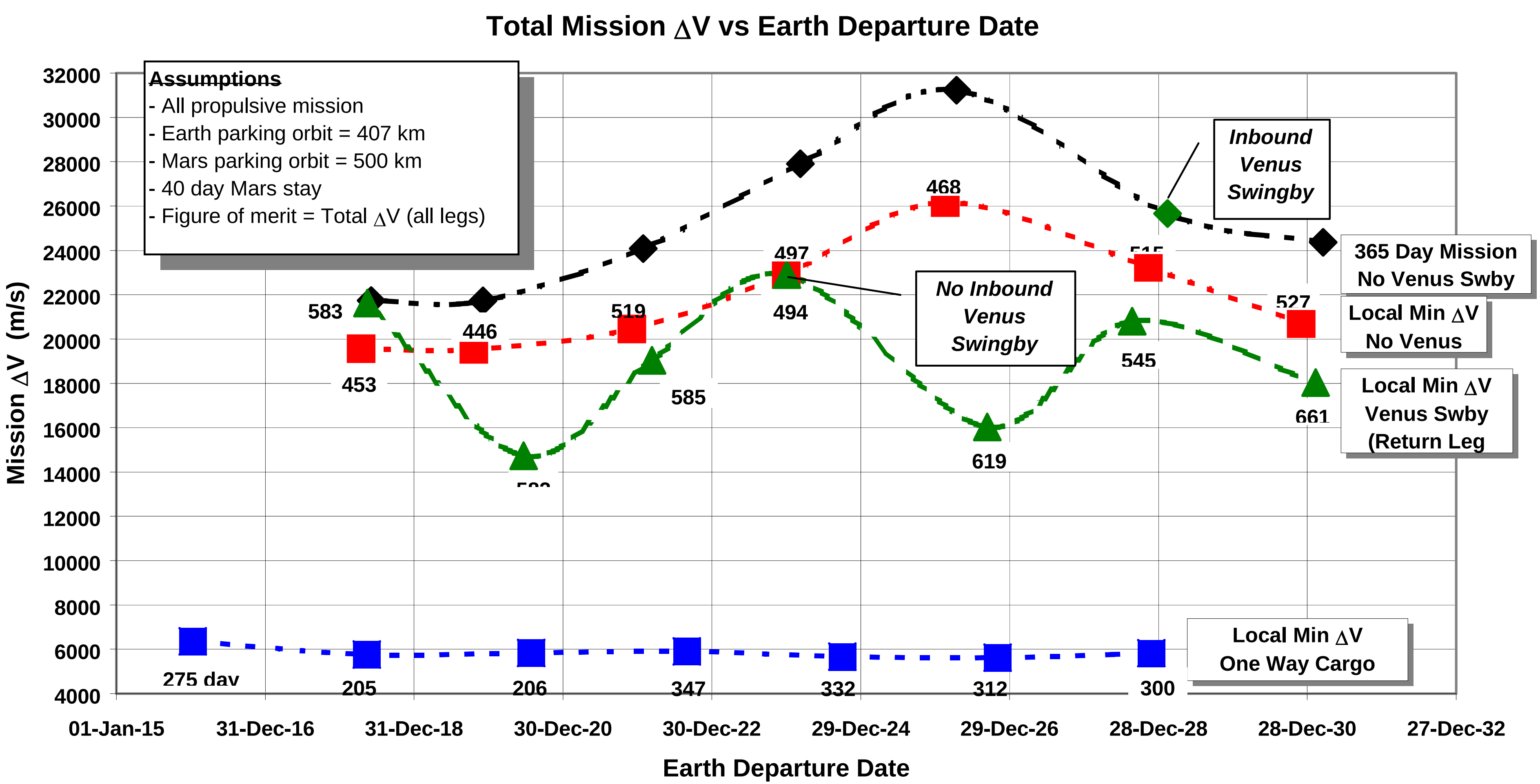
Shortening the Trip Times

- ***Trip times to and from Mars can be shortened depending on:***
  - Class of mission (conjunction or opposition)
  - Propulsion technology employed
  - Entry velocities at either Earth or Mars (if using aeroassist)



Total Mission ΔV vs Earth Departure Date

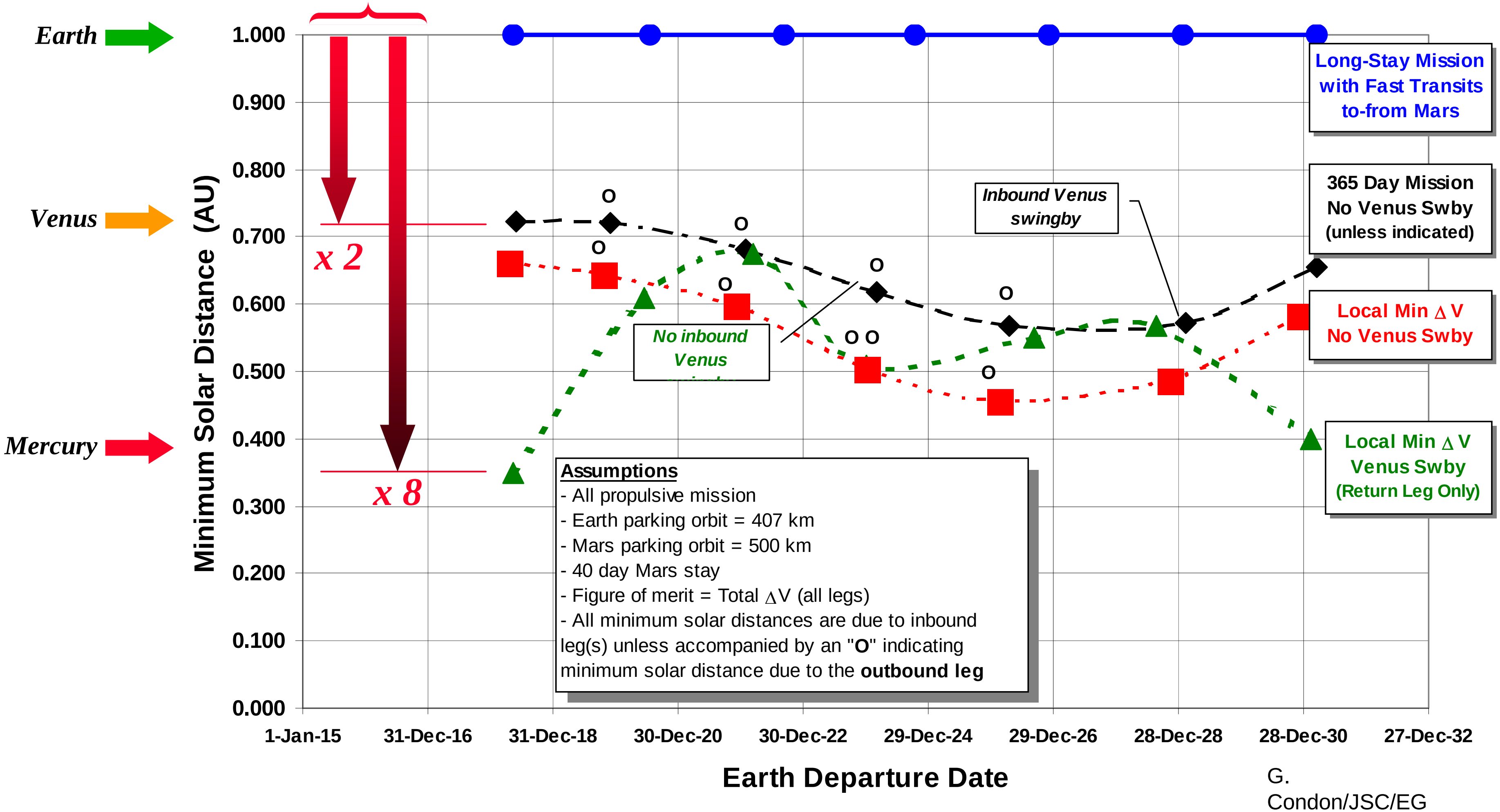
Short-Stay Mars Missions



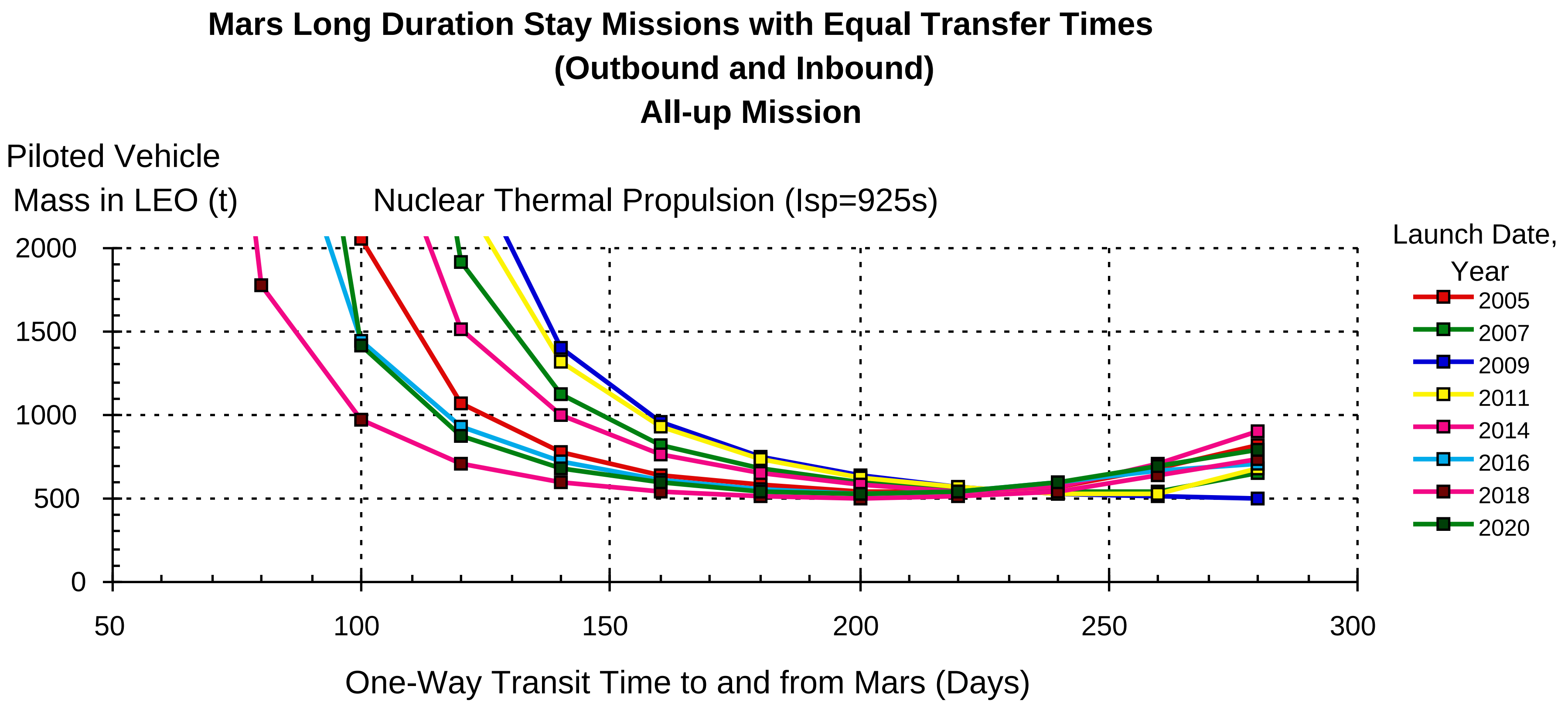
Minimum Solar Distance vs. Mission Opportunity

Short-Stay Mars Missions

Radiation doses during solar fly-by can increase 2-8 times



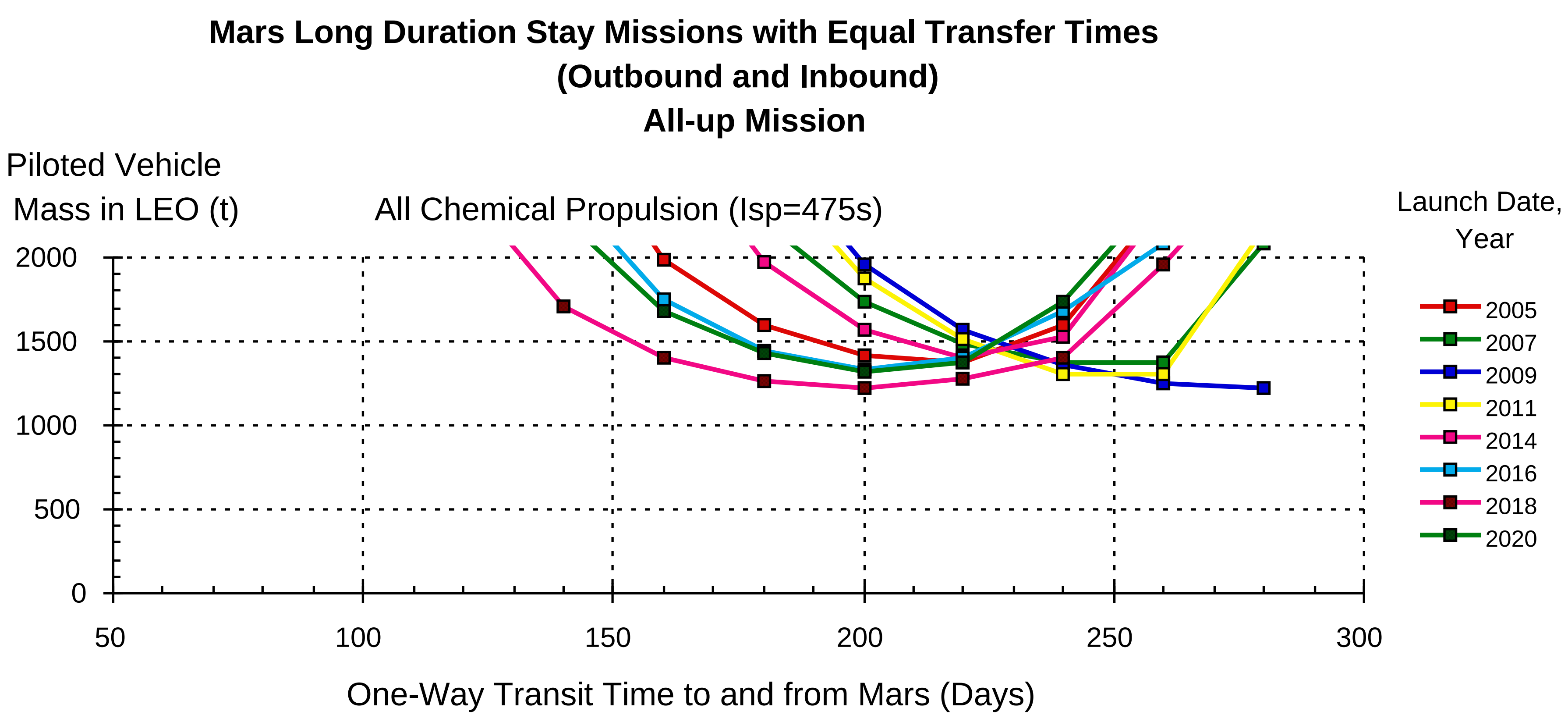
Trip Time Sensitivity: Long-Stay Missions



* Total mission durations range from 830-960 days

Mass estimates derived from vehicle scaling equations and are not based on detailed point designs

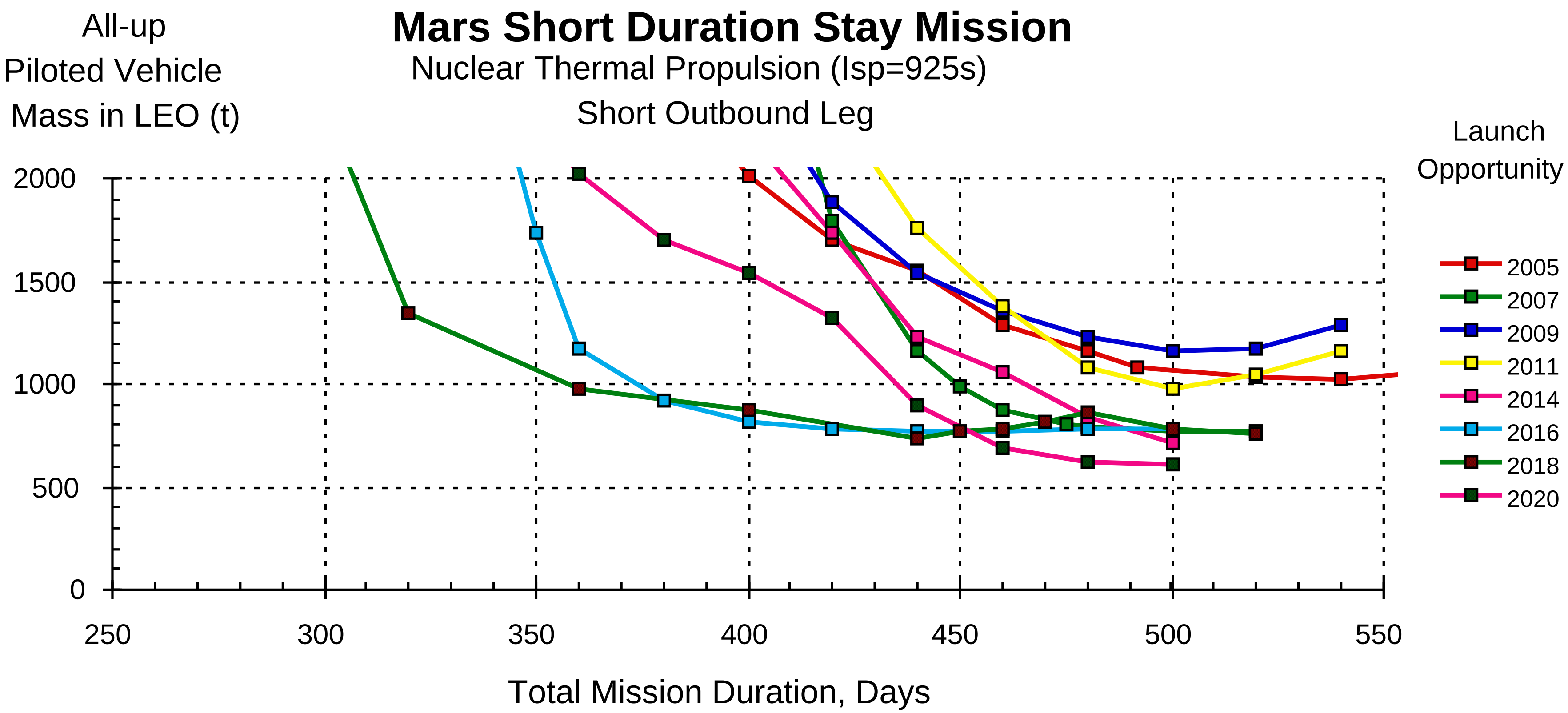
Trip Time Sensitivity: Long-Stay Missions



* Total mission durations range from 830-960 days

Mass estimates derived from vehicle scaling equations and are not based on detailed point designs

Trip Time Sensitivity: Short-Stay Missions



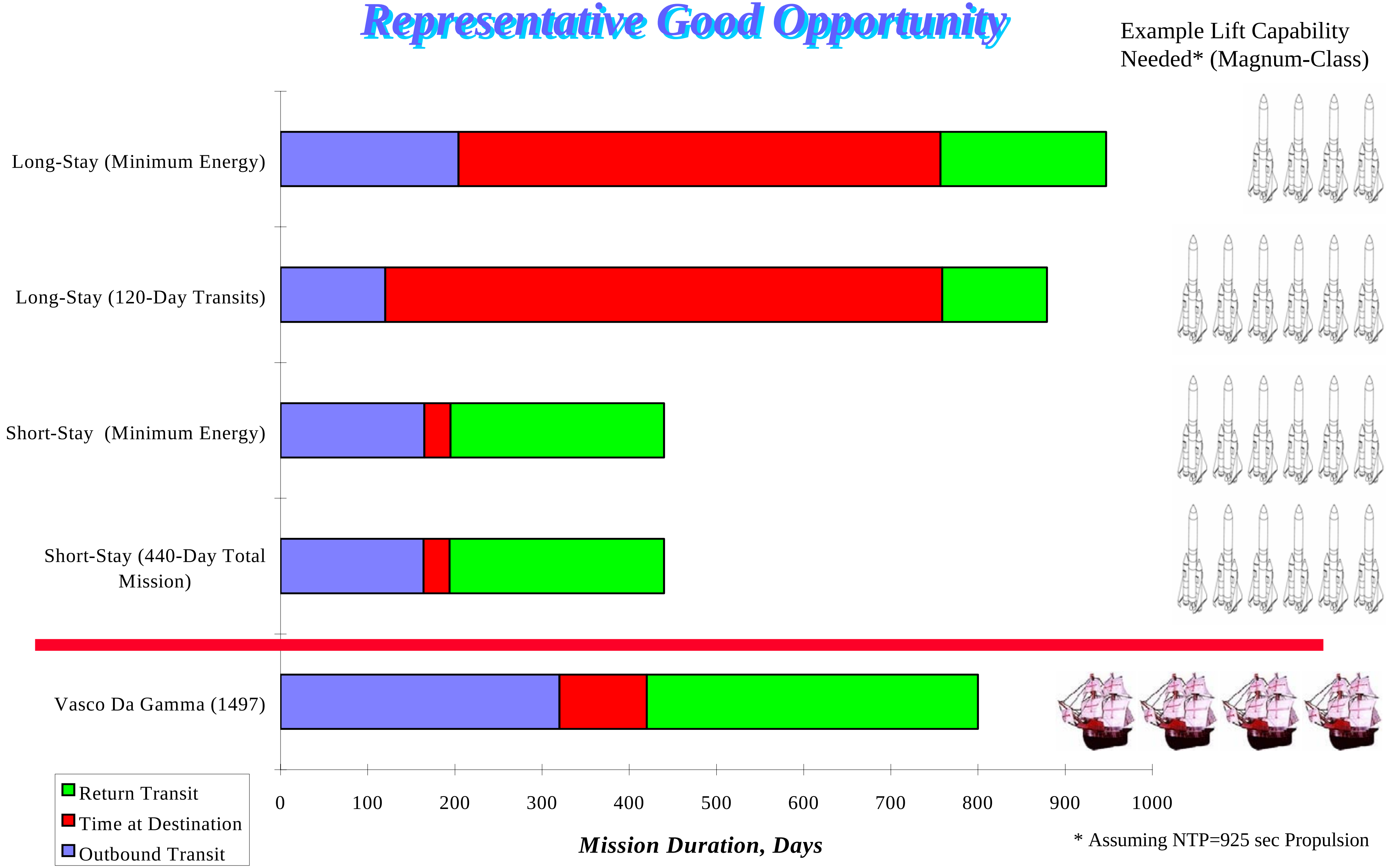
* Includes 30-day surface stay

Mass estimates derived from vehicle scaling equations and are not based on detailed point designs

Mars Mission Duration Comparison

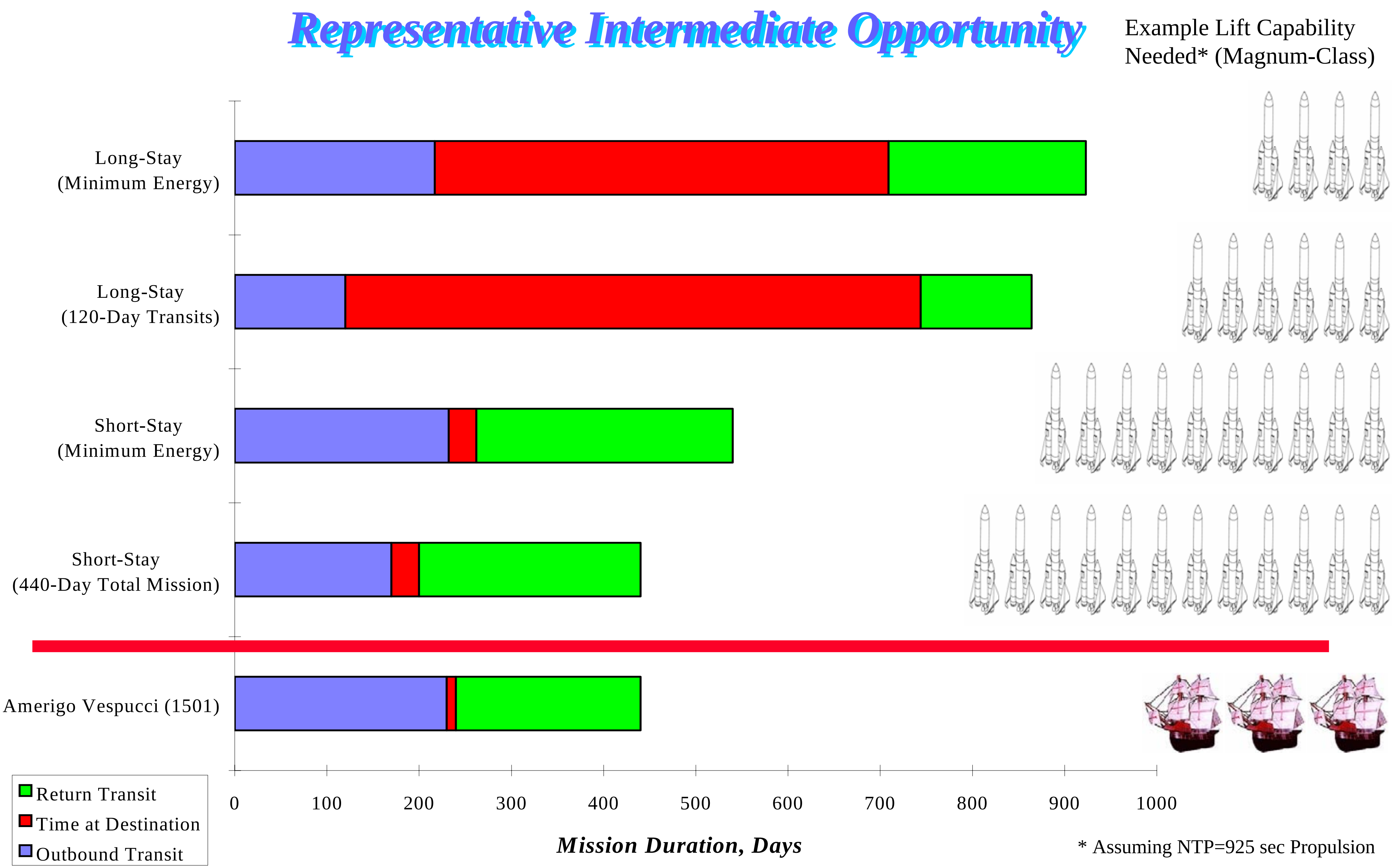
2018 Opportunity

Representative Good Opportunity



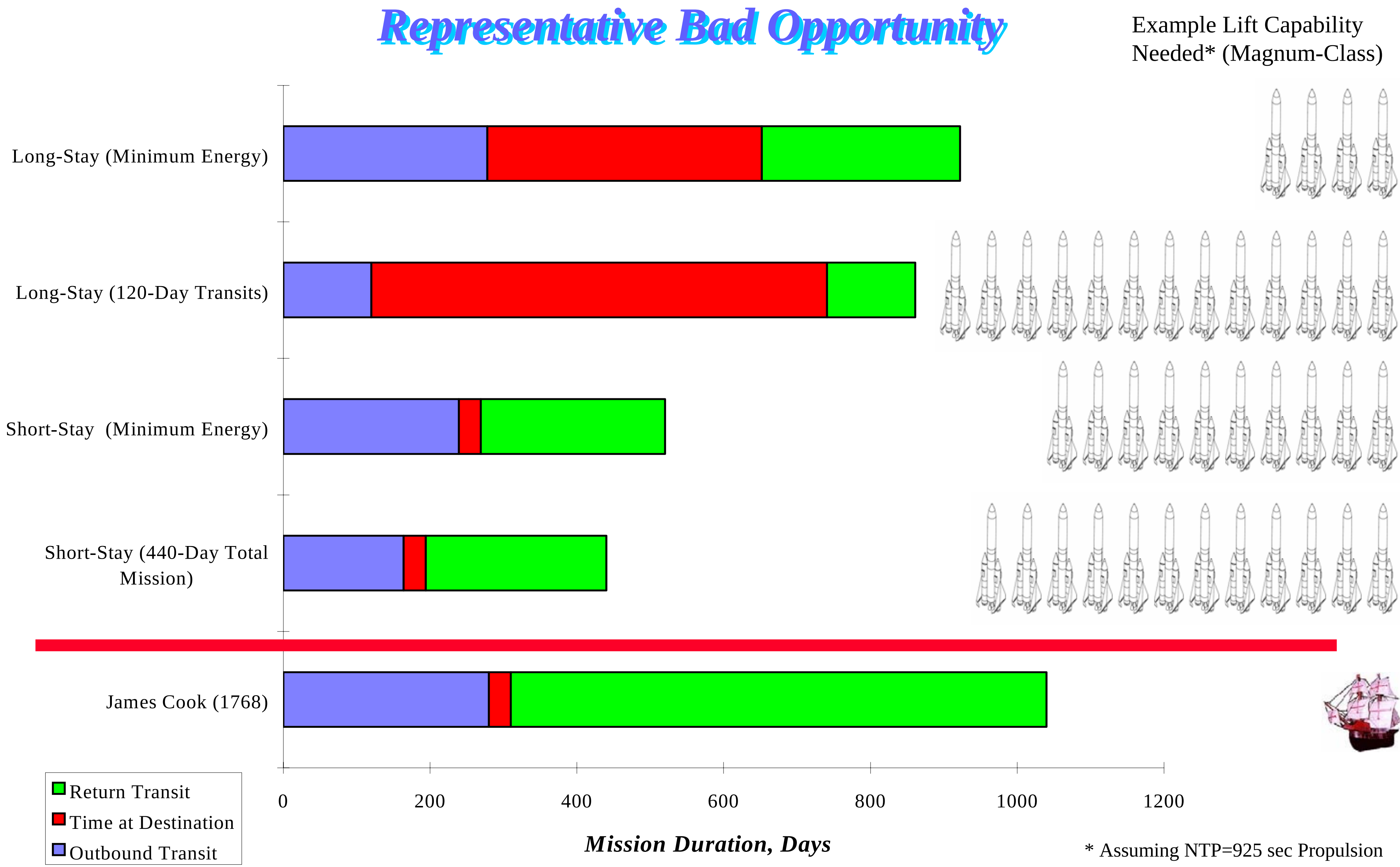
Mars Mission Duration Comparison

2005 Opportunity



Mars Mission Duration Comparison

2009 Opportunity



* Assuming NTP=925 sec Propulsion

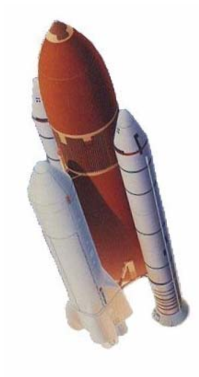
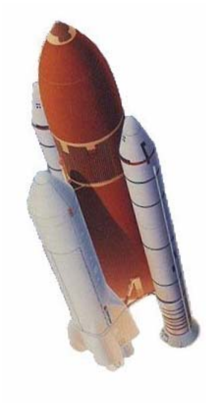
Advanced Concept Analysis in Support of the Integrated Space Plan

Section 4.2

Exploration Architecture Analysis
Launch Vehicle Definition

November 2002

Preliminary Concepts for Exploration Blueprint Launch Vehicle

	Shuttle Class	Shuttle Class Evolved	In-line HLLV	2 Stage In-line
Concept Configuration				
Concept Description	• 1.5 Stage Vehicle • Sidemount Payload Carrier - 15'x 82' Pld envelope • ET - LOX/LH2 Core • 3 SSME Boattail on Carrier • 2 - Four Segment SRBs	• 1.5 Stage Vehicle • Sidemount Payload Carrier - 25'x 90' Pld envelope • ET LOX/LH2 Core - 5 ft. stretch LH2 tank • 3 SSME Engines on Carrier • 2 - Five Segment SRBs	• 2.5 Stage Vehicle • Inline Payload Shroud - 31'x 90' Pld for Mars - 25'x 90' Pld for Near Earth • ET Derived, LOX/LH2 Core • 3 RS-68 Engines • 2 - Five Segment SRBs • Large LOX/LH2 Upper Stage - 2 J-2S Engines or - 1 SSME	• 2 Stage Vehicle • Inline Payload Shroud - 31'x 90' Pld for Mars - 25'x 90' Pld for Near Earth • LOX/RP First Stage • 8 RD-180 Engines • LOX/LH2 Second Stage - 4 J-2S Engines or - 2 SSME
GLOW	4.52 Mlb	5.37 Mlb	6.33 Mlb w/ J2S(2) 6.34 Mlb w/ SSME(1)	4.70 Mlb w/ J2S(4) 4.39 Mlb w/ SSME(2)
Performance (Destination)	85.6 mt (30 x 150 nmi Ellip.. @28.5°)	93.5 mt (30 x 150 nmi Ellip.. @28.5°)	108.5 mt w/ J2S(2) 113.5 mt w/ SSME(1) (30 x 150 nmi Ellip.. @28.5°)	102.0 mt w/ J2S(4) 102.0 mt w/ SSME(2) (30 x 150 nmi Ellip.. @28.5°)

Preliminary Concepts for Exploration Blueprint Launch Vehicle

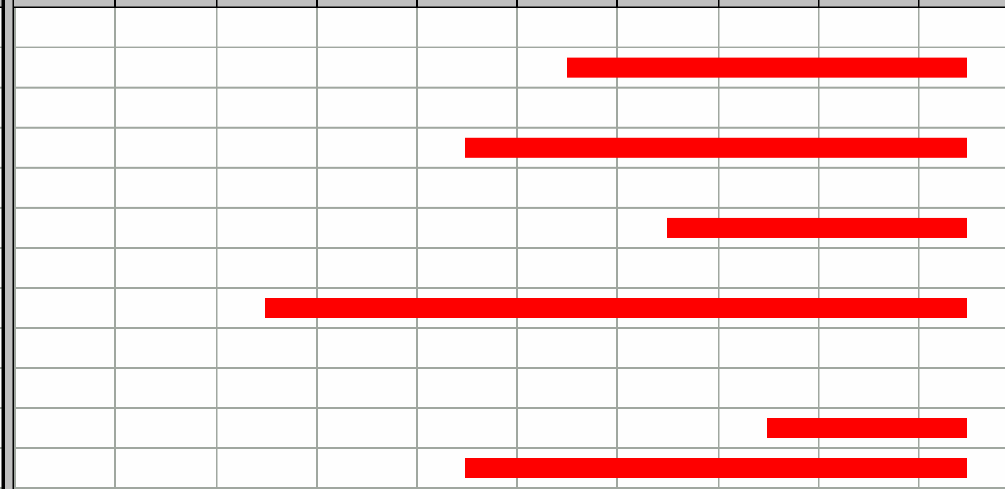
	Shuttle Class	Shuttle Class Evolved	In-line HLLV	2 Stage In-line
Concept Configuration				
Concept Description	• 1.5 Stage Vehicle • Sidemount Payload Carrier - 15’x 82’ Pld envelope • ET - LOX/LH2 Core • 3 SSME Boattail on Carrier • 2 - Four Segment SRBs	• 1.5 Stage Vehicle • Sidemount Payload Carrier - 25’x 90’ Pld envelope • ET LOX/LH2 Core - 5 ft. stretch LH2 tank • 3 SSME Engines on Carrier • 2 - Five Segment SRBs	• 2.5 Stage Vehicle • Inline Payload Shroud - 31’x 90’ Pld for Mars - 25’x 90’ Pld for Near Earth • ET Derived, LOX/LH2 Core • 3 RS-68 Engines • 2 - Five Segment SRBs • Large LOX/LH2 Upper Stage - 2 J-2S Engines or - 1 SSME	• 2 Stage Vehicle • Inline Payload Shroud - 31’x 90’ Pld for Mars - 25’x 90’ Pld for Near Earth • LOX/RP First Stage • 8 RD-180 Engines • LOX/LH2 Second Stage - 4 J-2S Engines or - 2 SSME
Pros	• Uses ET Design Heritage/Facilities • Uses Existing 4-Segment SRB • Uses Existing Engines • Production Status at Termination - Shortest Development Time • Least Facility Impact • Least Development Risk • Lower Cost	• Uses ET Design Heritage/Facilities • Uses Existing Engines • Larger Payload Carrier • Moderate Cost	• ET Evolved Design/Facilities • Inline Config Better for cg Track • Shroud Jettisoned Prior to Orbit	• Saturn V Heritage • Inline Config Better for cg Track • Shroud Jett Prior to Orbit • Growth Potential
Cons	• Less Aerodynamic configuration • cg Tracking Issues w/ Side Mount • SSME Expended • Does not Meet 100 mt Payload Req. • 15 ft. Dia. Payload Volume Constraint • Ground Processing Concerns w/ Solids	• Less Aerodynamic configuration • cg Tracking Issues w/ Side Mount • SSME Expended • Does not Meet 100 mt Payload Req. • Ground Processing Concerns w/ Solids	• Significant Pad/Facility Mods • SSME Air Start Program • J-2S Production Restart • VAB Height Concerns • SSME Expended • Longest Development Time • Higher Cost • Ground Processing Concerns w/ Solids	• 8 Engines on Booster • J-2S Production Restart or SSME Air Start Program • SSME Expended • Significant Pad/Facility Mods • Higher Cost

Development Schedule

Engineering Design Features/Technologies Per Vehicle Family

1.5 Stage	2.5 Stage	2 Stage	Task Name
A B G	C D	E F	Large Composite Structures
A B G	C D		New 5 Segment SRB
A B			Recovery System for 5 Segment SRB
A B			New Engine Development for RS-83
	C D	E F	New Large Upper Stage
			Air Start Capability for SSME
			Restart J-2S Production

2003 2004 2005 2006 2007 2008 2009 2010 2011 2012



A — 1.5 Stage w / 4 SRB

B — 1.5 Stage w / 4 SRB

C — 2.5 Stage w / SSME

D — 2.5 Stage w / J-2S

E — 2 stage w / SSME

F — 2 Stage w / J-2S

G — 1.5 Stage w / 2 SRB (25 ft)

Preliminary

Engineering Design Features/Technologies Per Vehicle Family

	1.5 Stage w / 4 SRB	1.5 Stage w / 4 SRB	2.5 Stage w / SSME	2.5 Stage w / J-2S	2 stage w / SSME	2 Stage w / J-2S	1.5 Stage w / 2 SRB
							
• Large Composite Structures - Advanced Composite Fabrication Processes and Facilities	○	○	○	○	○	○	○
• Recovery System for 5 Segment SRB - Higher Apogee Altitude May Require Recovery System Redesign	○	○					
• New 5 Segment SRB - Minimal DDT&E (Inherit from STS) - Increased Performance Over 4 Segment SRB	○	○	○	○			○
• New Engine Development for RS-83	○	○					
• New Large Upper Stage - Air Start Capability for SSME - Restart J-2S Production			○	○	○	○	

Shuttle Class Evolved

Vehicle Characteristics

Payload (30 x 150 nmi)	93.5 mt	
Gross liftoff mass	5.4	mlb
T/W @ liftoff	1.40	
Max Q	646	psf
Max accel	3.8	g
Shroud mass	N/A	klb

Booster (5-segment):

Propellants	HTPB	
Ascent propellant mass	2.9	mlb,
Burnout mass	430	klb,
Separation conditions	Mach= 4.8, Q= 17.0 psf, alt= 177 kft	

Vaccum Level thrust= 3.92 mlb each SL Isp= 265 sec

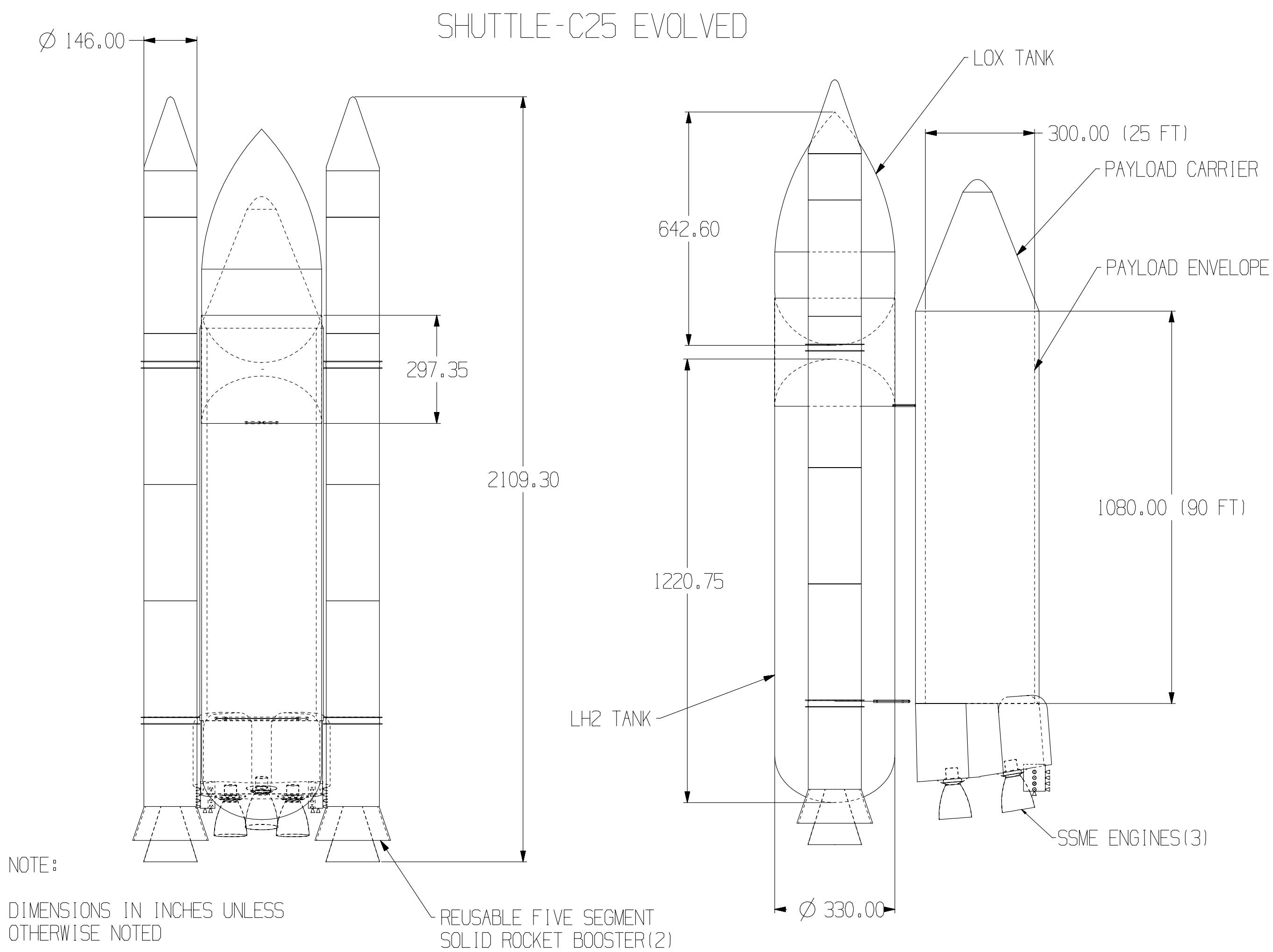
External Tank (SLWT w/ 5 ft stretch):

Propellants	LO2/LH2	
Ascent propellant mass	1.68	mlb
Burnout mass	104.0	klb
Engines	3 SSME Engines (104%)	

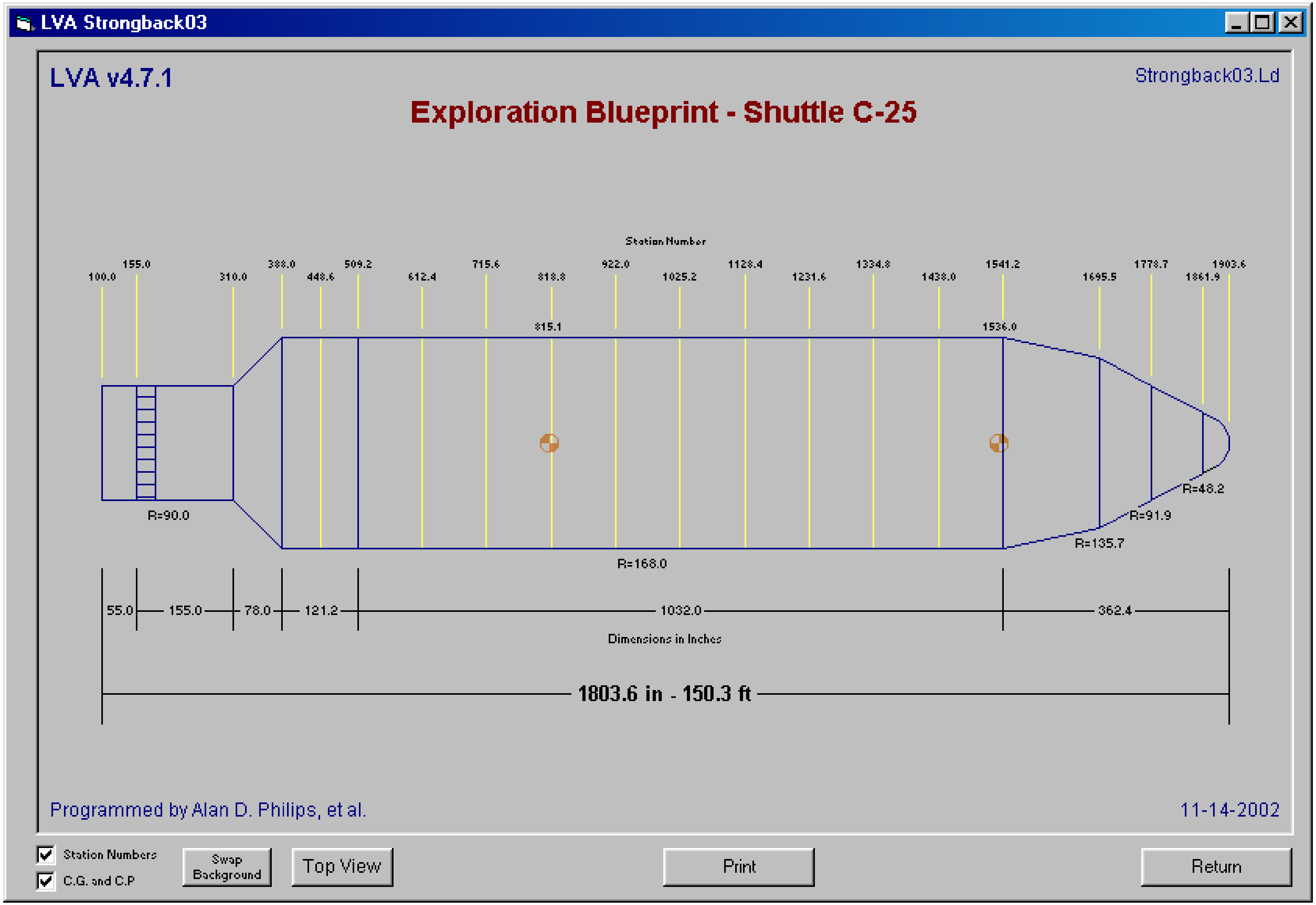
Vacuum thrust= 492 klb each vac Isp= 453 sec

Sea Level thrust= 397 klb each SL Isp= 365 sec

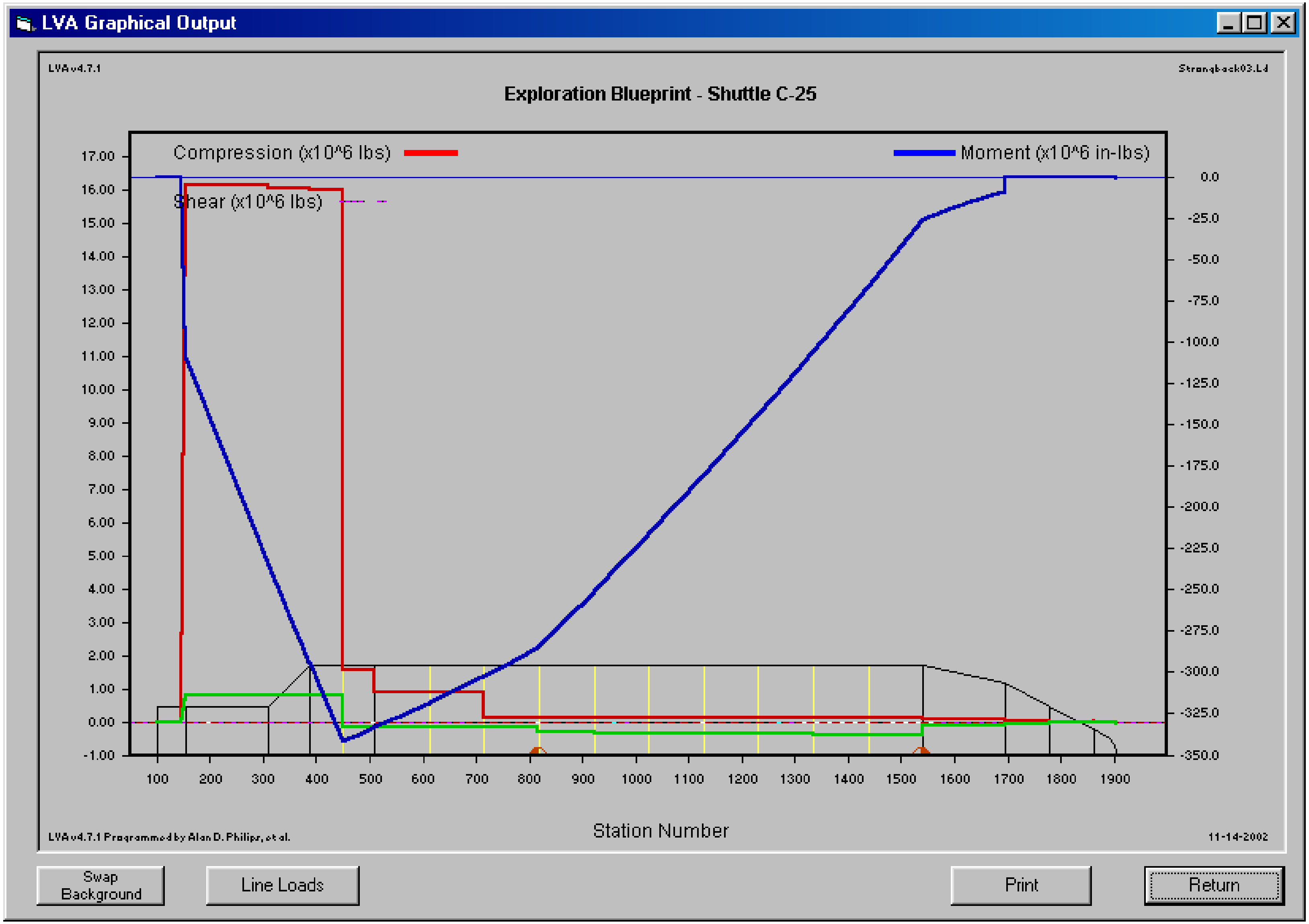
Shuttle Class Evolved Configuration



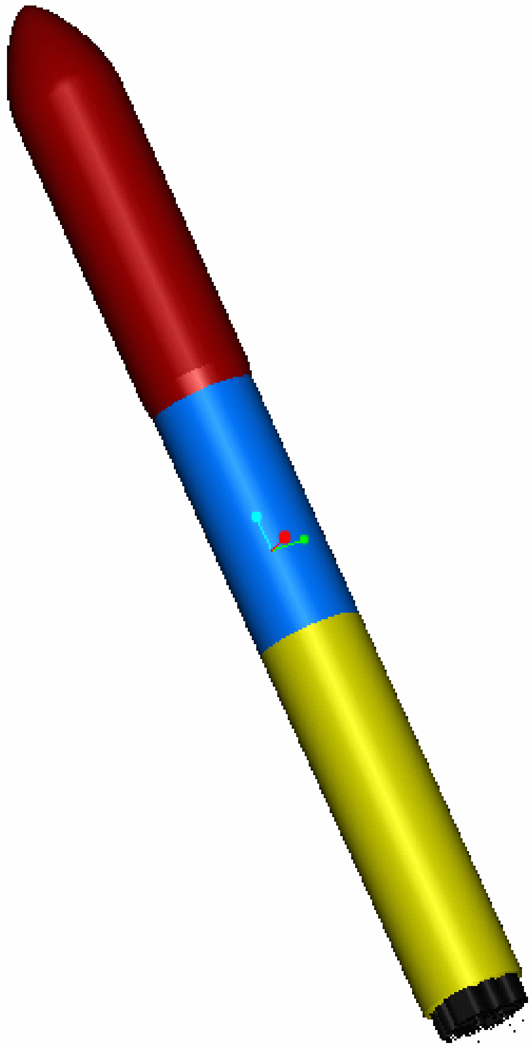
Shuttle Class Evolved Side-Mount Side View



Shuttle Class Evolved Side-Mount Combined Ascent Loads - Compression, Moment, & Shear



Two Stage In-Line Vehicle w/ SSME



Vehicle Characteristics

Payload (30 x 150 nmi)	102.0 mt
Gross liftoff mass	4.4 mlb
T/W @ liftoff	1.30
Max Q	700 psf
Max accel	5.0 g
Shroud mass	40.5 klb

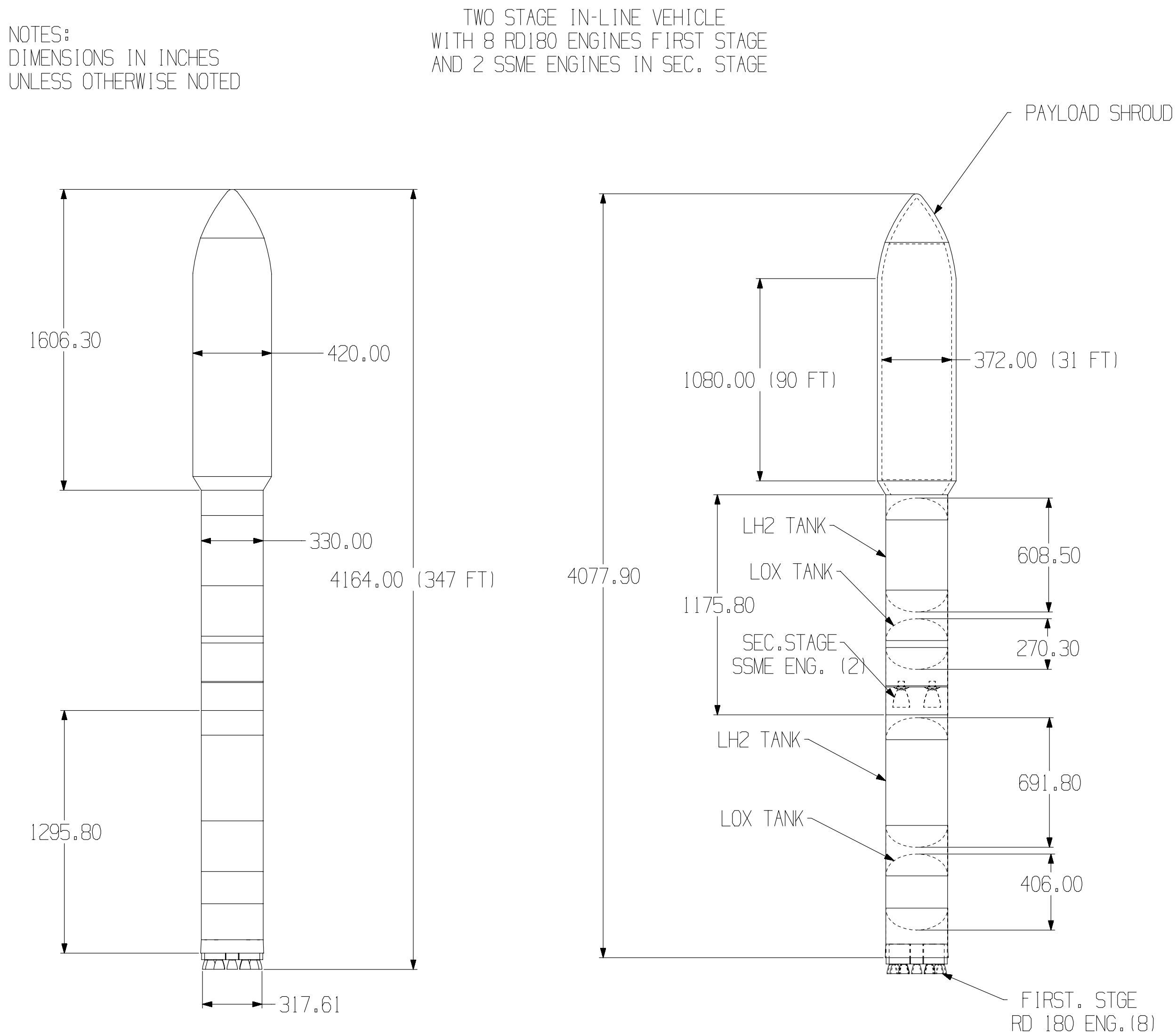
First Stage:

Propellants	LOX/RP		
Ascent propellant mass	2855 klb		
Burnout mass	290 klb		
Separation conditions	Mach= 7.6, Q= 37.2 psf, alt= 181 kft		
Engines (each)	8 RD – 180 Engines		
		Vacuum thrust= 951 klb each	vac Isp= 338 sec
		Sea Level thrust= 874 klb each	SL Isp= 311 sec

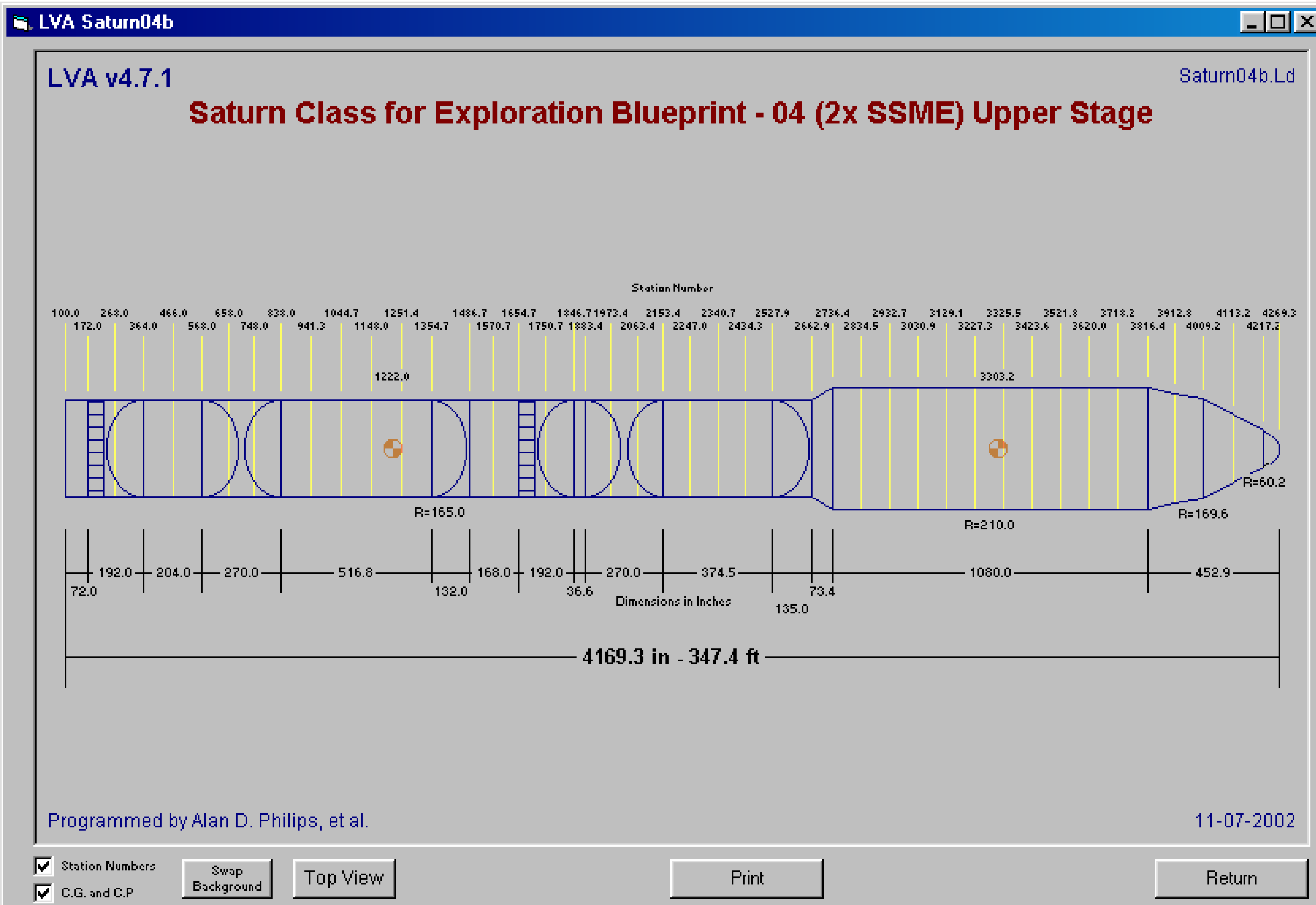
Second Stage:

Propellants	LO2/LH2		
Ascent propellant mass	809 klb		
Burnout mass	112 klb		
Engines	2 SSME Engines		
		Vacuum thrust= 471 klb each	vac Isp= 453 sec

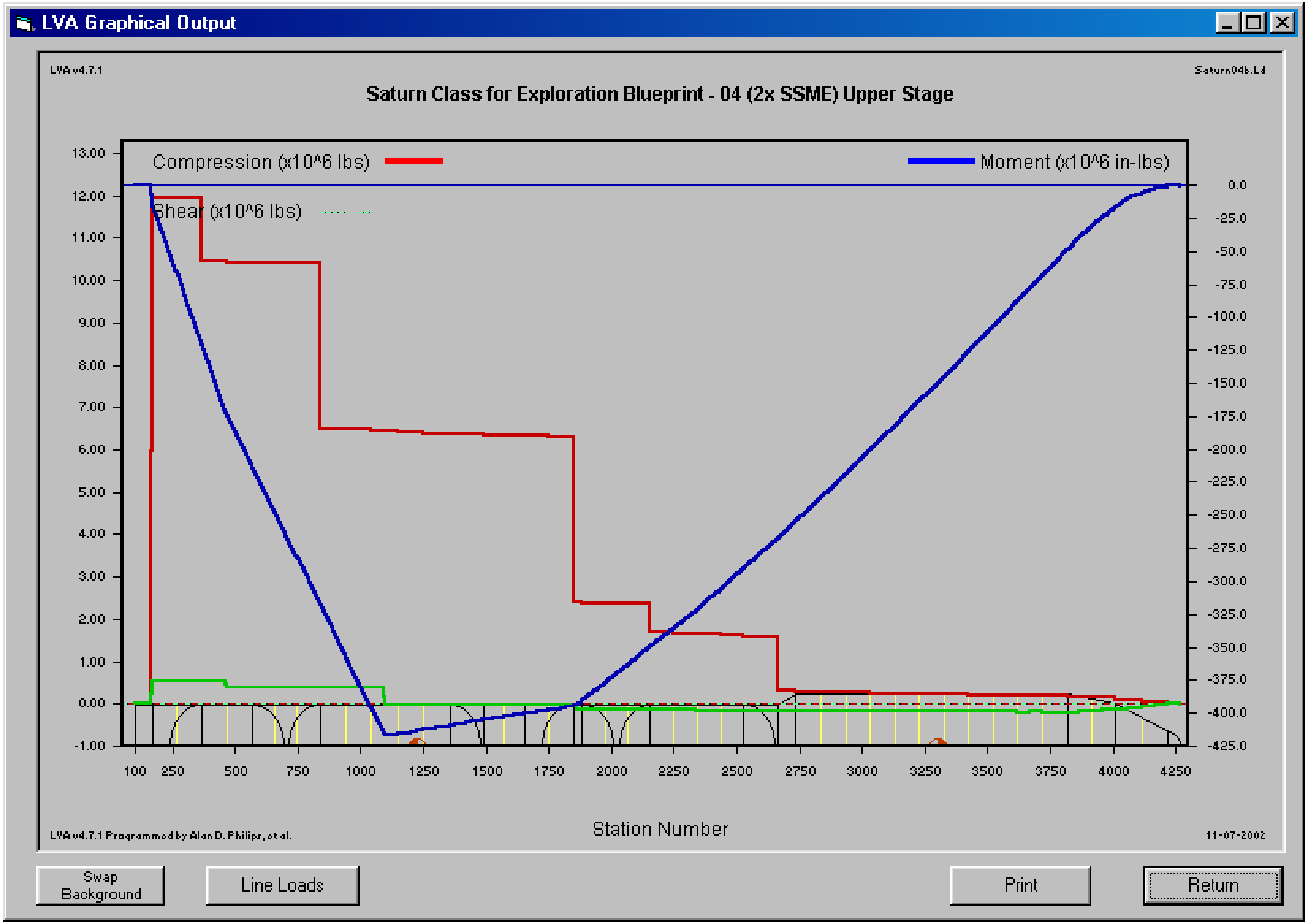
Two Stage In-Line w/ SSME Configuration



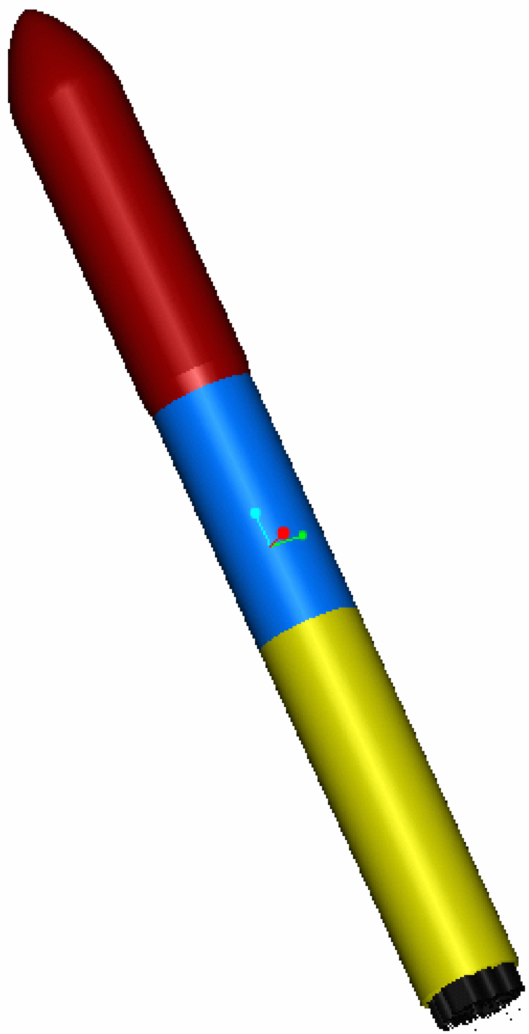
Two Stage In-Line Vehicle w/ SSME Side View



Two Stage In-Line w/ SSME Combined Ascent Loads - Compression, Moment, & Shear



Two Stage In-Line Vehicle w/ J-2S



Vehicle Characteristics

Payload (30 x 150 nmi)	102.0 mt
Gross liftoff mass	4.912 mlb
T/W @ liftoff	1.30
Max Q	600 psf
Max accel	4.81 g
Shroud mass	32.2 klb

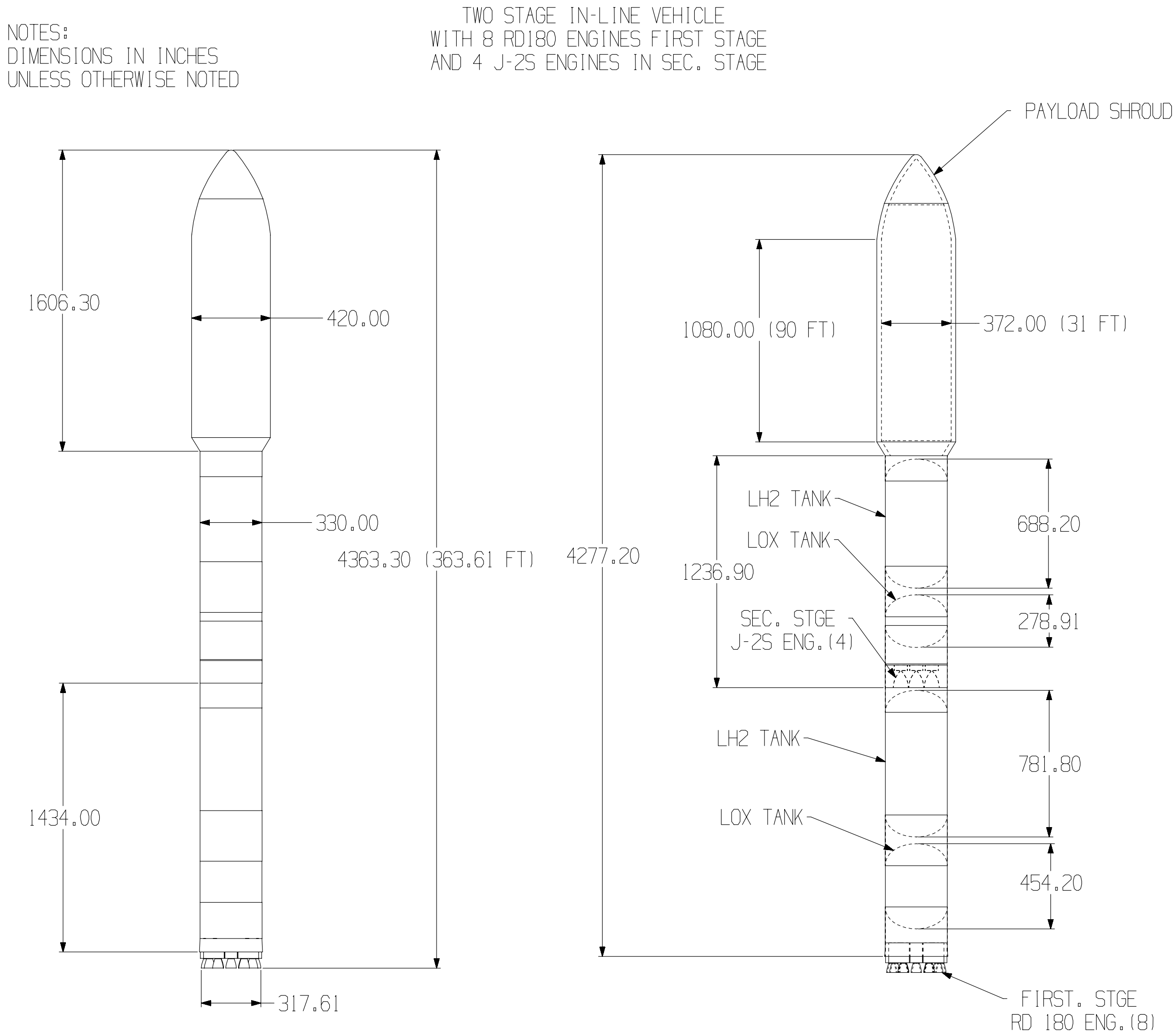
First Stage:

Propellants	LOX/RP		
Ascent propellant mass	3333 klb		
Burnout mass	313 klb		
Separation conditions	Mach= 7.89, Q= 28.5 psf, alt= 190 kft		
Engines (each)	8 RD – 180 Engines		
	Vacuum thrust=	951 klb each	vac Isp= 338 sec
	Sea Level thrust=	874 klb each	SL Isp= 311 sec

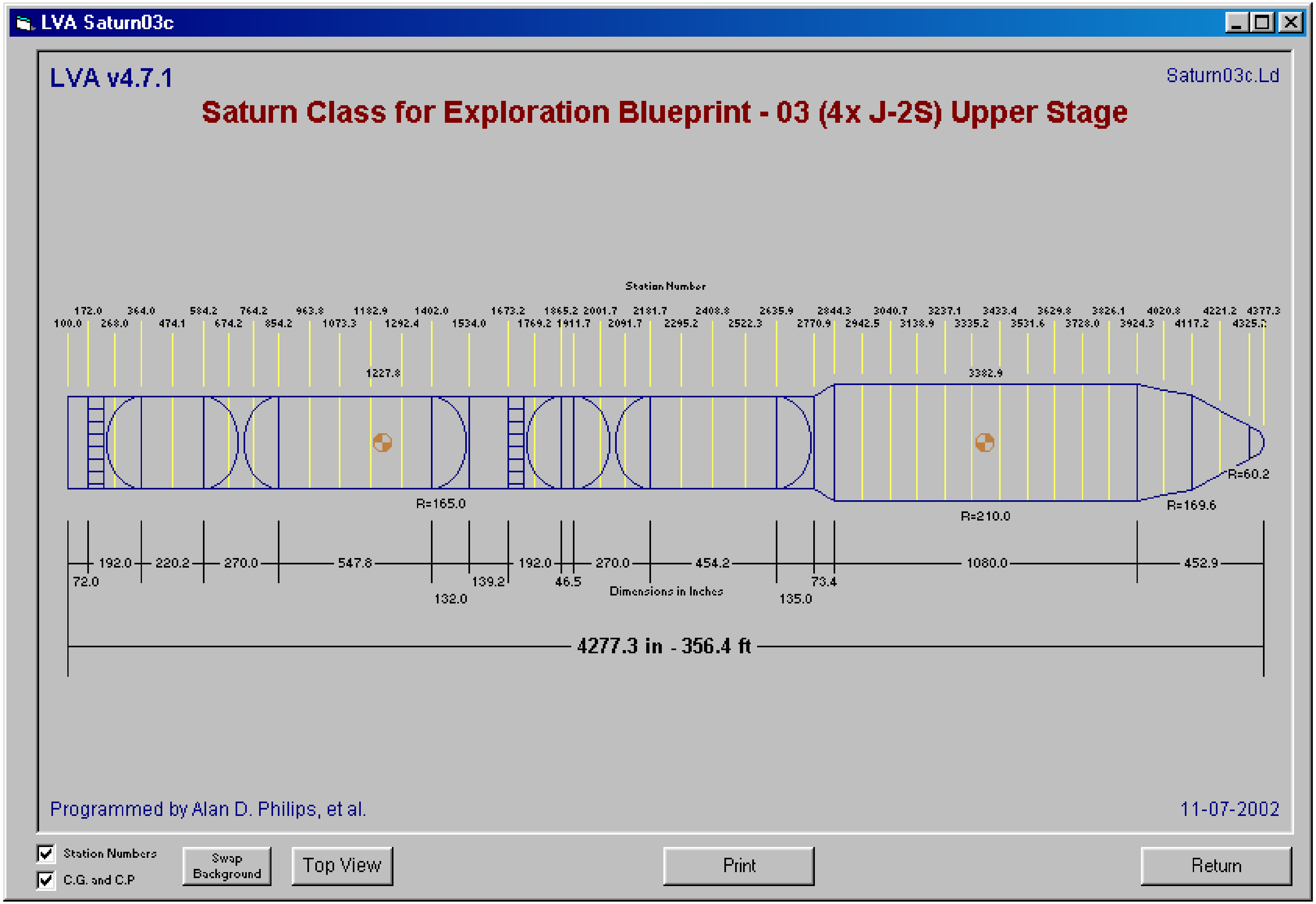
Second Stage:

Propellants	LO2/LH2		
Ascent propellant mass	878 klb		
Burnout mass	129 klb		
Engines	4 J-2S Engines		
	Vacuum thrust=	265 klb each	vac Isp= 435 sec
	Sea Level thrust=	201 klb each	SL Isp= 330 sec

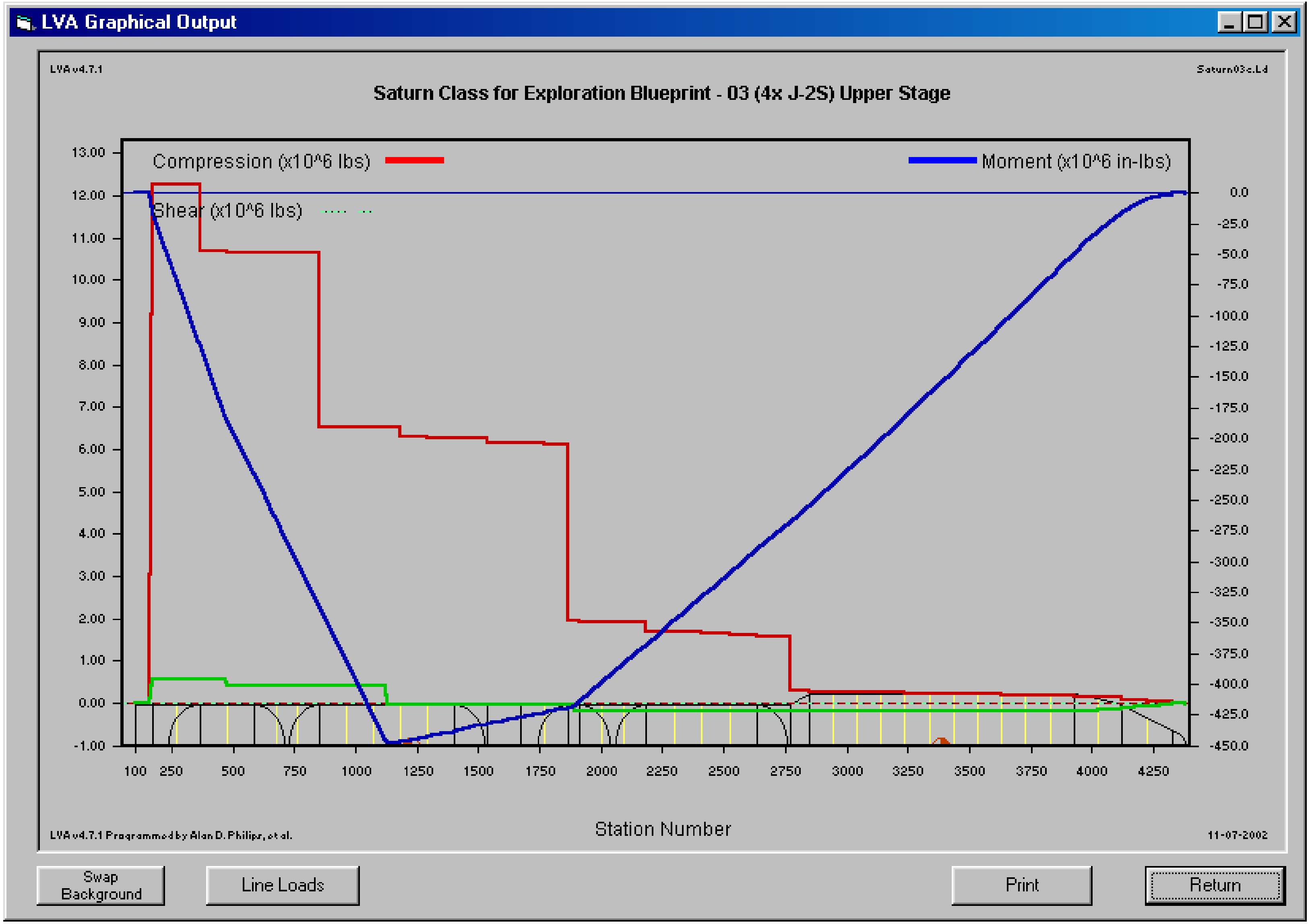
Two Stage In-Line w/ J-2S Configuration



Two Stage In-Line Vehicle w/ J-2S Side View



Two Stage In-Line w/ J-2S Combined Ascent Loads - Compression, Moment, & Shear

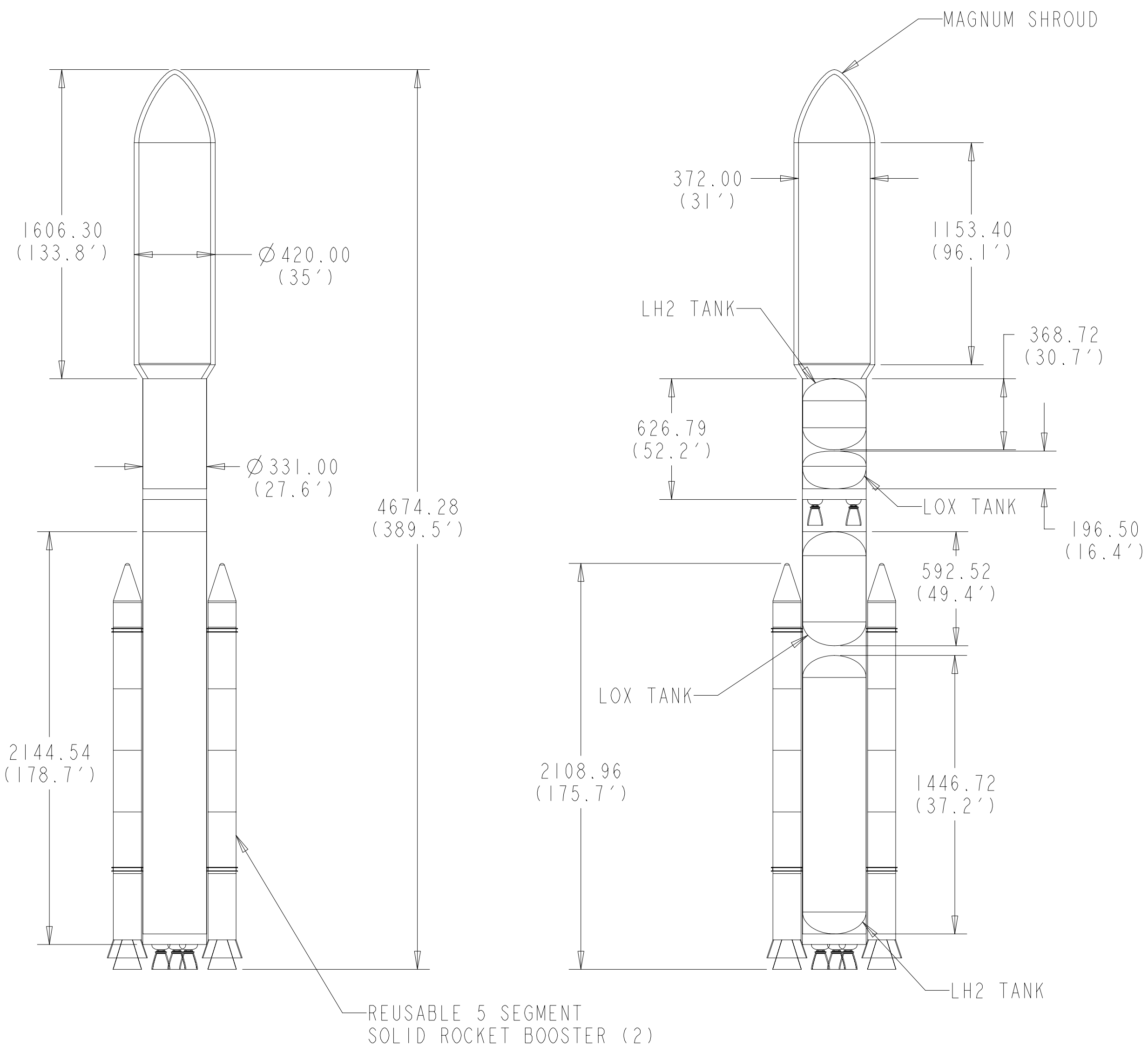


In-line HLLV w/ 2 J-2S, 30 x 150 nmi Elliptical

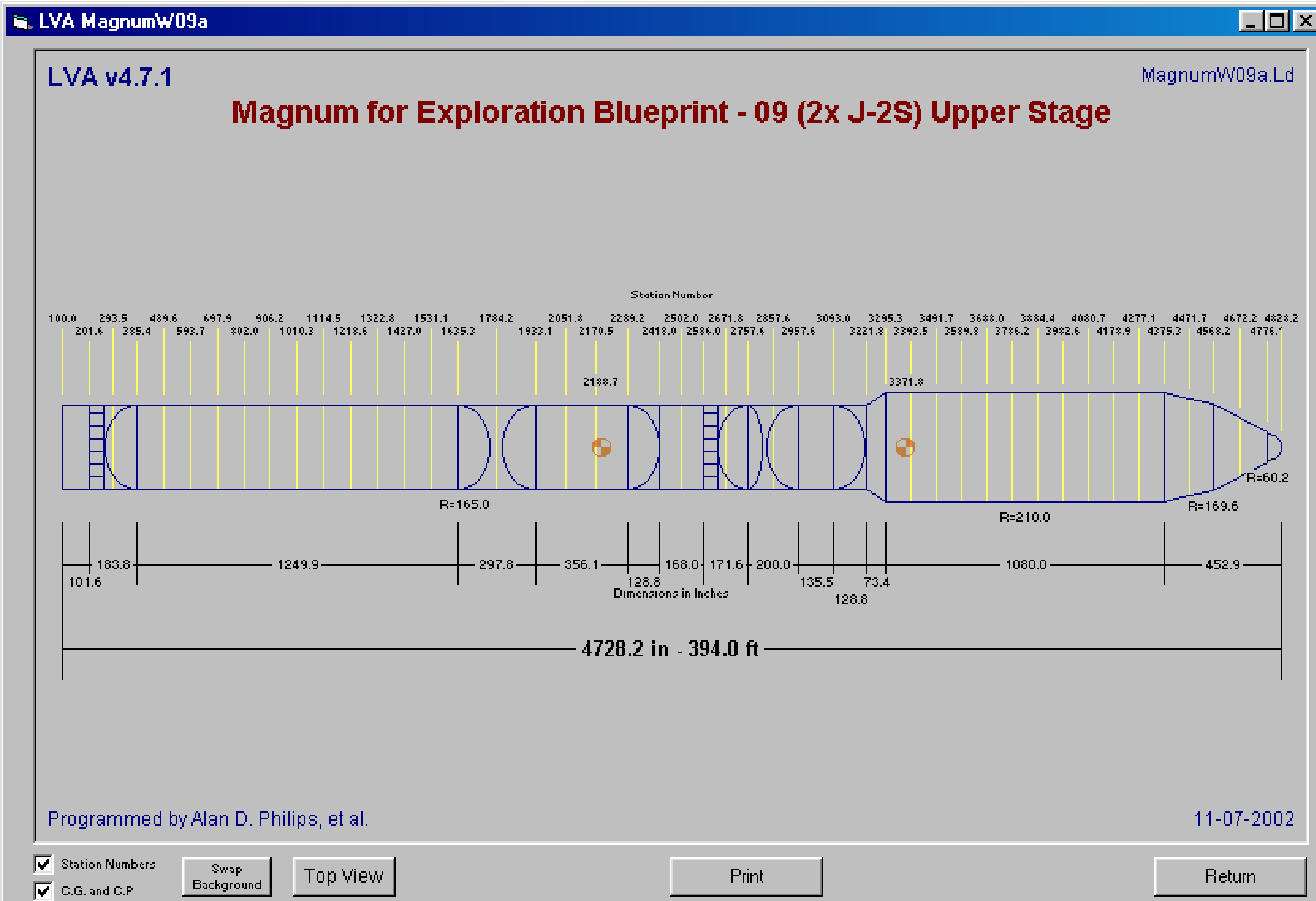
Vehicle Characteristics

Gross liftoff mass	6.324	Mlb				
T/W @ liftoff	1.37					
Max Q	600	psf				
Max accel	2.4	g				
P/L container mass	17997	lb				
Booster:	Five Segment SRB					
Number of Boosters:	2	SRBs				
Propellants	Solid Prop					
Ascent propellant mass	1428	klb, each				
Burnout mass	217	klb, each				
Separation conditions						
Engines (each)	1	Five segment Shuttle SRB				
	SL thrust=	3334	klb each	SL Isp=	265	sec
First Stage:	EB - HLV					
Propellants	LO2/LH2					
Ascent propellant mass	2043	klb				
Burnout mass	220	klb				
Engines	3	RS-68 Engines				
	Vacuum thrust=	751	klb each	vac Isp=	409	sec
	SL thrust=	656	klb each	SL Isp=	357	sec
Second Stage:	EB - HLV					
Propellants	LO2/LH2					
Ascent propellant mass	417	klb				
Burnout mass	81	klb				
Engines	2	J-2S				
	Vacuum thrust=	265	klb each	vac Isp=	436	sec
	SL thrust=	0	klb each	SL Isp=	0	sec
Target Payload:	100.0	mton to 30nmi x 150nmi	@ 28.5 (DRM)			
Payload:	108.5	mton to 30nmi x 150nmi	@ 28.5 (DRM)			

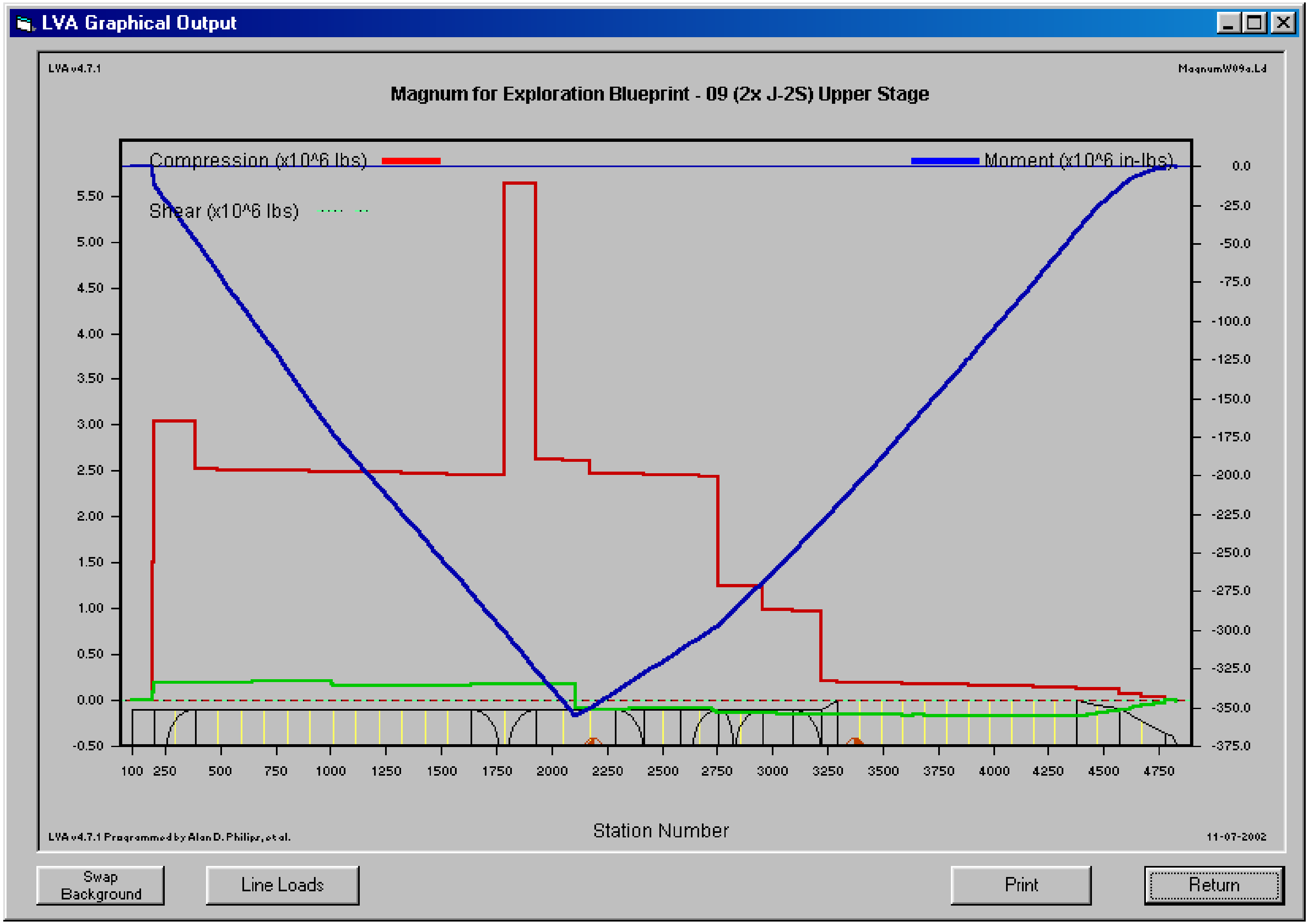
In-line HLLV w/ J-2S Configuration



In-Line HLLV w/ J-2S Side View



In-Line HLLV w/ J-2S Combined Ascent Loads - Compression, Moment, & Shear



In-line HLLV w/ 1 SSME, 30 x 150 nmi Elliptical

Vehicle Characteristics

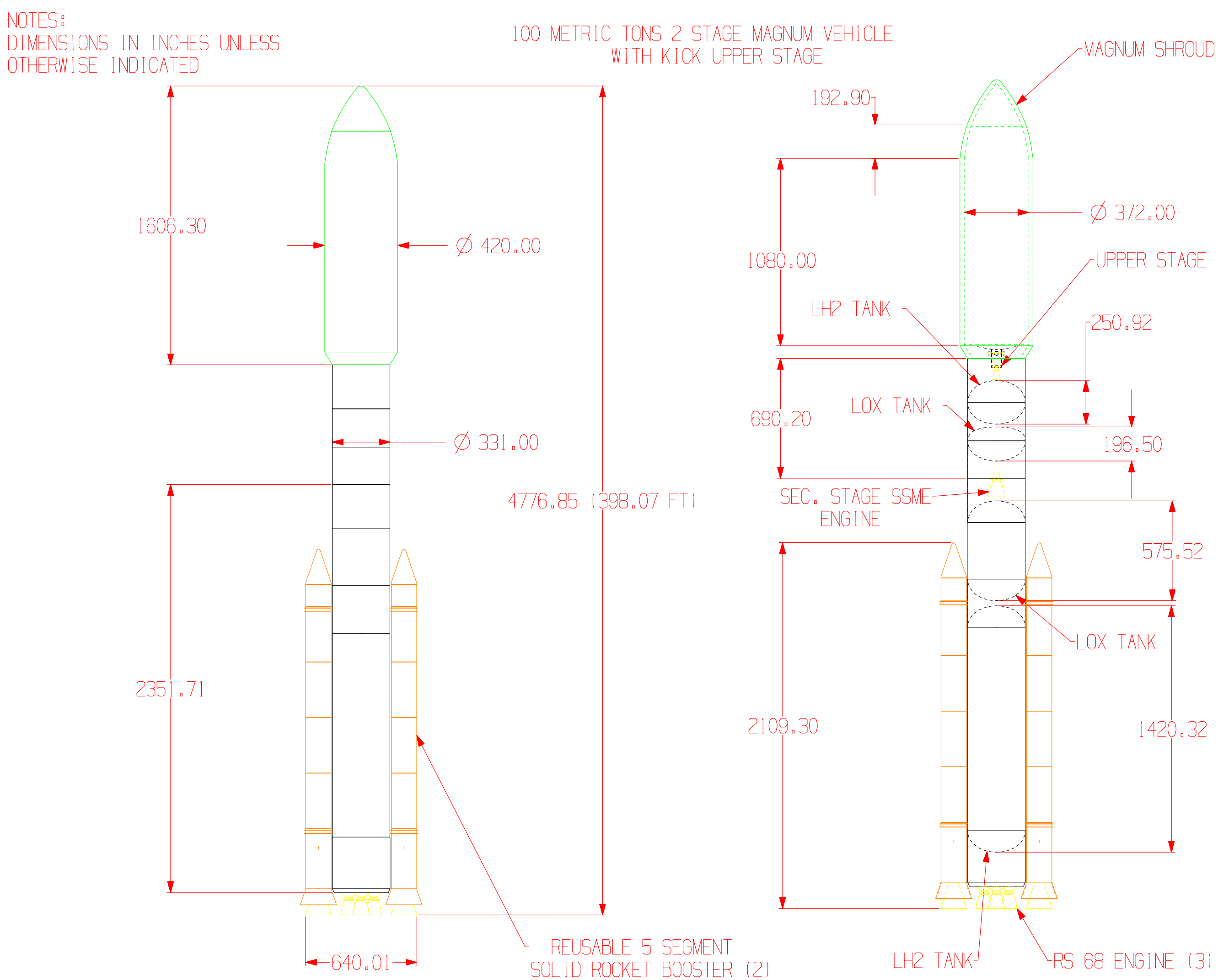
Gross liftoff mass	6.326 Mlb				
T/W @ liftoff	1.37				
Max Q	600 psf				
Max accel	2.5 g				
P/L container mass	17997 lb				
Booster:	Five Segment SRB				
Number of Boosters:	2 SRBs				
Propellants	Solid Prop				
Ascent propellant mass	1428 klb, each				
Burnout mass	217 klb, each				
Separation conditions					
Engines (each)	1 Five segment Shuttle SRB				
		SL thrust=	3334 klb each	SL Isp=	265 sec
First Stage:	EB - HLV				
Propellants	LO2/LH2				
Ascent propellant mass	2066 klb				
Burnout mass	218 klb				
Engines	3 RS-68 Engines				
		Vacuum thrust=	751 klb each	vac Isp=	409 sec
		SL thrust=	656 klb each	SL Isp=	357 sec
Second Stage:	EB - HLV				
Propellants	LO2/LH2				
Ascent propellant mass	407 klb				
Burnout mass	70 klb				
Engines	1 SSME				
		Vacuum thrust=	471 klb each	vac Isp=	453 sec
		SL thrust=	380 klb each	SL Isp=	365 sec
Target Payload:	100.0 mton to 30nmi x 150nmi @ 28.5 (DRM)				
Payload:	113.5 mton to 30nmi x 150nmi @ 28.5 (DRM)				

In-line HLLV w/ 1 SSME, 150 nmi Circular

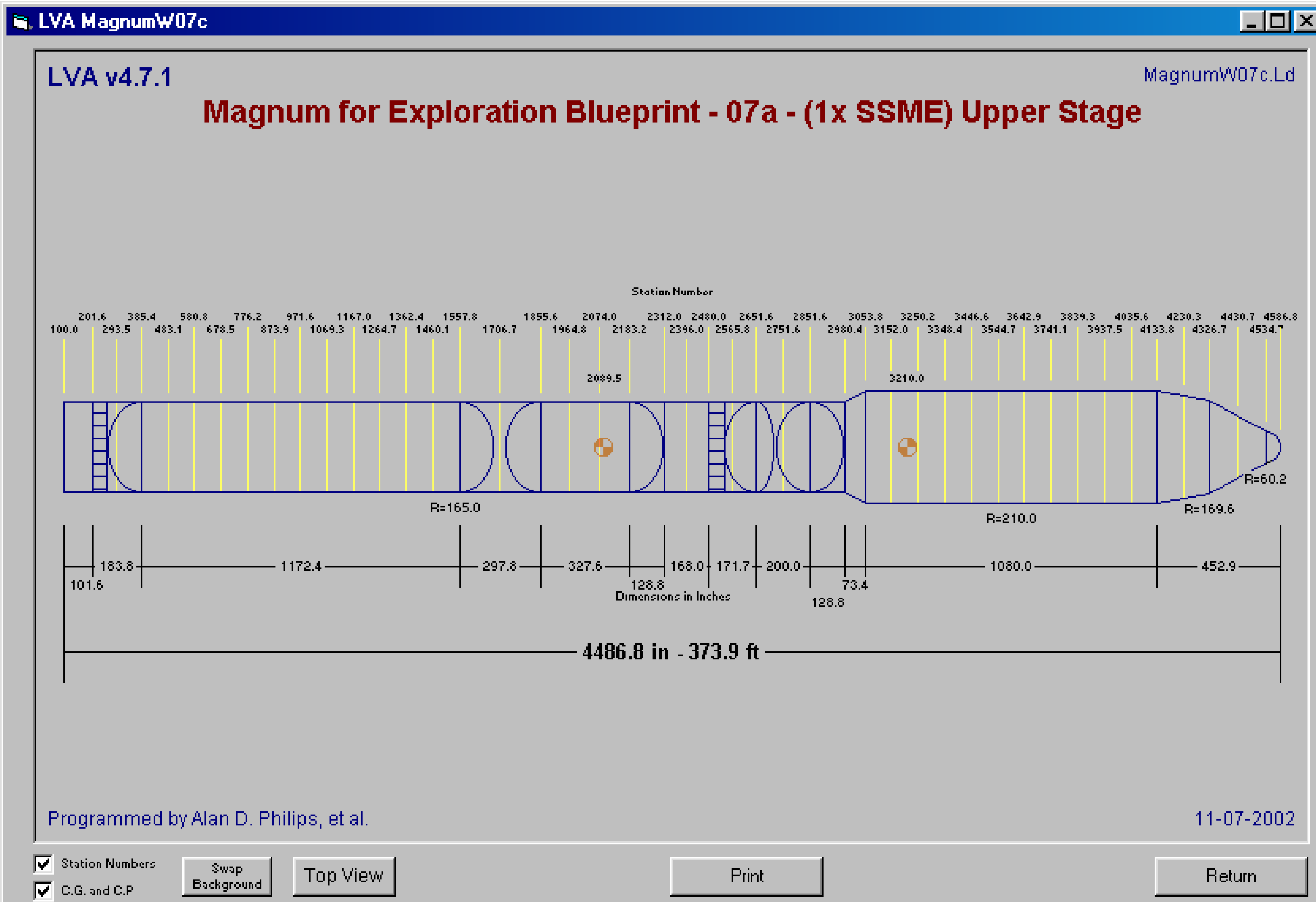
Vehicle Characteristics

Gross liftoff mass	6.137	Mlb
T/W @ liftoff	1.41	
Max Q	700	psf
Max accel	2.8	g
P/L container mass	40126	lb
Booster:	Five Segment SRB	
Number of Boosters:	2	SRBs
Propellants	Solid Prop	
Ascent propellant mass	1428	klb, each
Burnout mass	217	klb, each
Separation conditions		
Engines (each)	1	Five segment Shuttle SRB
		SL thrust= 3334 klb eachSL Isp= 265 sec
First Stage:	EB - HLV	
Propellants	LO2/LH2	
Ascent propellant mass	1974	klb
Burnout mass	216	klb
Engines	3	RS-68 Engines
		Vacuum thrust= 751 klb eachac Isp= 409 sec
		SL thrust= 656 klb eachSL Isp= 357 sec
Second Stage:	EB - HLV	
Propellants	LO2/LH2	
Ascent propellant mass	307	klb
Burnout mass	65	klb
Engines	1	SSME
		Vacuum thrust= 471 klb eachac Isp= 453 sec
		SL thrust= 380 klb eachSL Isp= 365 sec
Kick Stage:	Circularize @ 150 nmi	
Jettison mas	8350	lb
Target Payload:	100.0	mton to 150nmi circ @ 28.5 (DRM)
Payload:	103.6	mton to 150nmi circ @ 28.5 (DRM)

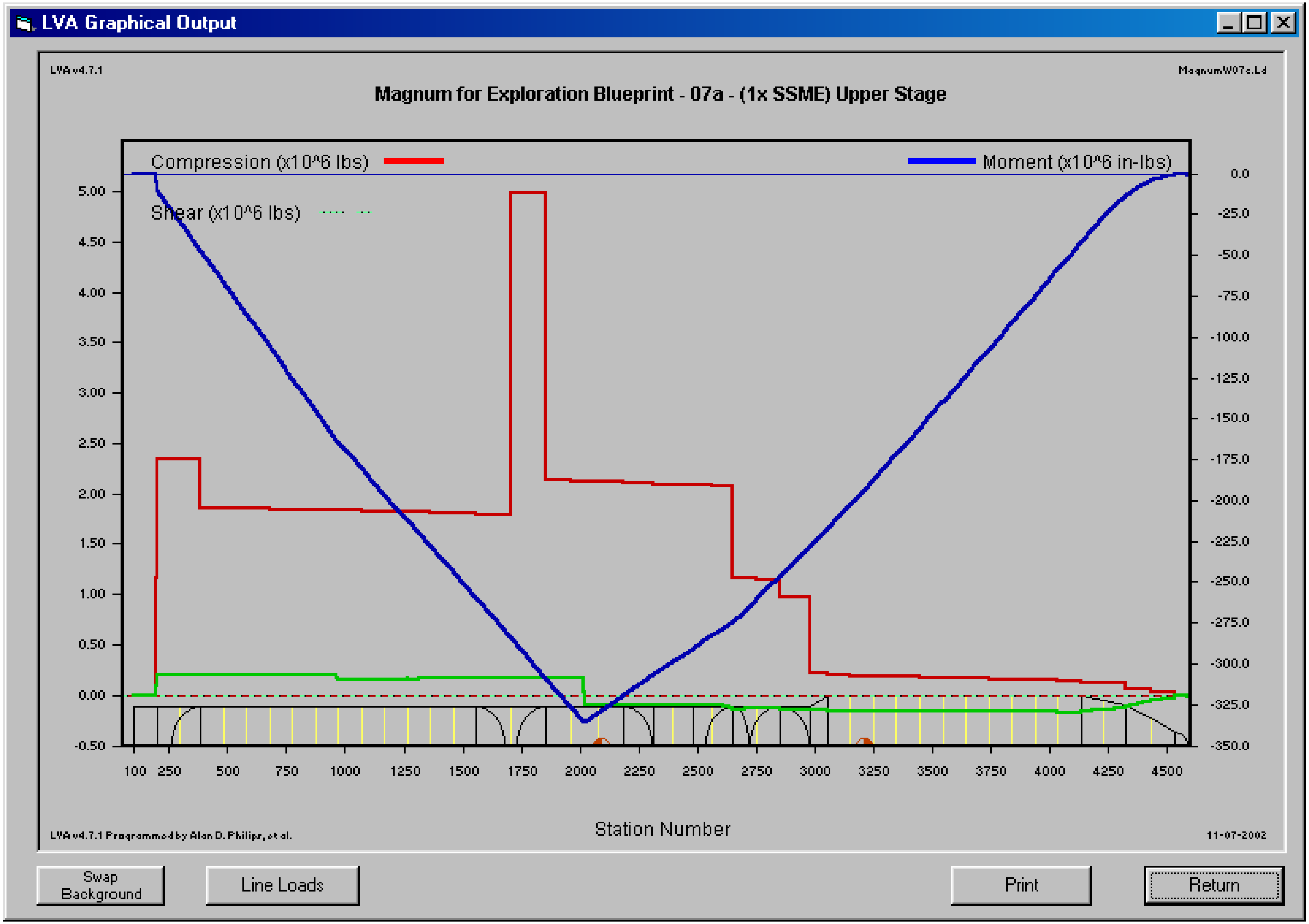
In-line HLLV w/ 1 SSME Configuration



In-line HLLV w/ SSME Side View



In-line HLLV w/ SSME Combined Ascent Loads - Compression, Moment, & Shear

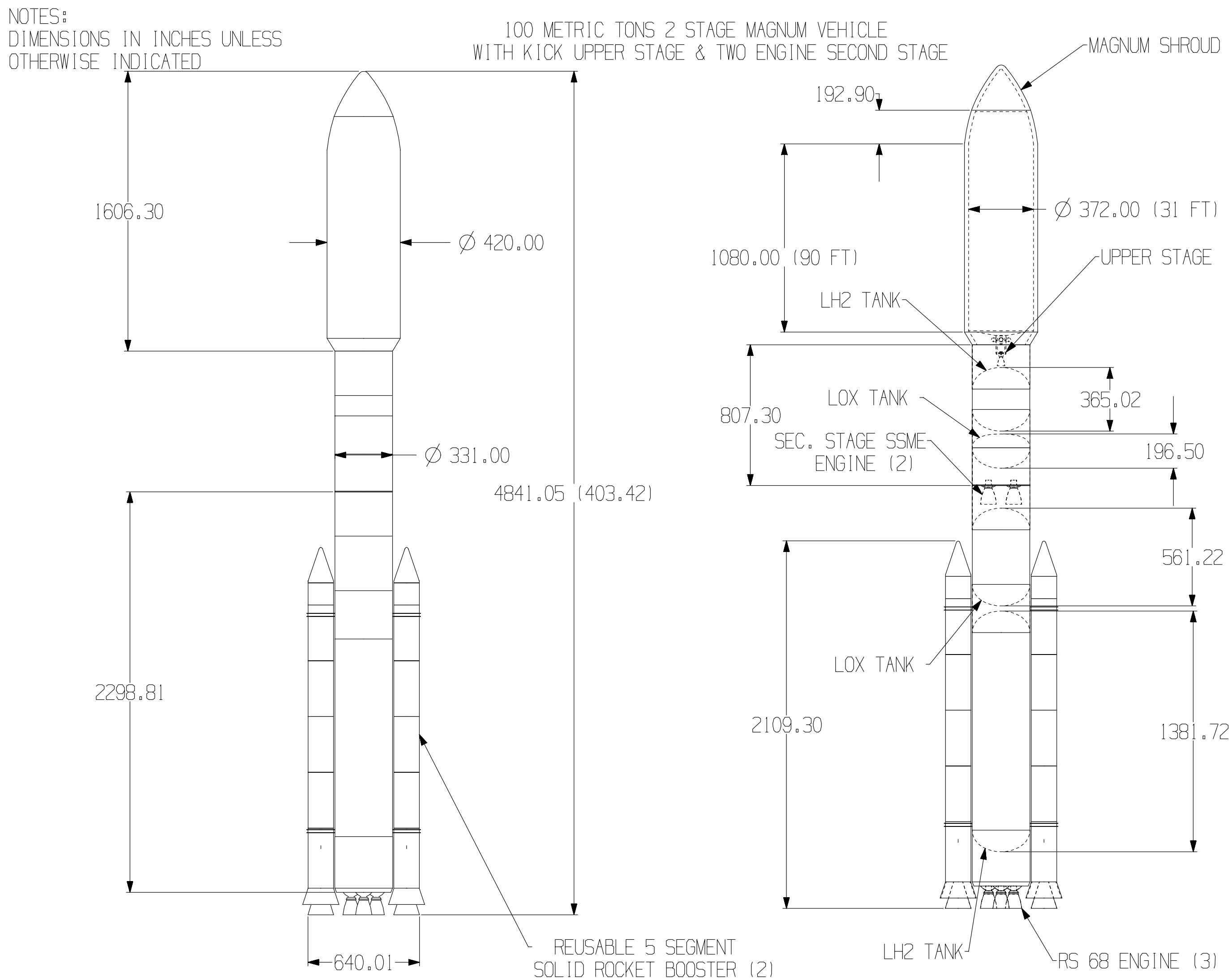


In-line HLLV w/ 2 SSME, 150 nmi Circular

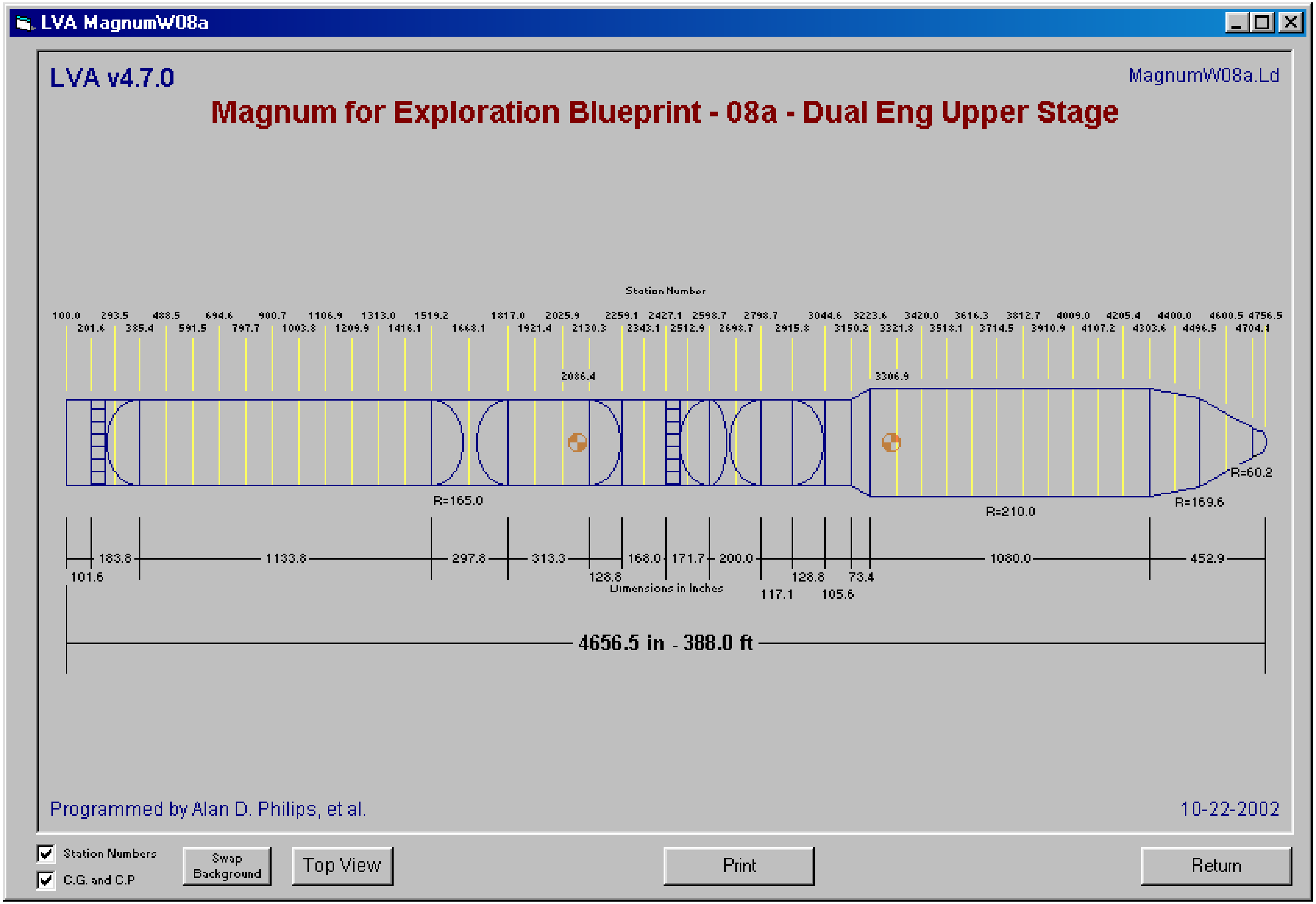
Vehicle Characteristics

Gross liftoff mass	6.210	Mlb
T/W @ liftoff	1.39	
Max Q	700	psf
Max accel	2.4	g
P/L container mass	40129	lb
Booster:	Five Segment SRB	
Number of Boosters:	2	SRBs
Propellants	Solid Prop	
Ascent propellant mass	1428	klb, each
Burnout mass	217	klb, each
Separation conditions		
Engines (each)	1	Five segment Shuttle SRB
	SL thrust= 3334 klb each	SL Isp= 265 sec
First Stage:	EB - HLV	
Propellants	LO2/LH2	
Ascent propellant mass	1916	klb
Burnout mass	215	klb
Engines	3	RS-68 Engines
	Vacuum thrust= 751 klb each	'ac Isp= 409 sec
	SL thrust= 656 klb each	SL Isp= 357 sec
Second Stage:	EB - HLV	
Propellants	LO2/LH2	
Ascent propellant mass	413	klb
Burnout mass	91	klb
Engines	2	SSME
	Vacuum thrust= 471 klb each	'ac Isp= 453 sec
	SL thrust= 380 klb each	SL Isp= 365 sec
Kick Stage:	Circularize @ 150 nmi	
Jettison ma:	8350	lb
Target Payload:	100.0	mton to 150nmi circ @ 28.5 (DRM)
Payload:	104.8	mton to 150nmi circ @ 28.5 (DRM)

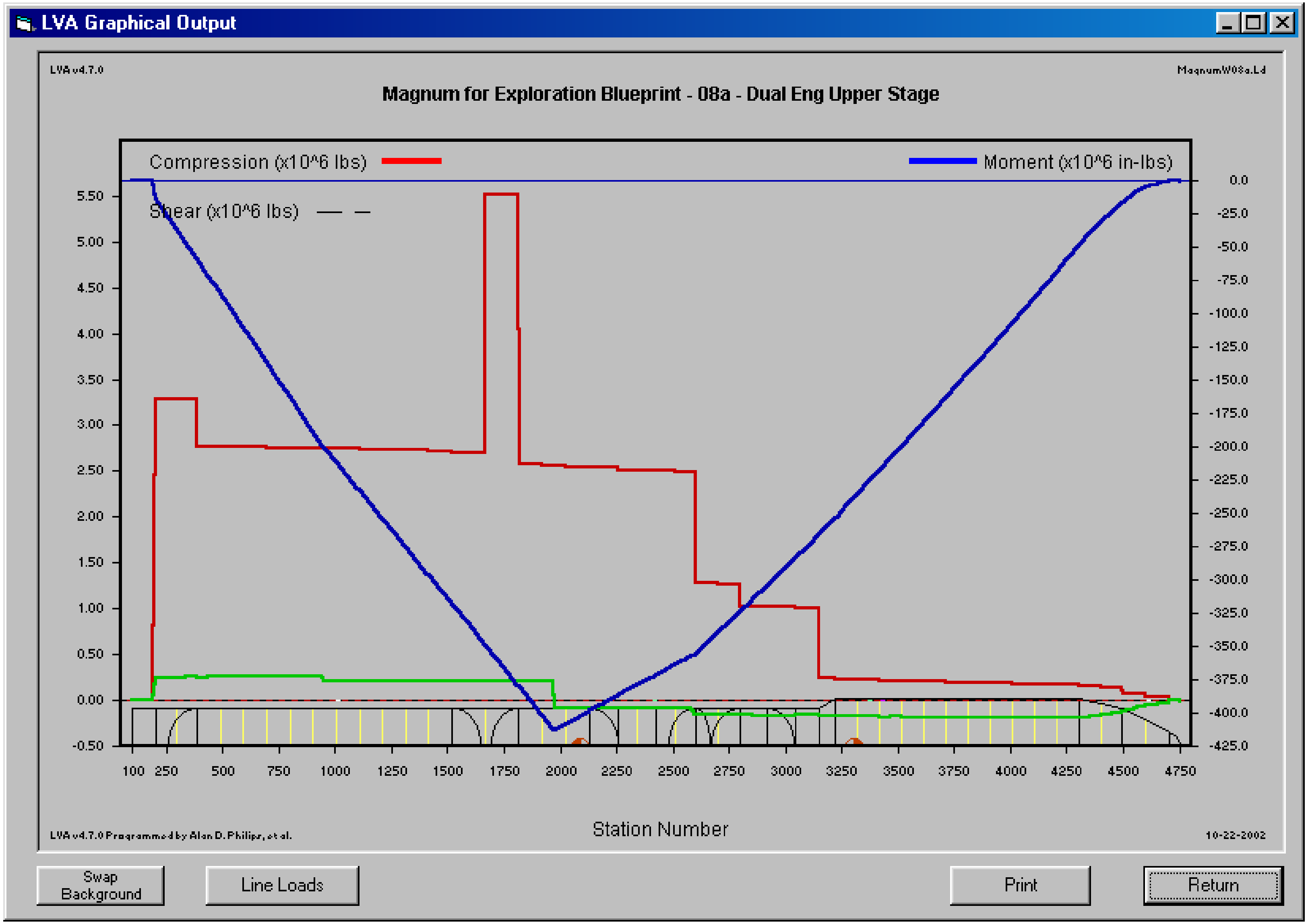
In-line HLLV w/ 2 SSME Configuration



In-line HLLV Dual Engine 2nd Stage Side View



In-line HLLV Dual Engine 2nd Stage Combined Ascent Loads - Compression, Moment, & Shear



Magnum Derived Launch Vehicle w/ 4 SRBs

Vehicle Characteristics

Gross liftoff mass	8.785 mlb
T/W @ liftoff	1.52
Max Q	700 psf
Max accel	3.30 g
Shroud mass	41.4 klb

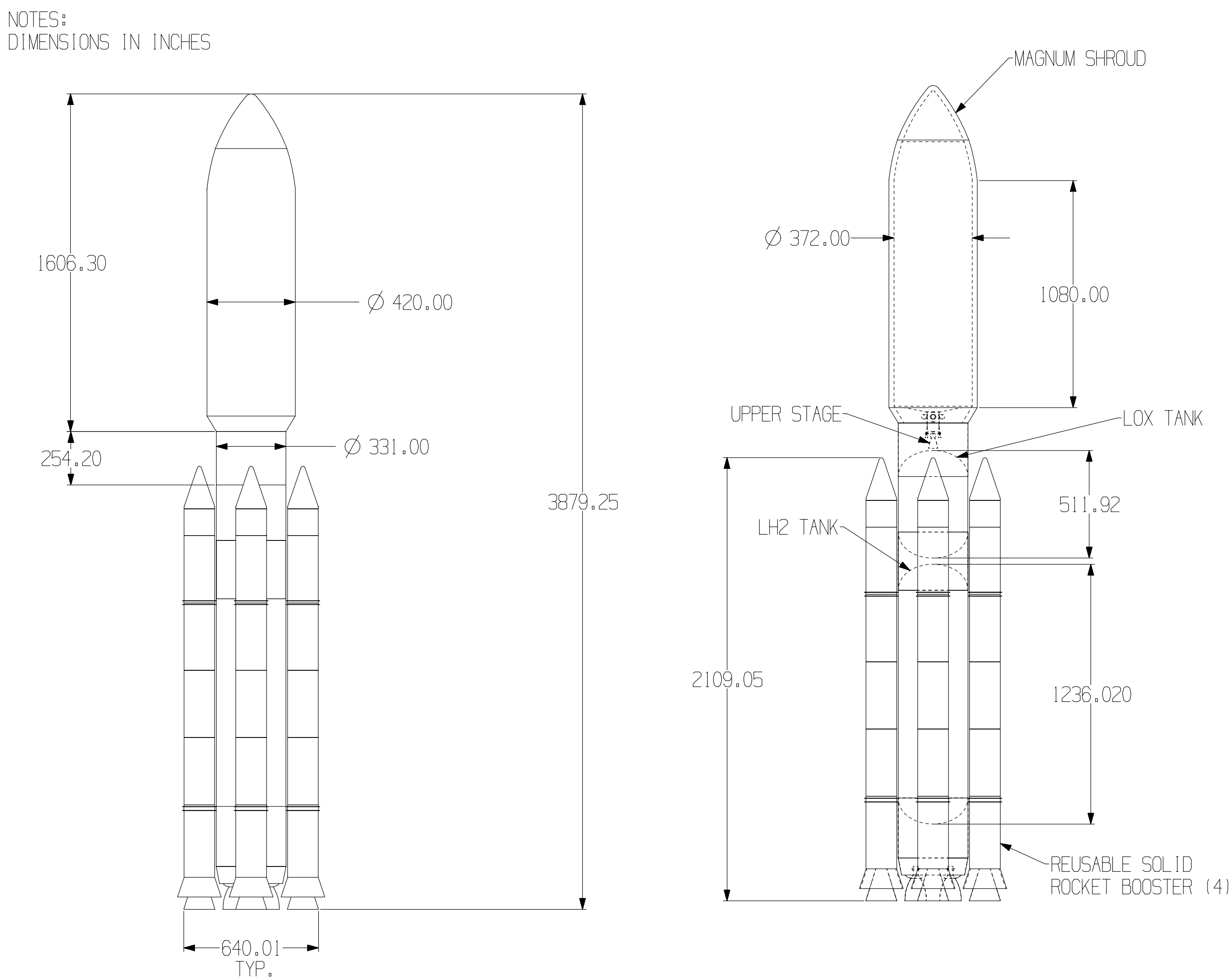
Booster:	Five Segment SRB		
Number of Boosters	4 SRBs		
Propellants	Solid Prop		
Ascent propellant mass	1428 klb, each		
Burnout mass	217 klb, each		
Separation conditions	Mach= 5.74, Q= 8.1 psf, alt= 205 kft		
Engines (each)	Five segment Shuttle SRB		
	Vacuum thrust=	3334 klb each	vac Isp= 265 sec
	Sea Level thrust=	3088 klb each	SL Isp= 245 sec

Core:	Magnum (2) RS-83		
Propellants	LO2/LH2		
Ascent propellant mass	1673 klb		
Burnout mass	231 klb		
Engines	2 RS-83 Engines		
	Vacuum thrust=	757 klb each	vac Isp= 449 sec
	Sea Level thrust=	640 klb each	SL Isp= 379 sec

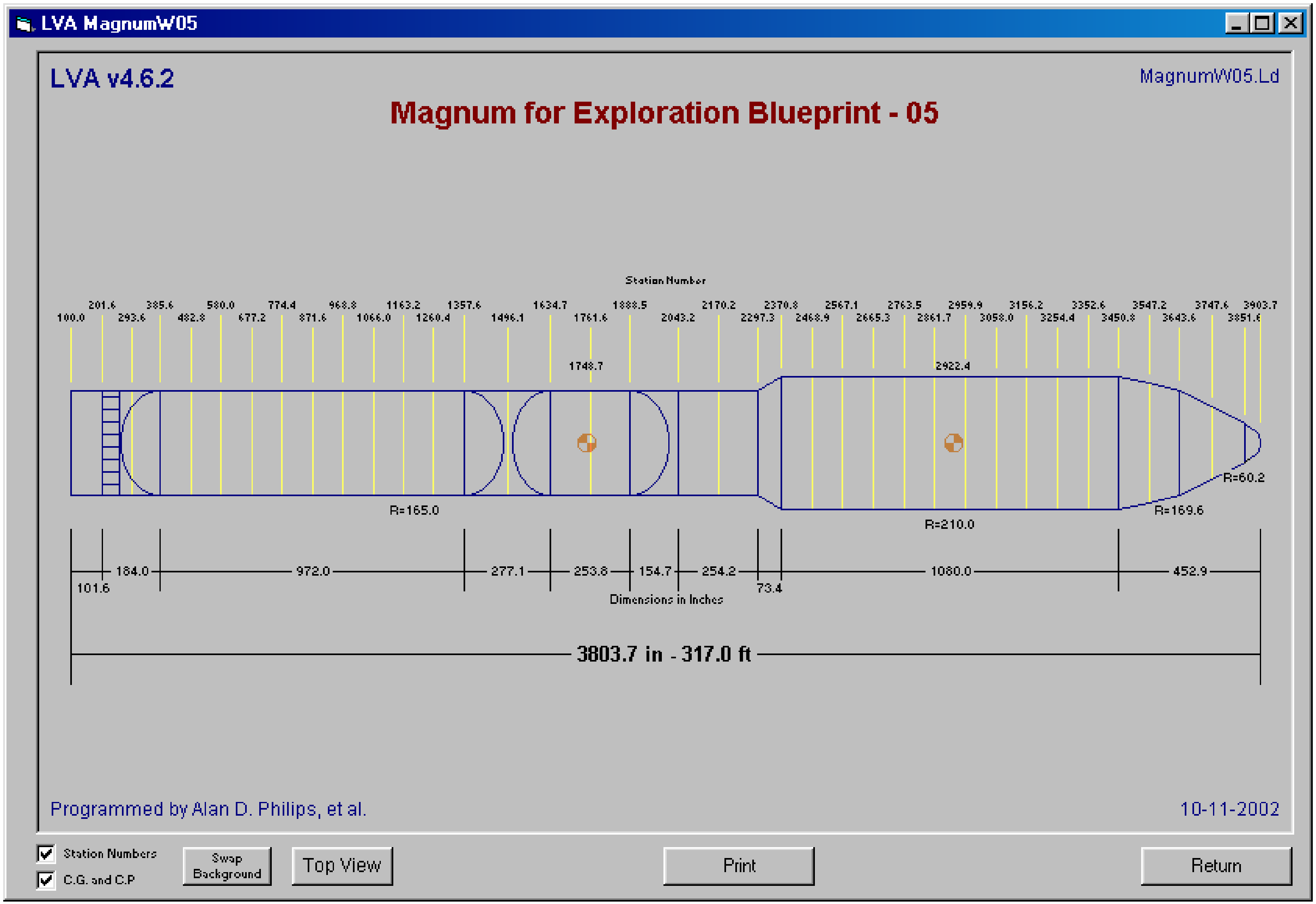
Kick Stage:	Circularize @ 150 nmi
Jettison mass	8.4 klb

Target Payload	100 MT to 150nmi circ @ 28.5 (DRM)
Actual Payload	106.6 MT to 150nmi circ @ 28.5

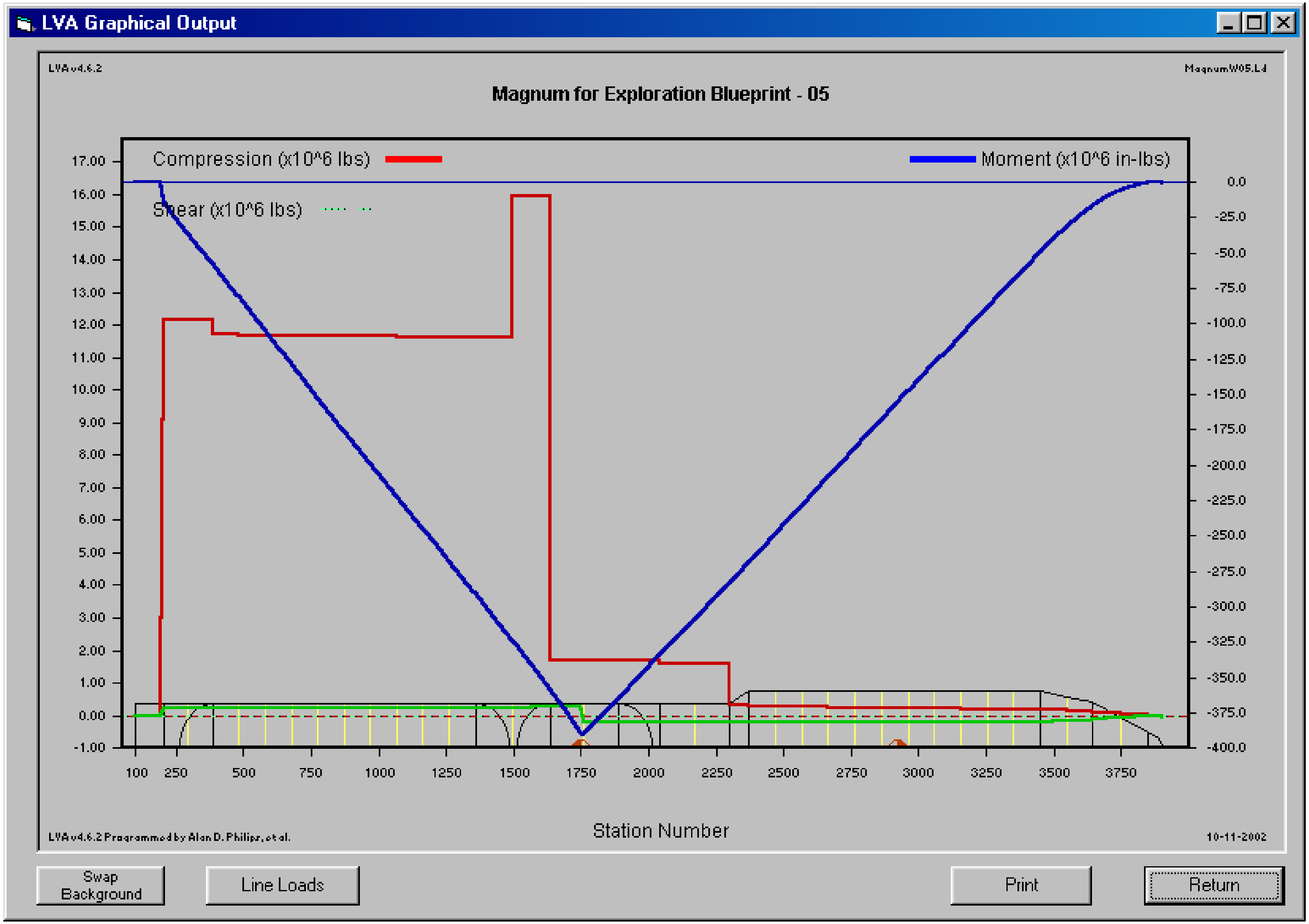
Magnum Derived Launch Vehicle w/ 4 SRBs



Magnum In-Line Side View



Magnum In-Line Combined Ascent Loads - Compression, Moment, & Shear



Shuttle-CX Launch Vehicle w/ 4 SRBs

Vehicle Characteristics

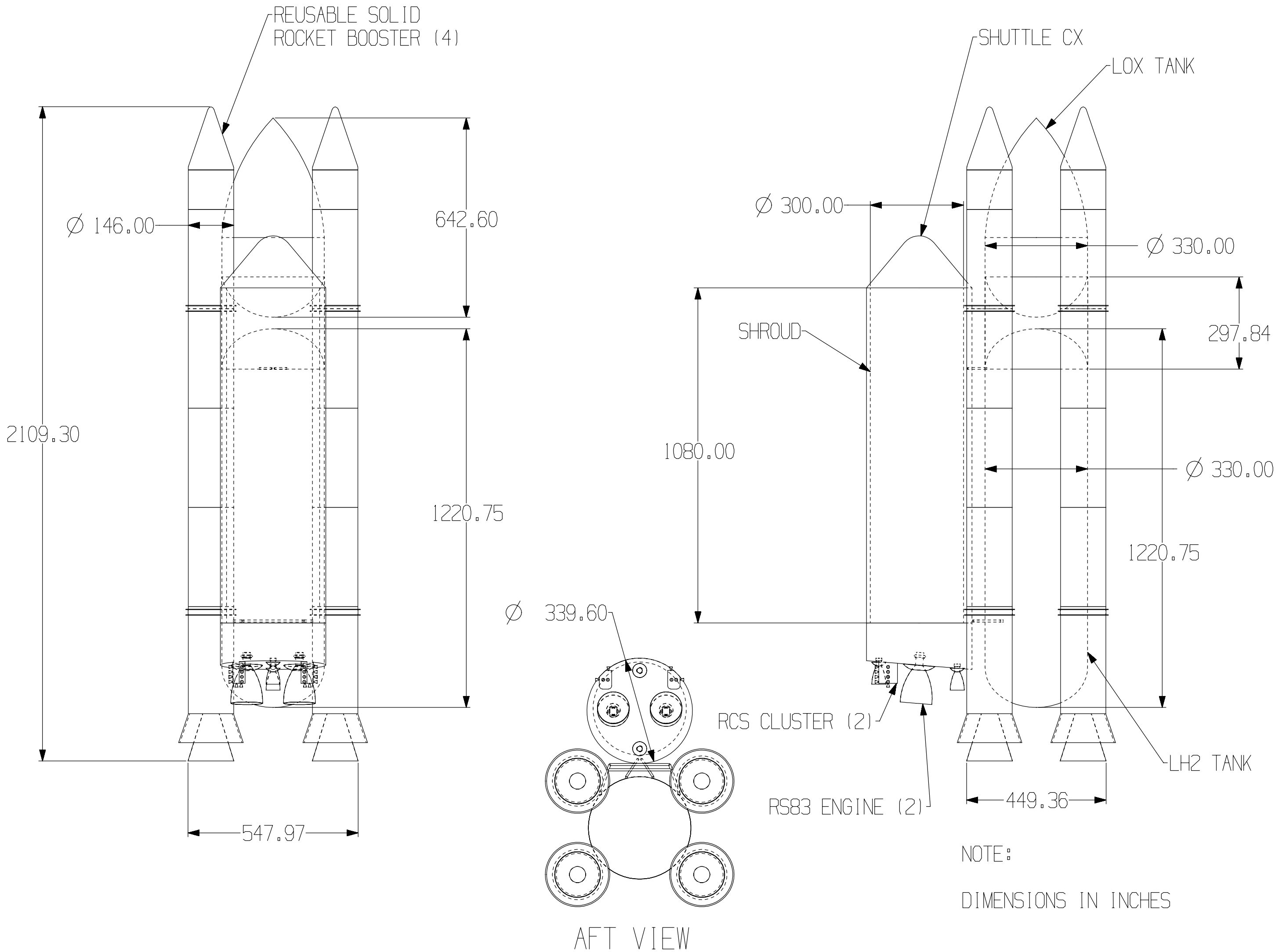
Gross liftoff mass	8.739 mlb
T/W @ liftoff	1.56
Max Q	694 psf
Max accel	3.00 g

Booster:	Five Segment SRB
Number of Boosters:	4 SRBs
Propellants	Solid Prop
Ascent propellant mass	1428 klb, each
Burnout mass	217 klb, each
Booster separation conditions	Velocity= 5709 ft/s, Q= 7.2 psf, alt= 206 kft, time= 132.4 sec.
Engines (each)	1 Five segment Shuttle SRB
	Vacuum thrust= 3334 klb each vac Isp= 265 sec
	Sea Level thrust= 3088 klb each SL Isp= 245 sec

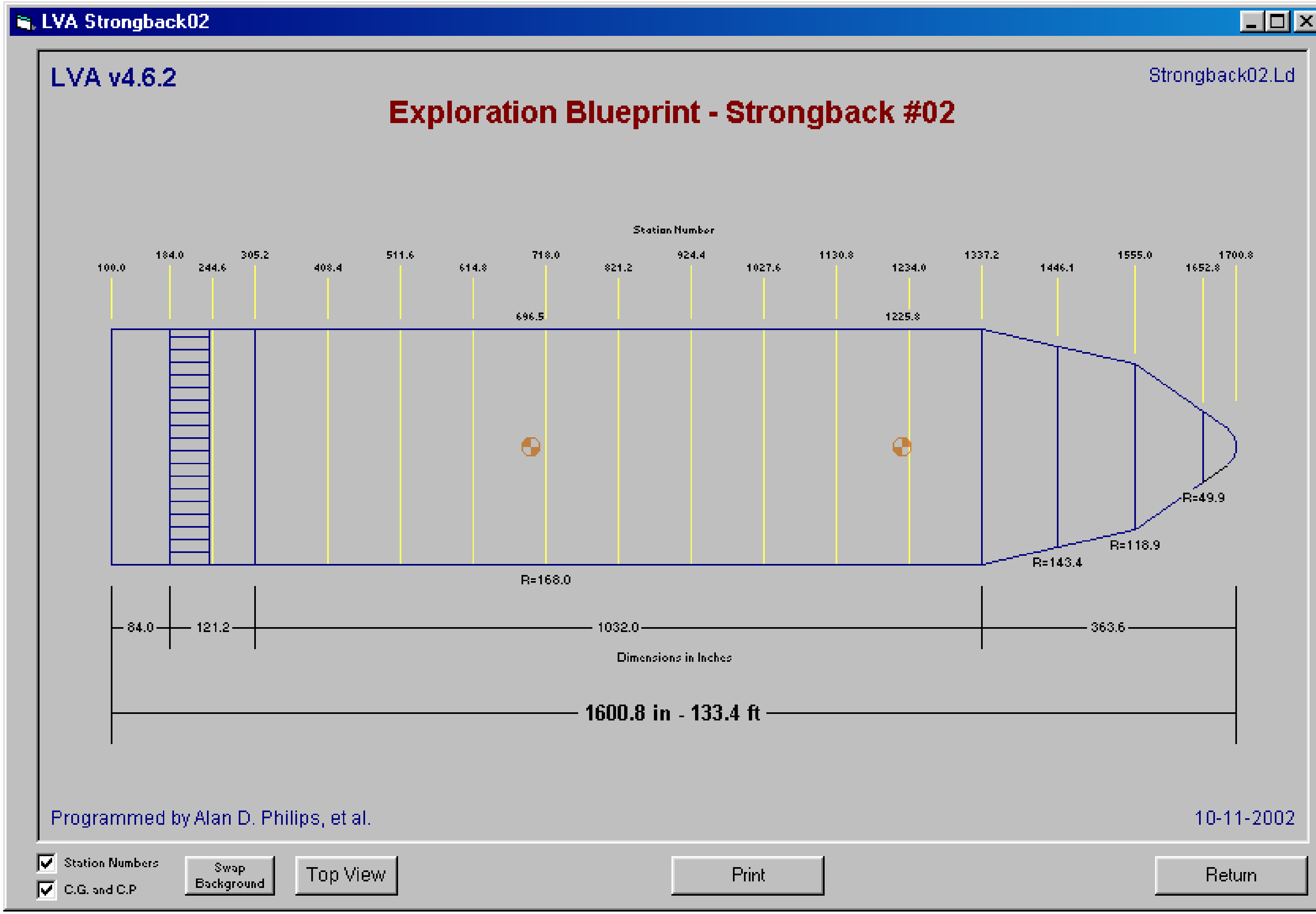
Payload Container	Shuttle-CX
Propellants	LO2/LH2
Ascent propellant mass	1674 klb
Shroud separation conditions	Velocity= 6902 ft/s, Q= 0.0 psf, alt= 400 kft, time= 220.6 sec.
Burnout mass w/o payload	141 klb
External Tank Dry Mass	64 klb
Engines	2 RS-83 Engines
	Vacuum thrust= 757 klb each vac Isp= 449 sec
	Sea Level thrust= 640 klb each SL Isp= 379 sec
	Shuttle OMS

Kick Stage:	n/a
Target Payload:	100 MT to 150nmi circ @ 28.5 (DRM)
Actual Payload:	102.9 MT to 150nmi circ @ 28.5

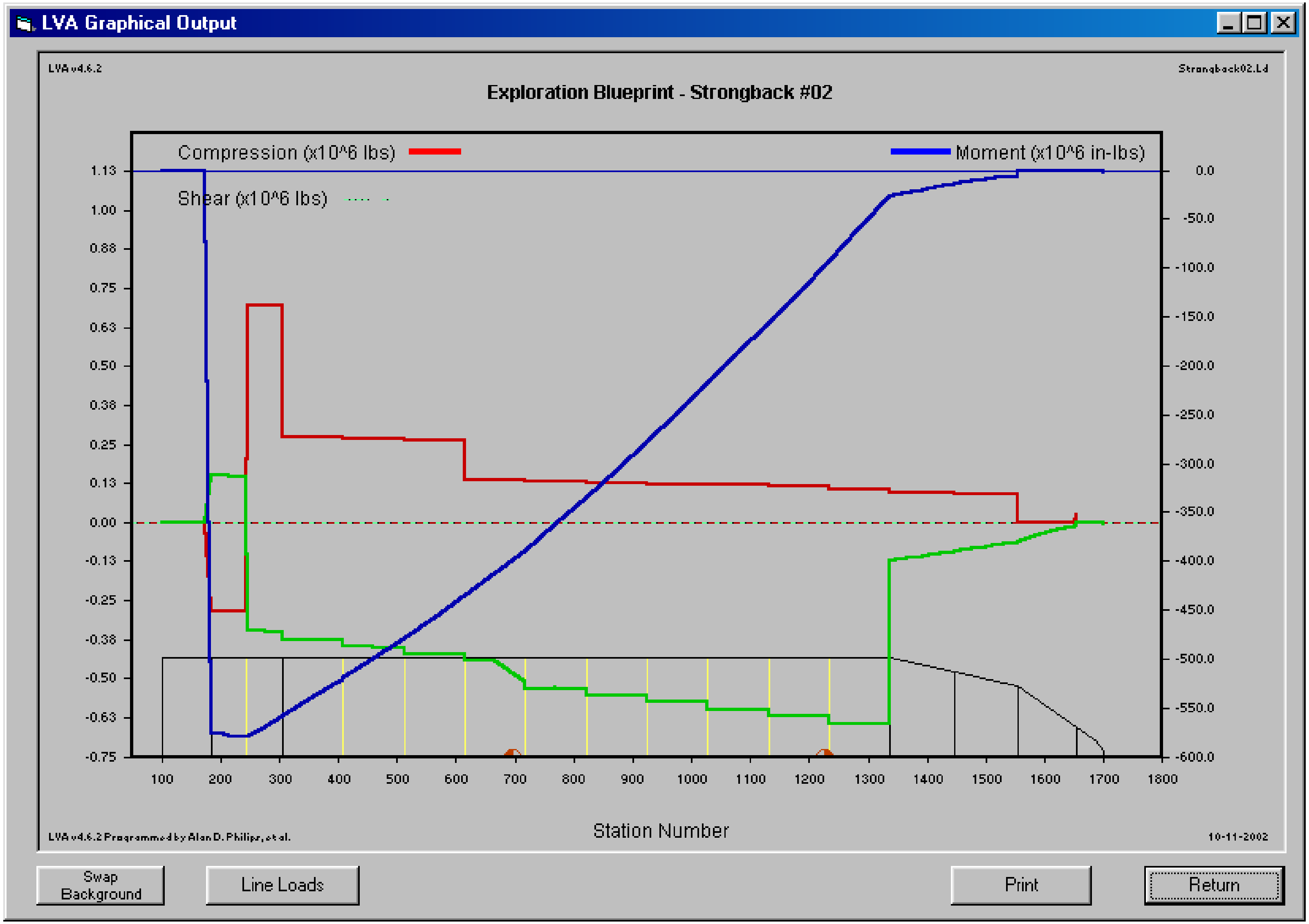
Shuttle-CX Launch Vehicle w/ 4 SRBs



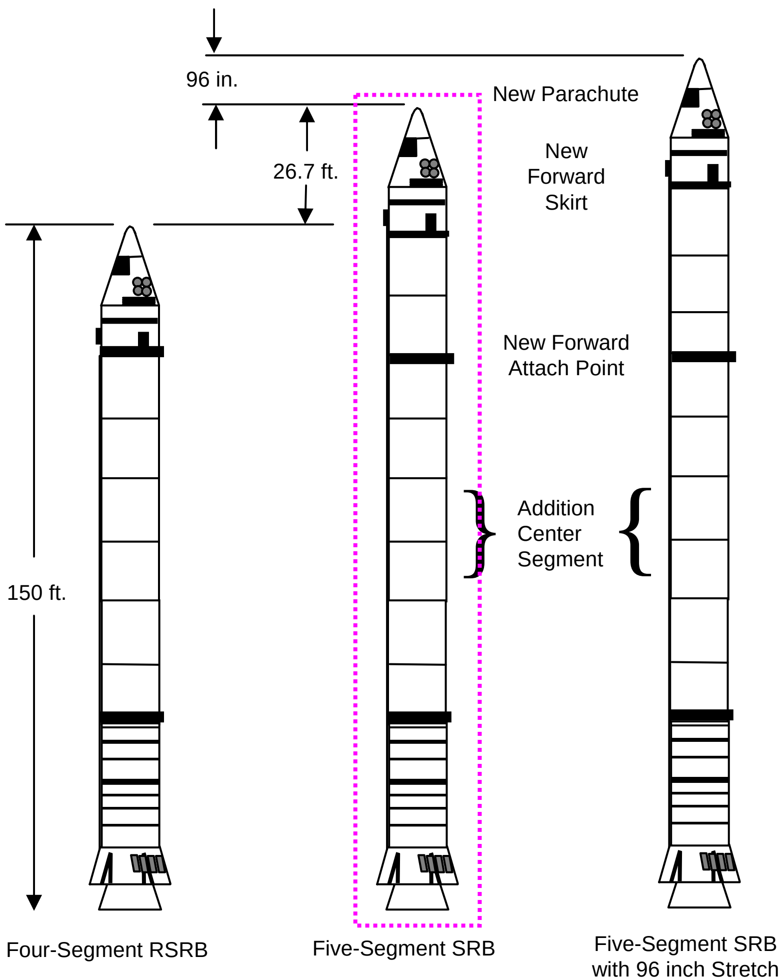
Shuttle-CX Side-Mount Side View



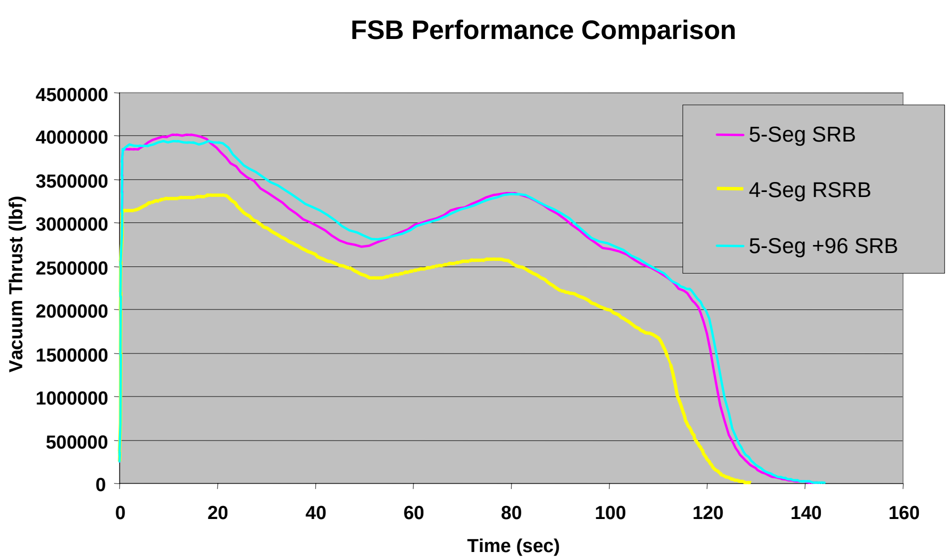
Shuttle-CX Side-Mount Combined Ascent Loads - Compression, Moment, & Shear



Five-Segment SRB

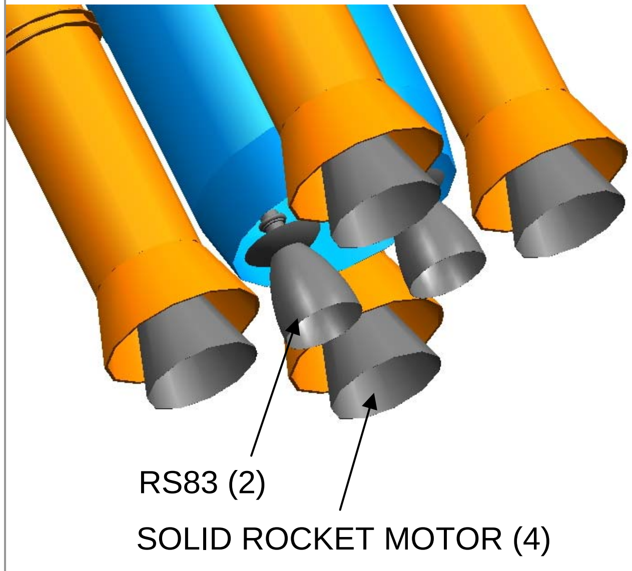


Performance Comaprison at 60F	Four-Segment RSRB	Five-Segment SRB	Five-Segment (+96") SRB
Reference Burn Rate (in/sec)	0.368	0.351	0.338
Nozzle Throat Dia. (in)	53.9	59.6	59.6
Maximum Operation Pressure (psia)	906.8	980	966.2
Maximum Thrust (M lbf)	3.145	3.921	3.943
Specific Impulse (sea level) (lbf-sec/lbm)	268.4	264.7	264.7
Action Time (sec)	123.5	128.9	133.0
Action Time Total Impulse (M lbf-sec)	296.9	368.28	388.73

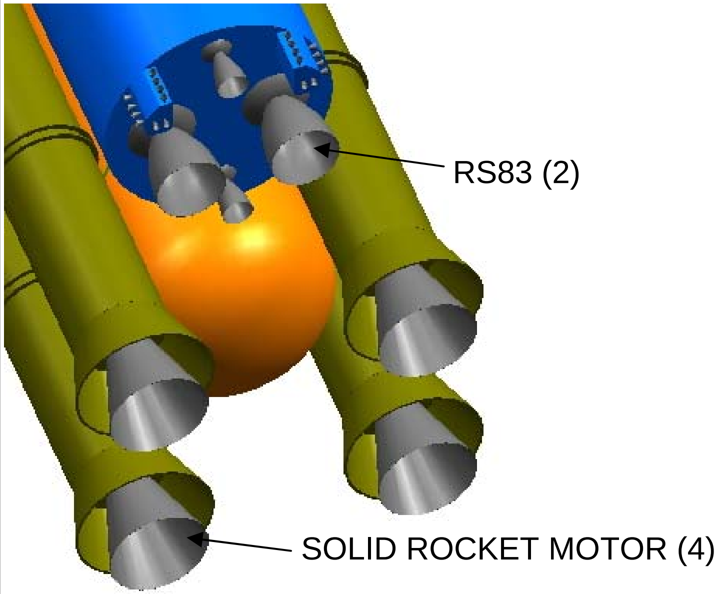


Motor and Engine

Magnum Arrangement



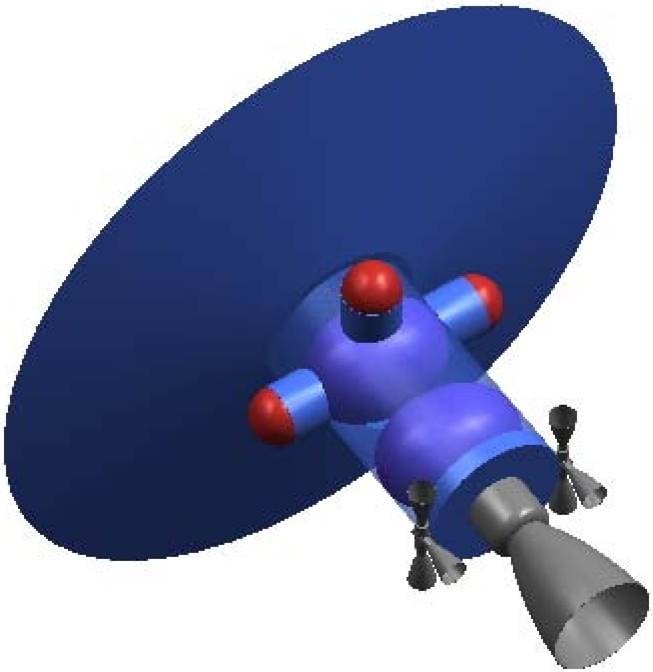
Shuttle-CX Arrangement



RS-83 Engine

Thrust, Sea Level:	640 Klbf
Thrust, Vacuum:	757 Klbf
Specific Impulse:	448.7 sec vac
Chamber Pressure:	2,800 psia
Mixture Ratio:	6.9 S.L. / 6.0 Alt
Engine T/W	55 S.L.
Area Ratio:	55:1
Throttling:	50 - 100% thrust

Magnum Circularization and De-orbit Stage



Overall Length: 174.3 in. (442.7 cm)
Maximum Diameter: 110.2 in. (279.9 cm)

Main Thruster: OMS derived, AeroJet AJ10-190 class, pressure-fed 6,000 lbf bipropellant thruster

Pc = 125 psia
Mixture Ratio = 1.65
Isp vac = 313 sec
Mass = 260 lbm (120 kg)

Reaction Control Thruster:
Marquardt R-4D class, bipropellant 110 lbf thruster

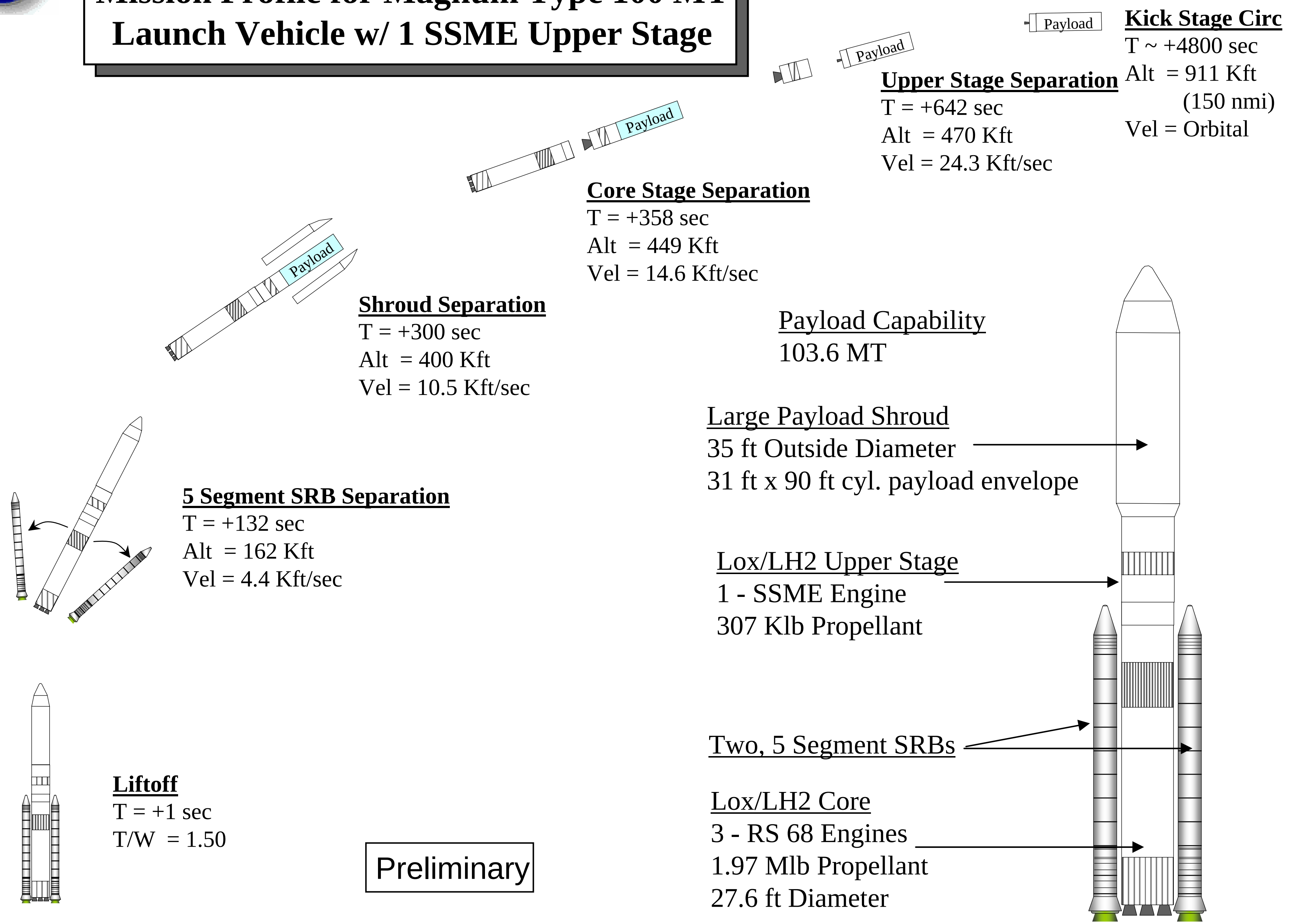
Pc = 100-400 psia
Mixture Ratio = 1.65
Isp vac (ss) = 311sec
Mass = 8.3 lbm (3.8 kg)

Stage Mass Breakdown

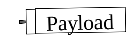
		lbm	kg	comments
Structures		1540.6	700	including pressurant tanks
Thermal*		140	64	
Electrical*		443	201	
GN&C*		118	54	
C&DH*		49	22	
Propulsion*		105	48	with intergrated RCS
design contingency		359	163	
Dry Mass Subtotal (15%)		2755	1252	
Propellant Mass				
NTO		3485	1584	
MMH		2112	960	
Pressurant		2	1	
Total Stage Mass		8354	3797	

* Masses derived from 2000 High Energy Upper Stage Study

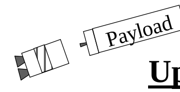
Mission Profile for Magnum Type 100 MT Launch Vehicle w/ 1 SSME Upper Stage



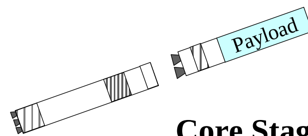
Mission Profile for Magnum Type 100 MT Launch Vehicle w/ 2 SSME Upper Stage



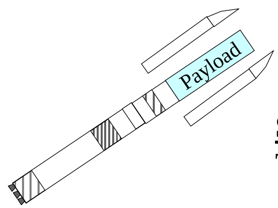
Kick Stage Circ
T ~ +4700 sec
Alt = 911 Kft
(150 nmi)
Vel = Orbital



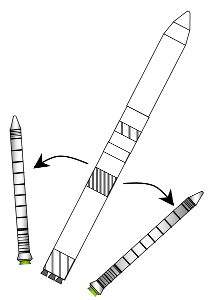
Upper Stage Separation
T = +539 sec
Alt = 471 Kft
Vel = 24.3 Kft/sec



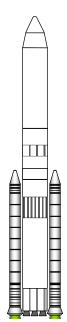
Core Stage Separation
T = +348 sec
Alt = 435 Kft
Vel = 12.8 Kft/sec



Shroud Separation
T = +300 sec
Alt = 400 Kft
Vel = 9.8 Kft/sec



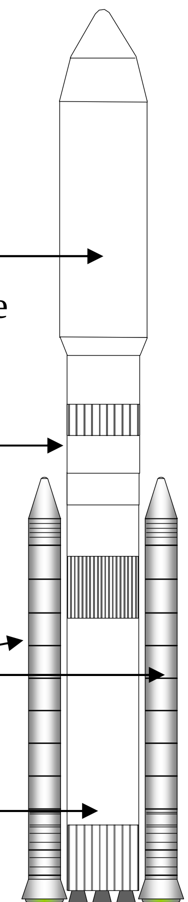
5 Segment SRB Separation
T = +132 sec
Alt = 160 Kft
Vel = 4.2 Kft/sec



Liftoff
T = +1 sec
T/W = 1.48

Preliminary

Payload Capability
104.8 MT



Large Payload Shroud
35 ft Outside Diameter
31 ft x 90 ft cyl. payload envelope

Lox/LH2 Upper Stage
2 - SSME Engine
413 Klb Propellant

Two, 5 Segment SRBs

Lox/LH2 Core
3 - RS 68 Engines
1.92 Mlb Propellant
27.6 ft Diameter

SSME Altitude Start Conclusions

from Alternate Propulsion Subsystem Concepts
NAS8-39210, DCN 1-1-PP-02147, March 1993

- Altitude sub-orbital start of SSME is feasible
- Preburner valve sequenced to higher positions and modified timings to accommodate lower inlet pressure
- Modify basic timing of the open loop and closed loop control modes
- Initial bootstrap rate reduced from current start time
- Time to reach main stage not affected
- Minimum propellant inlet pressures required, LOX – 40 psi, LH2 – 32 psi

A recent top-level look at air-starting an SSME for a two-stage RLV would require a Class A certification program with a ROM cost of approximately 100 million in 2003 dollars.

J-2S Restart Study Production Summary

Alternative Propulsion Subsystem Concepts
NAS8-39210, DCN 1-1-PP-02147, April 1993

Could be produced to existing drawings:
- **Only engine electronics absolutely require replacement**
- **No material changes**
- **All processes are still possible**

Desirable changes identified:
- **24 production changes (no change in form/fit/function)**
- **20 changes in fabrication technique (ie, castings, die forgings, etc.)**
- **12 material substitutions**
- **11 reliability & operational enhancements**

245 million 1992 dollars* production restart:
- **Assumes a 6 year production restart schedule**
- **Assumes one engine certification program**
- **Assumes certification results are a "one-for-one" match with historical data**
- **Unit cost of 10 million 1992 dollars* for a 10 lot buy**

*** 1992 to 2002 inflation index ~ 1.3**

Magnum Five-Segment SRB Recovery Issue

- The recovery issues related to the five-segment SRB with separation trajectory apogee in excess of 300k ft is valid for the four five-segment SRB Magnum configuration.

- With the two five-segment SRB Magnum configuration booster separation trajectory apogee is less than 260k ft, well under the five-segment SRB design requirement ceiling of 280k ft.

Structures Guidelines & Assumptions

- Gr/Ep IM7/8552 construction with Aluminum cryotanks
- Weights provided are best effort / preliminary
- Weights do not include any additional factors (weight growth, etc.)
- Ascent load input obtained from POST run provided

SLI Composite Structures Activities

- Tasks currently in place for further development
  - Primary composite cryotanks

- Tasks identified, but not currently being pursued
  - Airframe structural interface w/ large integral cryotanks
    - Attached orbiter / payload pod
    - Aerosurfaces
    - Thrust structure
    - Intertank

Advanced Concept Analysis in Support of the Integrated Space Plan

Section 4.3

Exploration Architecture Analysis
Vehicle Processing and Launch Operations Assessment

November 2002

Scope

- **Three launch vehicle designs and 5 payload types will be assessed.**
  - **Launch Vehicles**
    1. EELV (Exploration Class) – 35-45 MT
    2. Magnum with two Five-Segment Solid Rocket Boosters (FSB)
    3. Shuttle-C25 (large cargo) with two FSB
    4. Ancillary High-Level Assessments
       - Liquid Boosters vs. Solid Boosters
       - Magnum Type Concept and Shuttle-C25 Concept with Four Five-Segment SRBs
       - 2012 Saturn V
  - **Payload Processing Impacts**
    1. Lunar Transfer Vehicle (LTV)
    2. Gateway
    3. Lunar Lander (3-day stay)
    4. Lunar Habitat (30-day stay)
    5. Solar Electric Propulsion (SEP)
    6. Nuclear Payload Assessment/Assumptions
- **Items to be included in assessment for each vehicle:**
  - Groundrules, assumptions and exclusions
  - Overall Launch Site Processing Flow
  - Element Processing Timelines
  - Infrastructure Impacts/Modifications and Modification Schedule
  - High-level Manifest Assessment (sensitivity analysis)

KSC Team Members

Vehicle Processing and Launch Operations

- **Cristina Guidi** – 1998 Magnum/LFBB Ops Lead, KSC Blueprint Team Lead
- **Connie Milton** – Infrastructure
- **Darrell Foster** – ELV/Payloads
- **Darin Skelly** – ELV/Payloads
- **Tom Overton** – Shuttle Manifest
- **Frank Izquierdo** – Shuttle Upgrades
- **Jeff Campbell** – 1999 Magnum/SRB Ops Assessment Lead
- **Chuck Davis** – Propellant Handling
- **Don Burris** – Infrastructure

Supportability Team

- **Bob Cunningham**
- **Bill Roy**

Cost Comparison Team

- **Glenn Rhodeside**
- **Jim Roberts**

Significant Groundrules and Assumptions

- KSC Manifest must allow for 4 ISS resupply missions per year
- VAB approved for 1.5 flight sets of 5-Segment SRBs (VAB Quantity Distance still under review)
- Shuttle-CX cargo carrier element and Magnum core element will arrive at KSC with engines installed and will require minimal launch site checkout
- No Planetary Protection Requirements
- All Handling/transportation GSE will be provided by launch vehicle and payload provider for launch vehicle and payload processing
- No hazardous “off-line” payload processing requirements (e.g. all payload off-line activities will be performed in SSPF)

Study Exclusions Requiring Follow-on Evaluation

- Launch Processing System (ground software/hardware)
- Special testing (I.e. Demonstration flight, Flight Readiness Firing, “twang” test)
- Launch Pad Environment Impact studies (e.g.. Thermal, pressure, acoustic, vibration, lift off drift, excursions, etc.) may have an impact of facility modifications
- Mixed fleet impact/transition planning
- FTE assessments if new mission set is additive to current work load
- Environmental assessment for 2012 Saturn V and Nuclear Systems

General Nuclear Payload Assessment/Assumptions

- "Nuclear System" (i.e RTG, RPS, Reactor, etc.) will meet the analysis and data requirements for both launch approval and ground processing approval
- Ground processing of the "Nuclear System" and its integration into the payload will be performed at the appropriate "offline" payload hazardous processing facility and the appropriate handling and security measure will be implemented
- Final launch vehicle selected can accommodate late access at pad to install nuclear system
- NASA, DoE, and Federal Regulatory Agency (I.e NRC) will work together to determine the appropriate safety measures and licenses are in place at KSC/CCAFS
- Minimal "servicing" required for the "Nuclear System" once installed at the pad.
- Pad access will be extremely limited once "nuclear System" installed or arrives. If "nuclear system" installed at pad than controlled/limited access to area will be enforced.

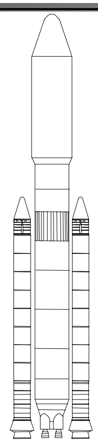
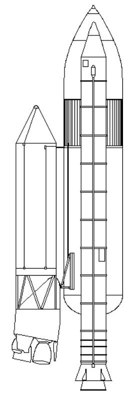
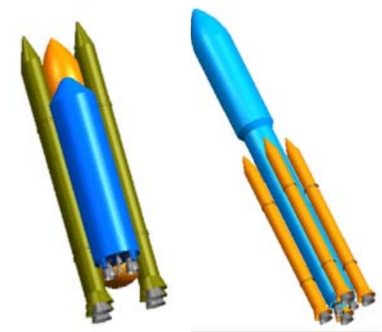
NOTE: Further detailed assessments will be performed as nuclear payload requirements are defined

Preliminary Assessment of Architectures

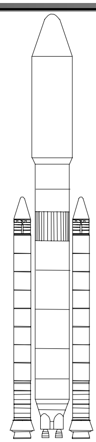
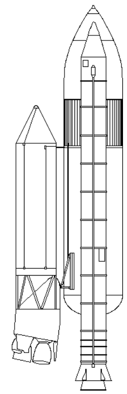
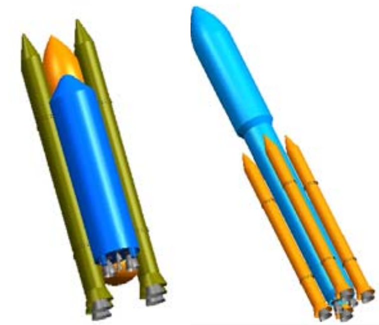
	Architecture A **Delta IV-Heavy Exploration Class**	**Architecture B** **Magnum w/ 2 FSB or Shuttle-C25 w/2 FSB**
Architecture Launch Campaign Options	**A1: If the Lunar Transfer Vehicle can be launched in the Shuttle Payload Bay with the exploration crew on-board (in the Shuttle cabin):** –5 STS launches per year –5 EELV launches per year **A2: If the Lunar Transfer Vehicle cannot be launched in the Shuttle Payload Bay (because of the cryogenic propellants on-board):** –5 STS launches per year –7 EELV launches per year **A3: If the Lunar Transfer Vehicle and exploration crew are launched on a human-rated EELV:** –3 STS launches per year –7 EELV launches per year	**B1: If the Magnum launch vehicle is human-rated and has 100 MT payload lift capability:** –5 Magnum/Shuttle-C25 launches per year or 4 Magnum launches with 1 EELV launches per year **B2: If the Magnum launch vehicle is NOT human-rated and has 100 MT payload lift capability:** –2 STS launches per year –5 Magnum/Shuttle-C25 launches per year or 4 Magnum launches with 1 EELV launches per year
KSC Impacts	**EELV Impacts** • Both Boeing and LMA developing Exploration class “paper rockets” • Based on maximum launch rate (7 EELV’s launches first year) architectures A1-A3 are feasible on EELV’s. • Recommend multiple EELV providers (Delta IV & Atlas V) be carried forward to allow for LV development and for unknown future commercial launch rates. • If single EELV Provider carried forward than recommend additional dedicated “exploration class” EELV Pad for manifest flexibility **Shuttle impacts:** • Architecture A1: Launching payloads with cryogenics is not permitted in the Shuttle Payload Bay • Architectures A1 & A2 are stressing the manifest capability when including the 4 ISS resupply missions (maximum of 9 launches per year) – increase in manpower required • Facility impacts minimal (minor payload processing modifications) **Overall Assessment:** • All Architecture A options are feasible	**Magnum w/ 2 FSB** and **Shuttle-C25 w/ 2 FSB** at **Complex 40/41** were ruled out due to excessive infrastructure requirements (new standalone core processing facility or cargo carrier facility, new Vehicle Integration Facility, new SRB Buildup and Stacking Facility, Major pad modifications) • LC-39 Area has been selected as leading candidate for Magnum and Shuttle-C25 **Overall Assessment:** • All options are feasible however there are infrastructure impacts • All flight scenarios can be supported with 1 new MLP for Magnum/1 new MLP for Shuttle-C25 and 3 existing MLPs for Shuttle. • All flight scenarios can be supported by 2 modified launch pads • Five-segment Booster processing will require a new SRB Build-up and Stacking facility because of Quantity Distance restrictions and manifest • Magnum or Shuttle-C25 launch manifest must accommodate 4 ISS resupply missions per year • To maintain manifest, will require OPF processing timelines to be less than (80) days and additional workforce will be required

NOTE: Flight rate above is in addition to the 4 mandatory ISS Resupply missions performed by Shuttle per year

KSC Launch Site Impacts – Quick Look

Concept Configuration	 **Magnum w/ Two FSB**	 **Shuttle-CX w/ Two FSB**	 **2012 Saturn V**	 **Magnum and Shuttle-CX w/ Four FSB**
Infrastructure Impacts	- New SRB Build-up & Stacking Facility - VAB High Bays 1 & 3 Access Platforms - Additional New RPSF Surge Facility - 1 New Magnum-dedicated MLP with Launch Umbilical Tower - New Cargo Transporter (shroud) - Pad Modifications: Additional LH2 sphere, SRB Forward Skirt Access, Flame Trench & Sound Suppression System, Methane Loading/venting/capture Capability (payload), Cryo Propellant loading/venting/capture GSE (payload) - Operations & Checkout (O&C): Removal of storage and payload test stand for Magnum core stage standalone processing - Retrieval and Disassembly: Diver Operated Plug (DOP), Additional Rail Dollies, Slip Crane	- New Cargo Carrier Processing Facility (CCPF) -New SRB Build-up & Stacking Facility - VAB High Bays 1 & 3 Access Platforms and High Bays 2 & 4 ET Checkout Cells modifications - Additional New RPSF Surge Facility - 1 New Additional MLP similar in design to Shuttle MLP -New Shuttle-CX Payload Canister / Transporter -1 New Extended-ET Barge - Pad Modifications: PCR Modifications, SRB Forward Skirt Access, GOX Vent Arm Notch Modification, Flame Trench & Sound Suppression System, Methane Loading/venting/capture Capability (payload), Cryo Propellant loading/venting/capture GSE (payload) - Retrieval and Disassembly: Diver Operated Plug (DOP), Additional Rail Dollies, Slip Crane	- VAB High Bays 1 & 3 Access Platforms - 1 New Saturn V -dedicated MLP with Launch Umbilical Tower - New Cargo Transporter (shroud) - Pad Modifications: Flame Trench & Sound Suppression System,RP-1 loading capability, Methane Loading/venting/capture Capability (payload), Cryo Propellant loading/venting/capture GSE (payload)	-New Launch Pad required or <u>extensive</u> modifications to existing pads -New Stacking/Integration Facility due to Quantity Distance (QD) limitations in the VAB - Four 5-Segment SRBs invalidate the QD requirement - Integration of this vehicle cannot occur in the VAB unless QD requirement is changed to allow 4 stacks at one time -New MLP -New Crawler -Two (2) New RPSF Surge Facilities -Retrieval and Disassembly: -Two (2) additional Retrieval Ships -Two (2) additional sets of rail dollies -Environmental issues - Acoustic effects to surrounding community -SRB exhaust deposition and new pad construction impact on ecosystem

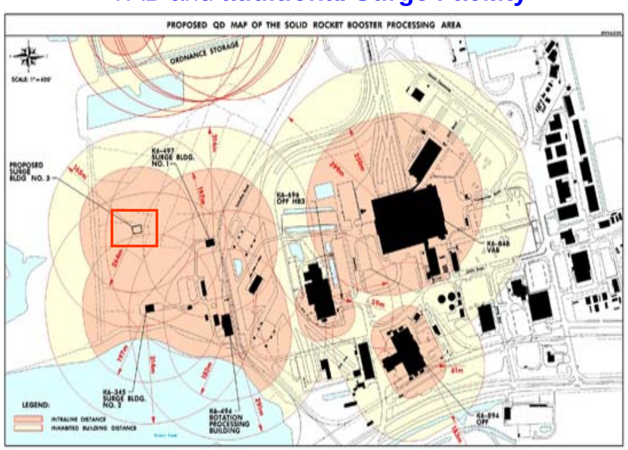
KSC Launch Site – Vehicle Pros and Cons

Concept Configuration	 **Magnum w/ Two FSB**	 **Shuttle-CX w/ Two FSB**	 **2012 Saturn V**	 **Magnum and Shuttle-CX w/ Four FSB**
Pros	•Infrastructure modifications are moderate	•Infrastructure modifications are moderate	•Infrastructure modifications are minor	•NONE
Cons	•Quantity Distance issue with Five segment booster •Construction of two new facilities required	•Quantity Distance issue with Five segment booster •Construction of three new facilities required		• Infrastructure impacts are extreme •Quantity Distance issue with Five segment booster

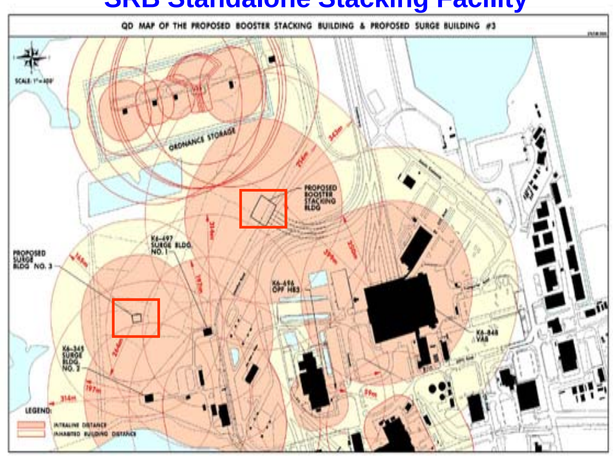
Quantity Distance (QD) Challenge

- Due to the required increase of solid propellant for FSB, significant processing challenges must be overcome
  - **Quantity Distance (QD)** for VAB limits the number of segments allowed within the VAB at any time
    - Current limit is approximately 4.4 million lbs. (2 flight sets of 4-Segment SRBs)
    - FSB propellant weight is approximately 5.6 million lbs. (2 flight sets of 5-Segment SRBs)
  - **If this propellant quantity limit is retained for 5 segment booster, no more than 15 segments (1.5 flight sets) would be allowed to be housed in the VAB**
    - This restriction would create a bottle neck in VAB processing operations which would prevent the current long term manifest from being met

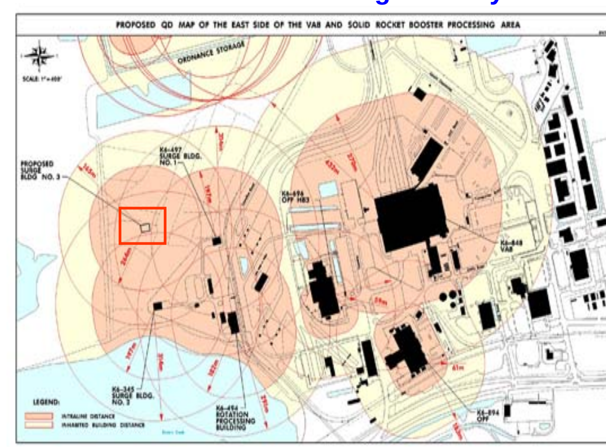
QD with current **4-segment boosters** in VAB and **additional Surge Facility**



QD with **current 4-segment booster limit** in VAB, **additional Surge Facility**, and **new SRB Standalone Stacking Facility**

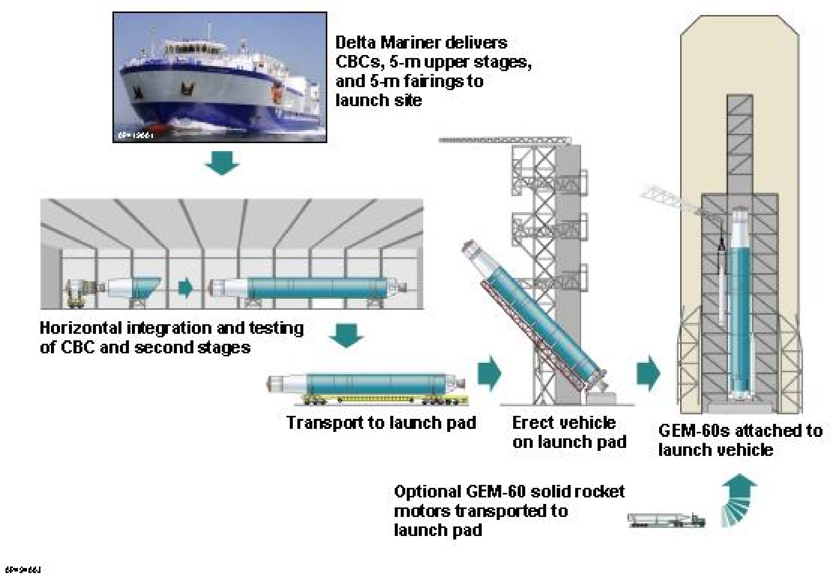


QD with **5-segment boosters** in VAB and **additional Surge Facility**

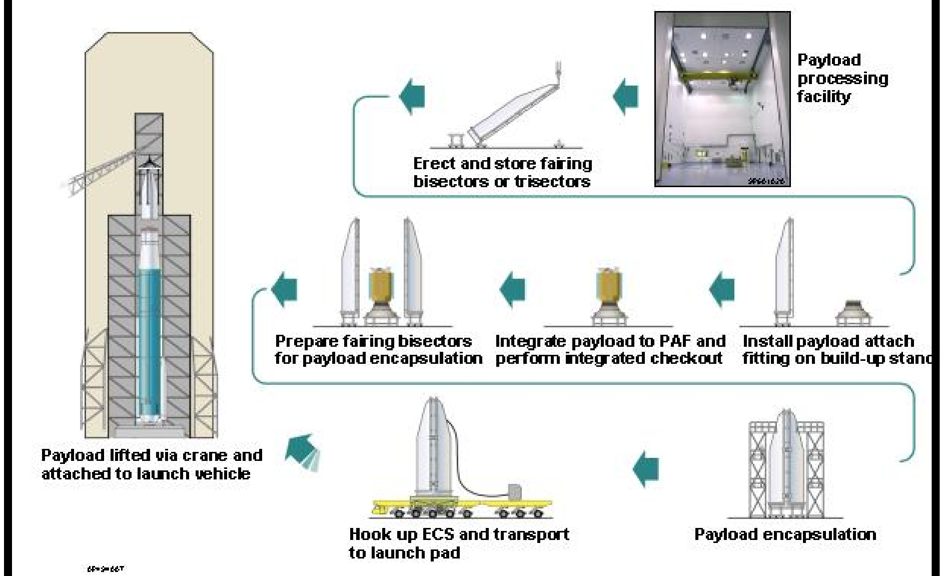


Backup Charts

Delta IV LV Launch Site Flow Processing

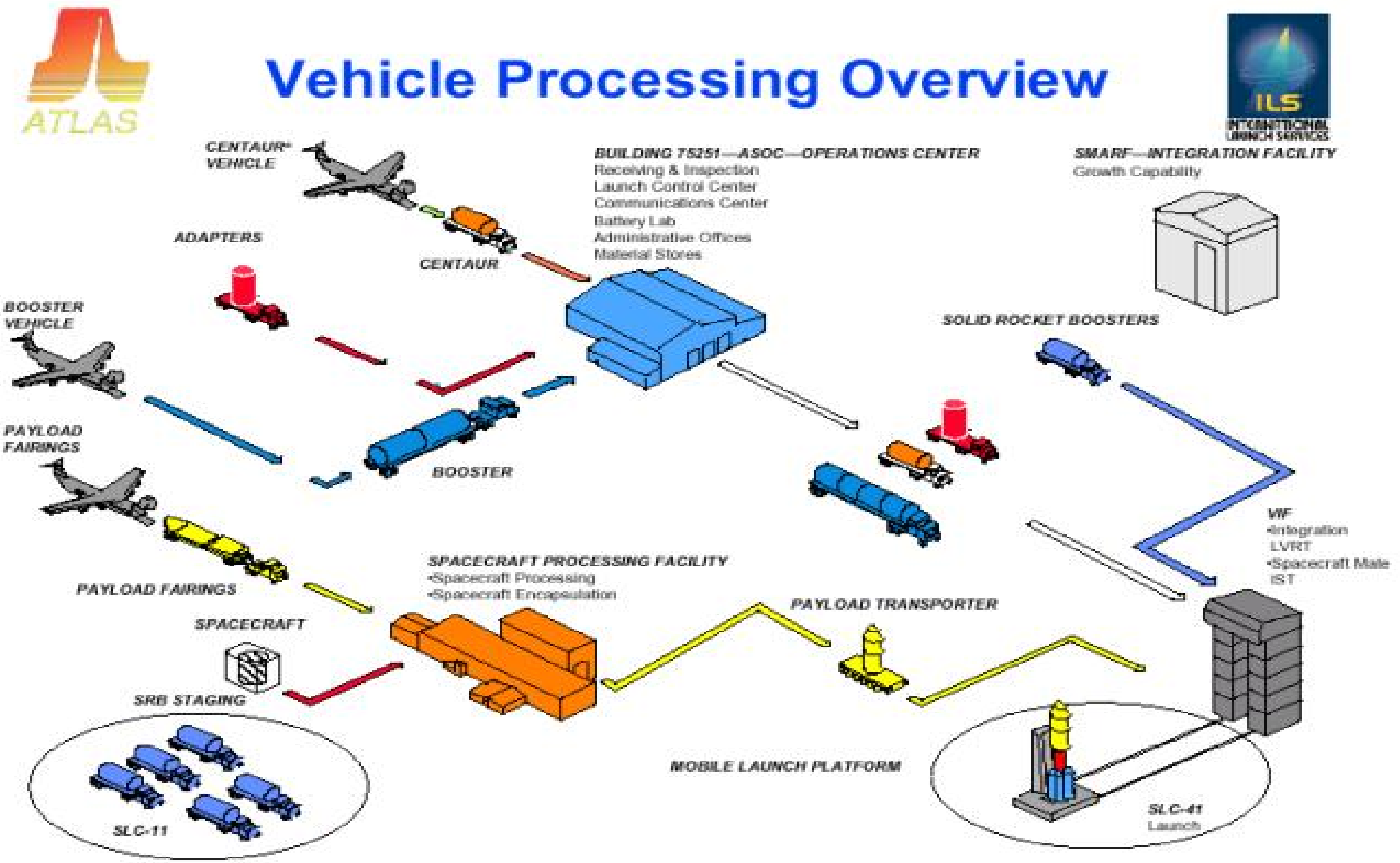


Booster Processing

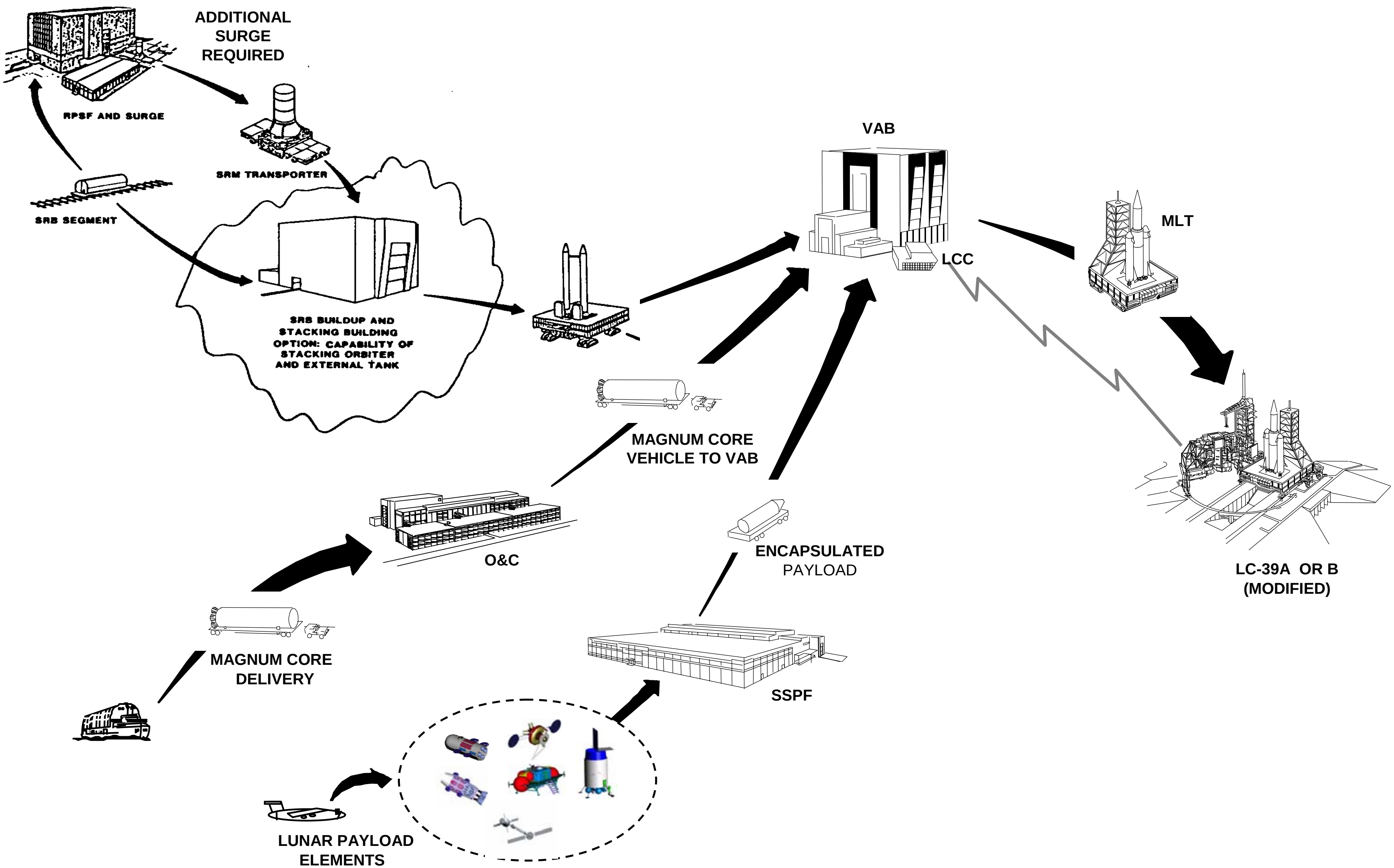


Payload Integration/ encapsulation (parallel)

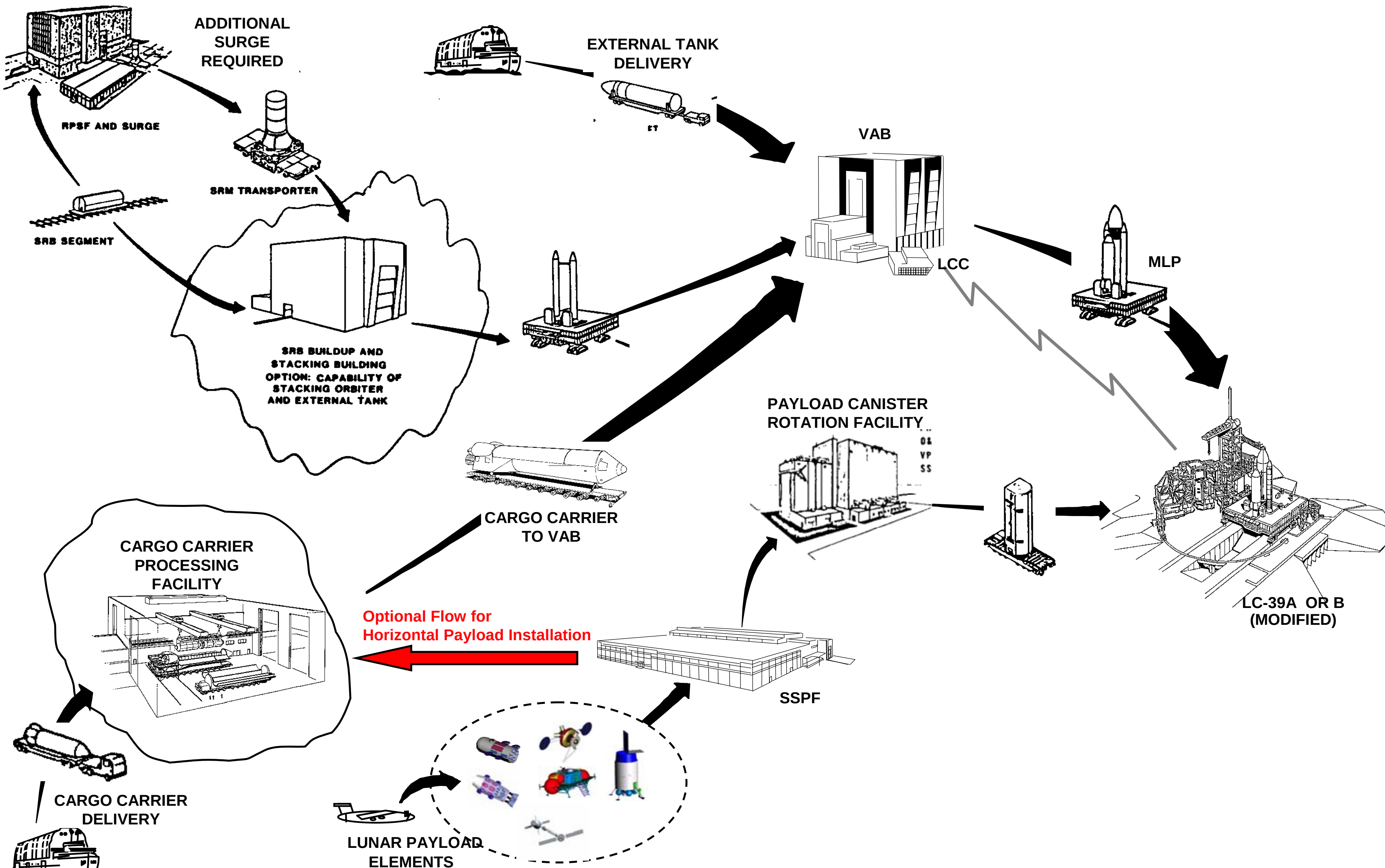
ATLAS V LV Launch Site Processing Flow



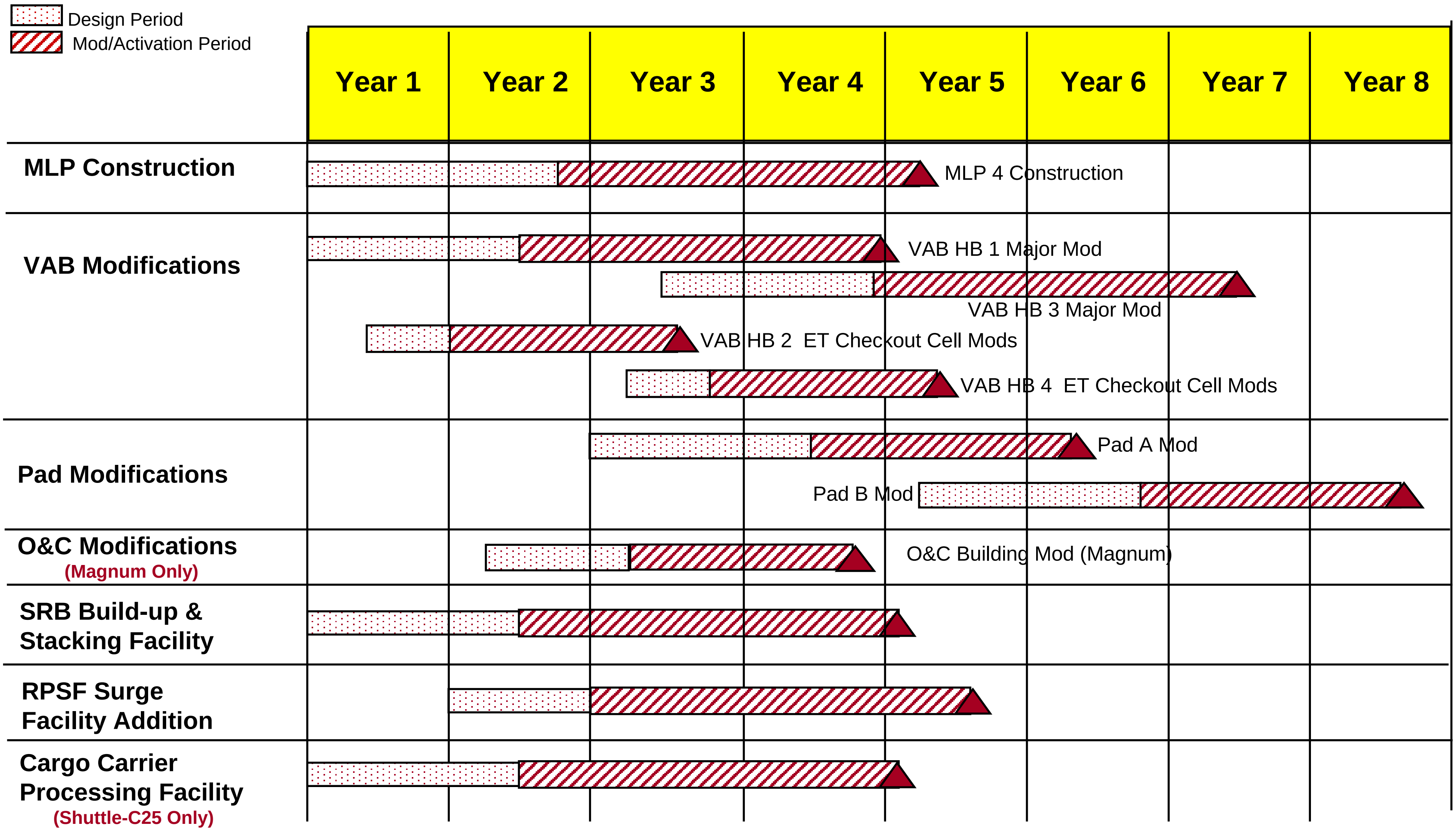
Overall Launch Site Processing Flow
(Magnum w/ FSB)



Overall Launch Site Processing Flow
(Shuttle-C25 w/ FSB)



Facility Modification Timeline



Backup – Infrastructure Impacts
For Architecture B only

RPSF Facility Modifications

Modification required for <u>any vehicle design</u> that uses 5-Segment Boosters

- Segment Railcars
  - ~ 6 more rented railcars at higher weight capacity will be needed for FSB
    - Accommodates longer / heavier fwd segment
- Exit Cone Elevator Mod
  - Due to longer exit cone
- Additional surge facility
  - Construct additional Surge Facility capable of holding 4 forward segments

Additional RPSF Surge Facility

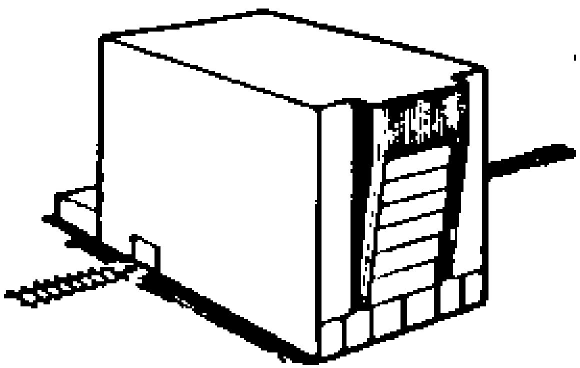
Data from USA Ground Operations for FSB Abort to Orbit Study

New SRB Build-up & Stacking Facility

- **Modification required for <u>any vehicle design</u> that uses 5-Segment Boosters**
  - **70,000 sq.ft. Processing Highbay**
    - MLP mount mechanisms
    - Vertical lift and Horizontal rolling doors
    - 800-ton bridge crane
  - **Options include and need further assessment:**
    - Stacking segments on the MLP (similar to current VAB process) – *impacts MLP turnaround timelines*

    or

    - Assembling the entire stack in a stacking cell and transferring the booster to MLP – *segment pinhole design needs to evaluated for load characteristics. Also requires a larger crane capacity.*



SRB Build-up and Stacking Facility (conceptual drawing)

Data from NASA Study March 1990
Reference Drawing 79K29971

VAB Modifications
(Magnum w/FSB)

- **Vehicle Assembly Building (VAB) integration cells will be required to support the Magnum Vehicle**
  - Highbays 1 and 3 were selected for Magnum integration

- **Extendible vehicle access platforms Modifications**

<u>Magnum-Driven Mods</u>

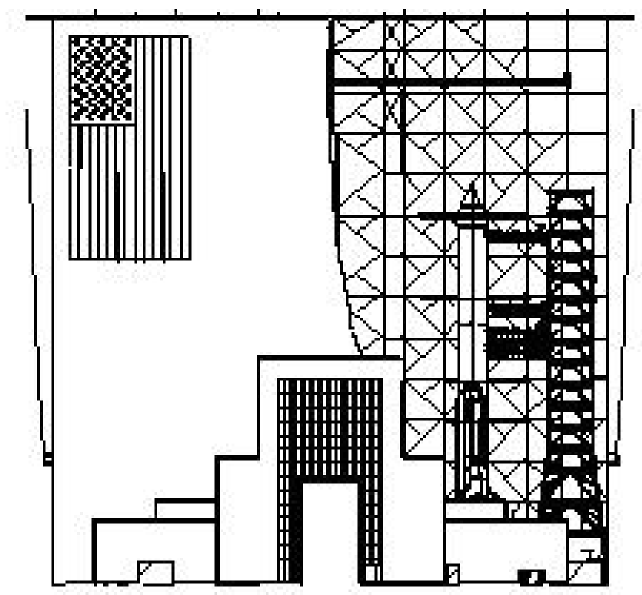
– Install new platforms at higher levels and modify lower platforms

<u>FSB-Driven Mods</u>

– Provide access to new fwd segment and ET forward attach

– Modify platforms “C” and “E”

– Relocate AP- 46/47 and AP-100



Magnum Vehicle in the Vehicle Assembly Building (VAB) - Highbay 1
(Front View)

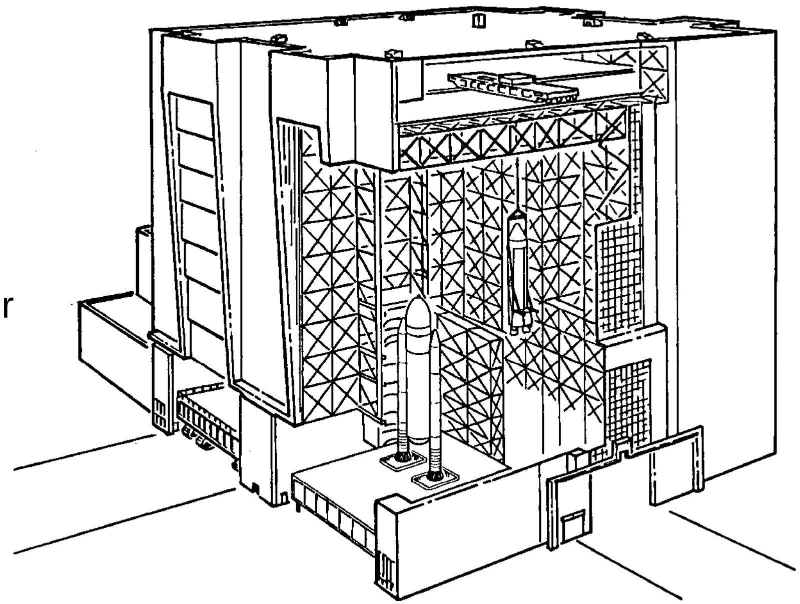
VAB Modifications
(Shuttle-C25 w/FSB)

- **Vehicle Assembly Building (VAB) integration cells will be required to support the Magnum Vehicle**

- **Integration Cells (Highbays 1 and 3)**

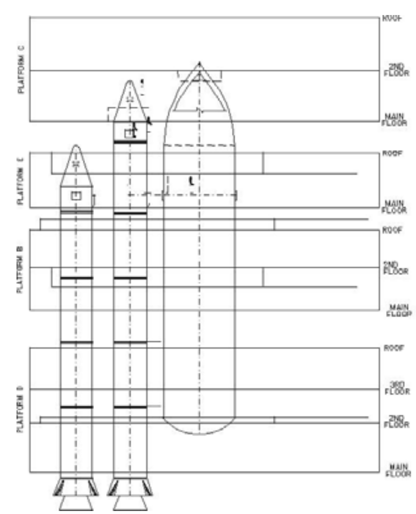
  <u>Cargo Carrier-Driven Mods</u>
  – Modify platforms due to increased girth of cargo carrier

  <u>FSB-Driven Mods</u>
  – Provide access to new fwd segment and ET forward attach
  – Modify platforms "C" and "E"
  – Relocate AP- 46/47 and AP-100



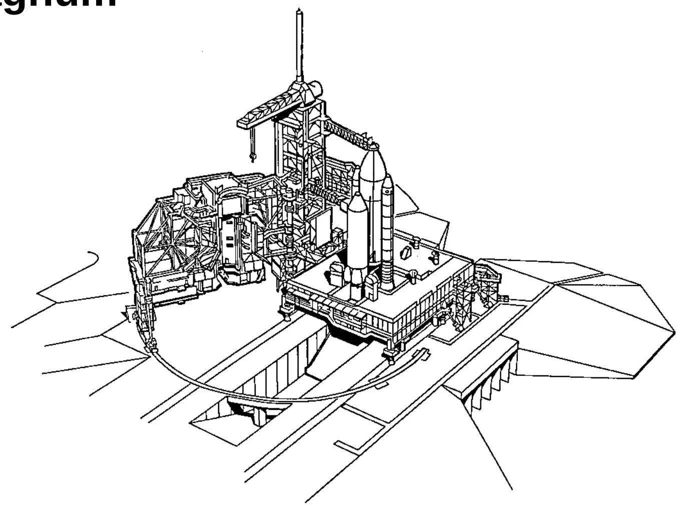
- **ET Checkout Cells (Highbays 2 and 4)**

  – Modify platforms due to increased length from Shuttle ET configuration *(must maintain capability to process Shuttle ET)*
  Or
  – Incorporate "Ship and Shoot" concept to eliminate facility modifications



Pad Modifications
(Magnum w/FSB)

- **Both pads will be modified to have both Shuttle and Magnum or Shuttle-C25 capabilities**



Magnum Unique Pad Modifications:

- Additional LH2 storage sphere and associated lines
- Flame Trench & Sound Suppression System
- Methane Loading/venting/capture Capability (payload)
- Cryo Propellant loading/venting/capture GSE (payload)

<u>FSB-Driven Mods</u>

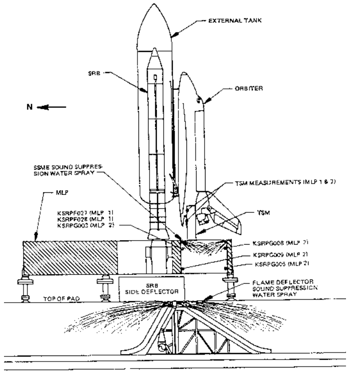
- Install new Forward Skirt Access platform at approximately the 241’ level

Shuttle-C25 Pad Modifications :

- RCS Room interference mods
- Hammerhead crane removed
- PCR interference due to larger diameter
- Flame Trench & Sound Suppression System
- Methane Loading/venting/capture Capability (payload)
- Cryo Propellant loading/venting/capture GSE (payload)

<u>FSB-Driven Mods</u>

- Install new Forward Skirt Access platform at approximately the 241’ level
- Modify GOX Vent arm to provide booster clearance

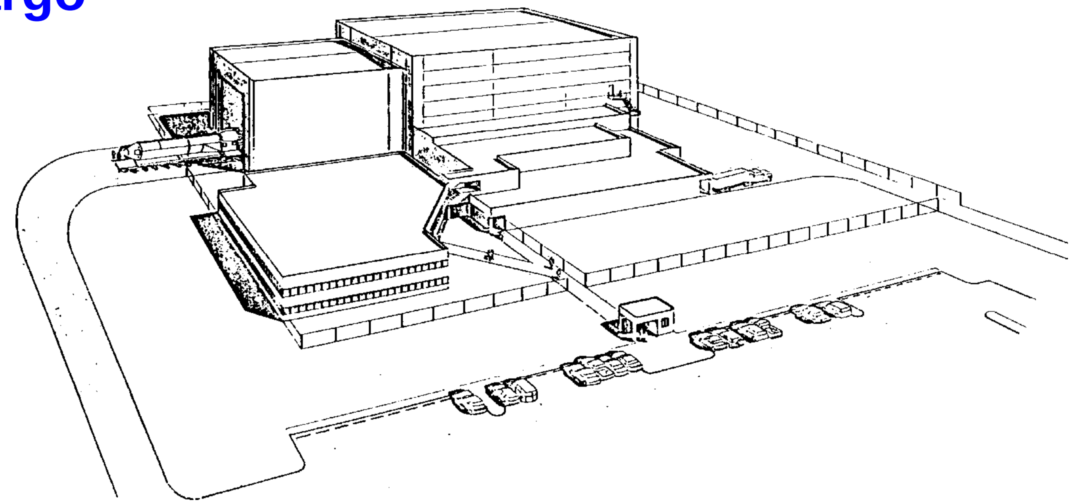


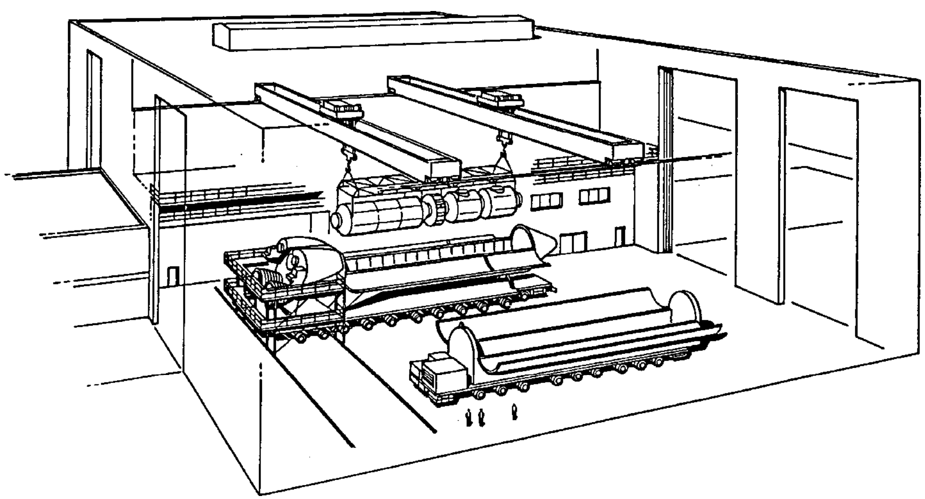
- TBD Payload Prop loading capability at pads

New Cargo Carrier Processing Facility
(Shuttle-C25 only)

New Facility for Shuttle C25 Cargo Carrier Processing

- Comprises three (3) main functional areas:
  - Operations Support Annex (OSA) 70,000 sq. ft.;
  - Logistics and Staging (L&S) 60,000 sq. ft.;
  - Integration and Checkout (I&C) High Bay 50,000 sq. ft
  - An airlock (25,000 sq. ft.) accommodating vehicle entry into the I&C high bay
- Fueling of payloads and flight vehicles shall not be a function of the CCPF Process and check out the Shuttle-C25;
- Integrate segmental payloads into a single payload;
- Integrate and test single, multiple and segmental payloads with the Shuttle "C";

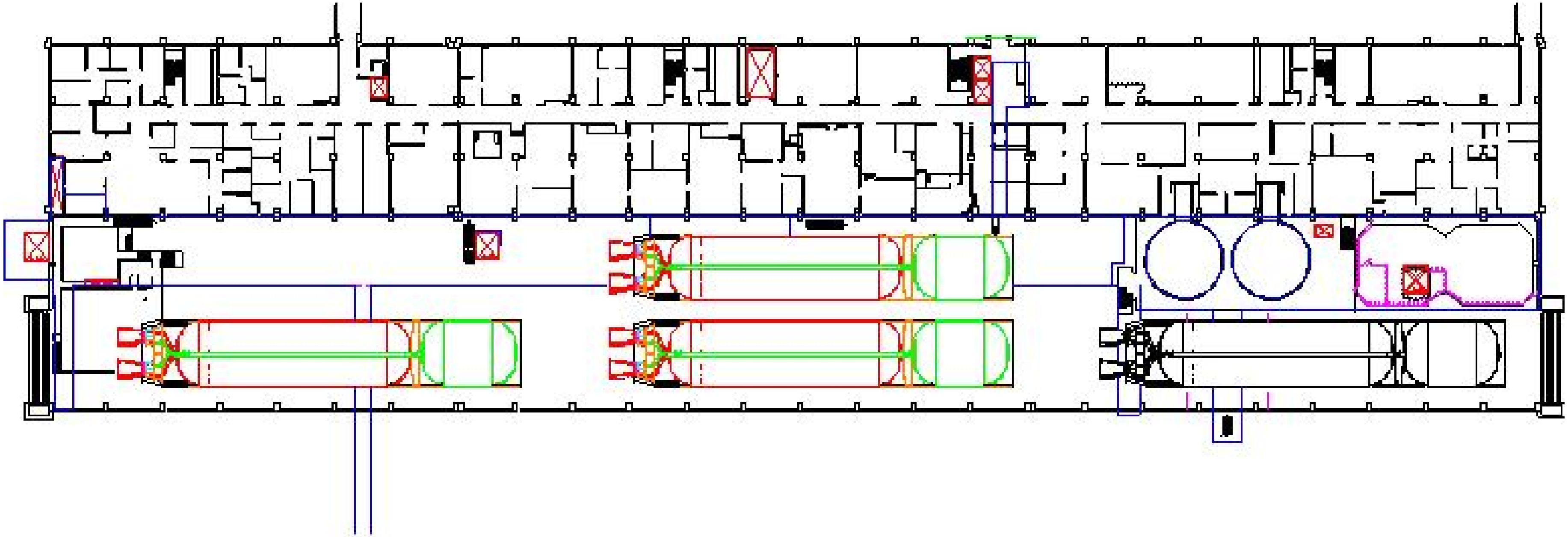




Magnum Core
Standalone Processing Facility

•**Due to the physical size of the Magnum core vehicle, the Operations and Checkout (O&C) Building is best suited to process the core vehicles simultaneously**

•**Modifications to the O&C require removal and storage of payload test stands and clean room**



Three Magnum Cores processing in the Operations and Checkout Building (O&C).
Fourth core shows contingency storage--Top View

This assumes no hazardous commodities on board during all times in O&C.

MLP Acquisition

- One New Mobile Launcher Platform (MLP) will be required to support the Magnum w/ FSB Program **OR** the Shuttle-C25 w/ FSB Program and not interfere with the Space Shuttle Program

- Increased number of MLPs is due to 5-Segment SRB processing timelines and short timeline between un-manned and crewed Lunar Missions (2 launches within 30 days)

Magnum MLP Unique Features:

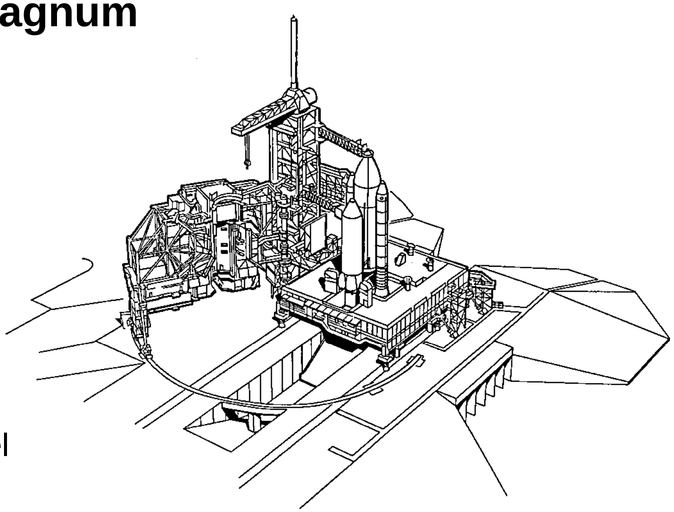
- Launch Umbilical Tower with 5 swing arms
  - *Human-rated Magnum will require personnel access arm to payload shroud area and white room for crew ingress*
- FSB – driven mods (see below)

Shuttle-C25 MLP:

- Modifications to the existing Shuttle MLP design are driven by the 5-Segment Booster design
  - New holddown posts
  - Modify pedestals for increased pre-launch loads
  - Modify Blast Shield (add ablative)

Pad Modifications
(Magnum w/FSB)

- **Both pads will be modified to have both Shuttle and Magnum or Shuttle-C25 capabilities**



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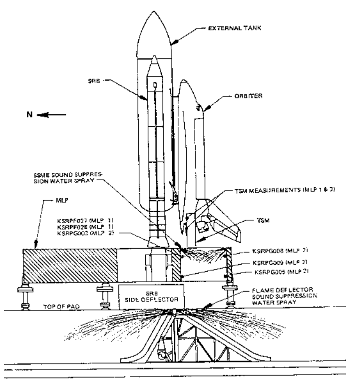

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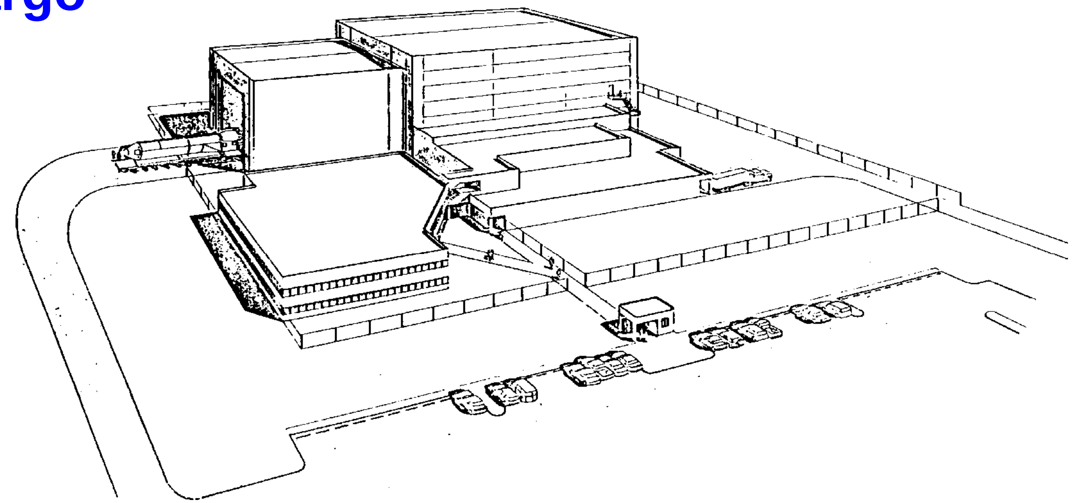

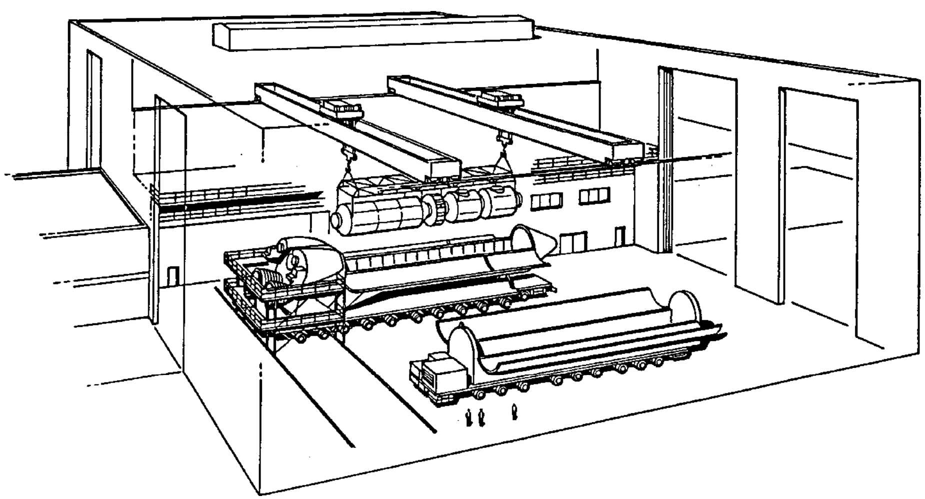

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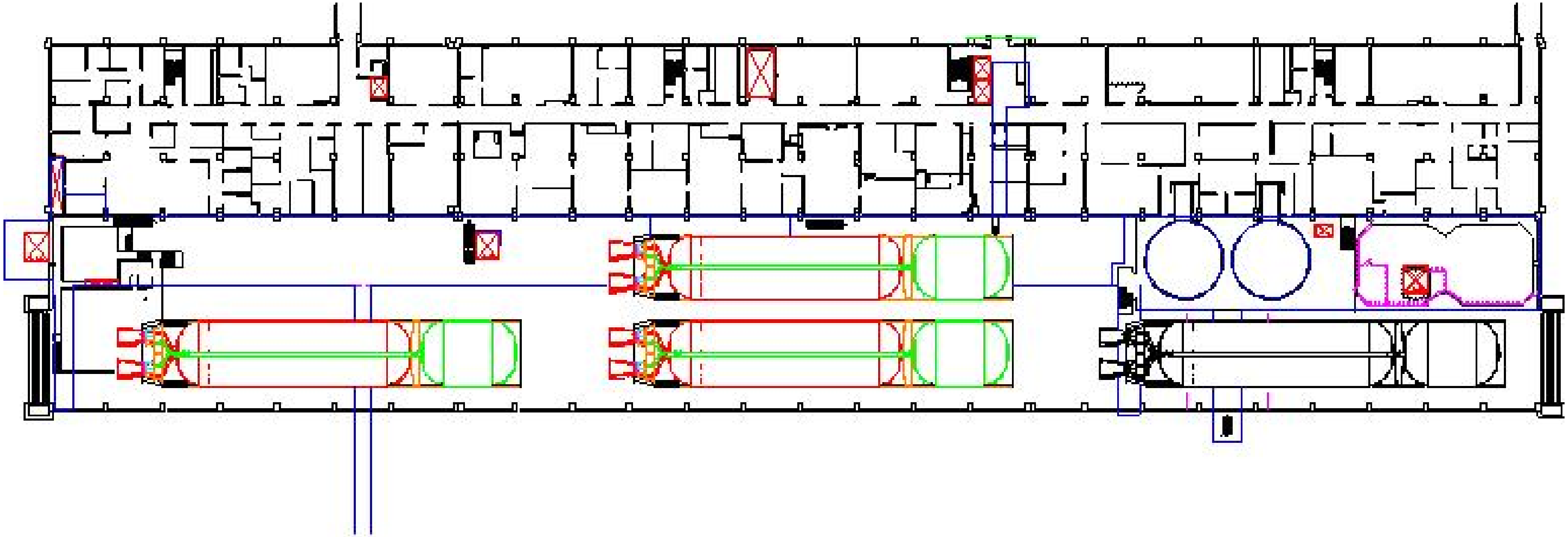


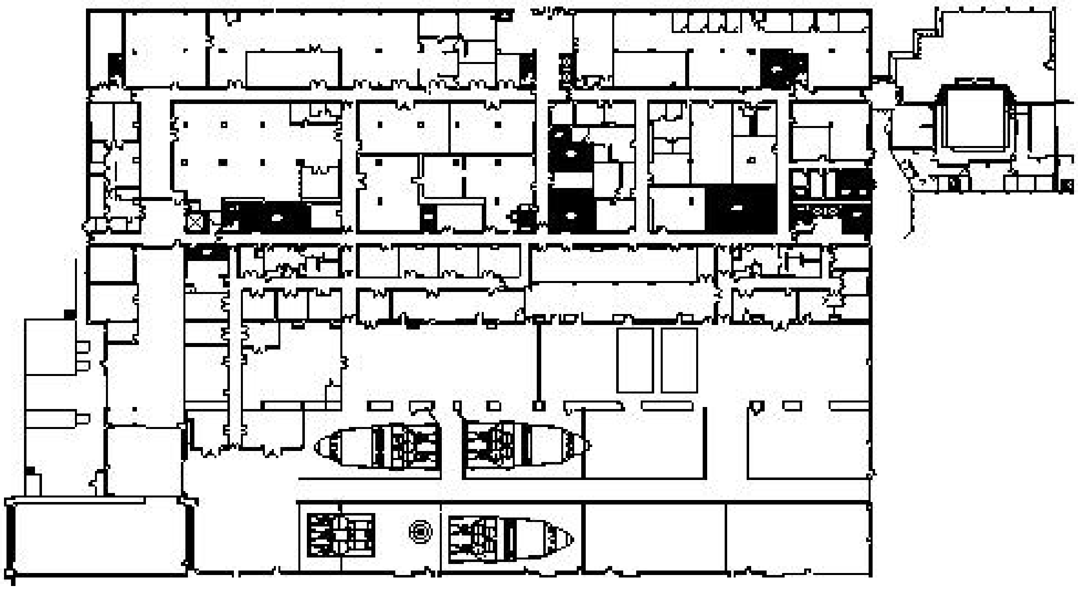
Three Magnum Cores processing in the Operations and Checkout Building (O&C).
Fourth core shows contingency storage--Top View

This assumes no hazardous commodities on board during all times in O&C.

Payload Processing Facility - SSPF

- All lunar payloads *(Lunar Transfer Vehicle, Gateway, Lunar Lander, Lunar Habitat, kick stage)* will be processed, integrated and encapsulated in the Space Station Processing Facility (SSPF) while also allowing for ISS resupply processing

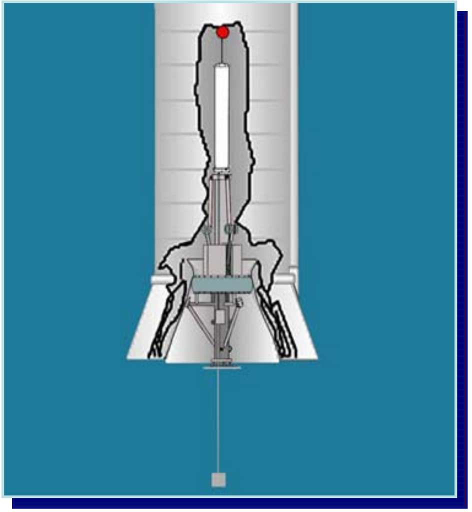
- No major modifications required



Lunar Payloads in the Space Station Processing Facility (SSPF)--Top View

AF Hangar Modifications

- **Modification required for any vehicle design that uses 5-Segment Boosters**
  - Fabricate 2 new dollies for forward segment
  - Redesign and fabricate 4 DOPs to conform to larger throat and exit cone
  - Crane operations modification



Advanced Concept Analysis in Support of the Integrated Space Plan

Section 4.4

Exploration Architecture Analysis Supportability

November 2002

Supportability

Supportability Concept **-** missions beyond LEO must become independent of support from Earth because of extended, or nonexistent, supply chain

•***Maintenance Concept Defined*** **-** enable robust, autonomous maintenance capabilities for future missions.

- •Enable comprehensive onboard failure diagnosis capabilities.
- •Repair rather than replace.
- •When replacement is required, replace at the lowest possible hardware level - minimize mass requirements.
- •Fabricate structural and mechanical replacements rather than carry unique spares.

•***Enhanced Crew Support Functions*** **–** reduce crew time for overhead tasks & reduce mass for crew support

- •Enhanced habitability – e.g. launder clothes, efficient housekeeping operations
- •Transparent inventory management
- •Recycle waste products

Maintainability Design/Requirement Themes

•Require commonality and standardization at LRU-level, SRU-level, and lower level among major architecture elements.

•Design for the operational environment (e.g. pressure differential effects on structure, 0-g human factors, number of closeout fasteners).

•Design for maintainability, graceful degradation, upgrades, and adaptation.

Supportability

Enabling Technologies

•**<u>Avionics Repair</u>** (e.g. robust diagnostic capabilities - failure isolation to component, verification test capabilities, hands-off electronics rework)

•***<u>In-Situ</u>* <u>Fabrication</u>** (e.g. solid freeform fabrication, welding, machining, NDE/QA, metrology)

•**<u>Crew Support</u>** (e.g. washing machine, transparent inventory management, waste disposal, hygiene, food preparation)

DoD Analogs **-** ongoing technical interaction with DoD to leverage their experience supporting advanced systems in harsh operational environments

•**<u>Air Force</u>** – F/A-22 program: advanced maintenance concept, diagnostics, and technical information management

•**<u>Army</u>** – TACOM's Mobile Parts Hospital: *in-situ* fabrication capability, NASA/DoD Interagency Coordinating Committee established; Corps of Engineers' Cold Regions Research and Engineering Laboratory in conjunction with NSF: maintenance operations at Antarctic bases and maintainability considerations in South Pole Station modernization project

•**<u>Navy</u>** – NAVAIR & NAVSEA: Microminiature electronics repair; 1998 benchmarking study by KSC of submarine support operations

•**<u>Interagency Coordinating Committee</u>** – Informal working group including NASA, Army TACOM, Army ARL, Air Force AFRL, Navy NAVSEA, Navy ONR, Navy NRL to collaborate on development of electron beam solid freeform fabrication technology

Supportability

Maintenance Concept

• **Enable robust, autonomous maintenance capabilities for future missions.**

• **Provide system availability that meets program defined values while minimizing the mass and volume of spares and crew time required for maintenance.**

- Enable autonomous failure diagnosis and repair by crew.
- Perform Organizational maintenance and repair at the lowest hardware level that is feasible.
- Perform Organizational maintenance via remove-and-replace of SRUs to the maximum extent possible when lower level repair is not feasible.
- Perform Organizational maintenance via remove-and-replace of LRUs for all other hardware.
- Manifest/stow common and standardized hardware onboard.
- Preposition critical spares.
- Fabricate structural and mechanical replacements rather than carry unique spares.
- Manifest unique spare hardware with crews.
- Perform preventive maintenance as required.
- Perform Intermediate and Depot maintenance on the ground when cost-effective.
- Enable utilization of common SRU/LRU/piece part/components across entire vehicle set.
- Consider reconfigurable hardware – use changes with mission phase.
- Utilize ground-based assessment of onboard system health and failure isolation for missions of brief duration.

Supportability

Maintainability Design/Requirement Themes

- Require commonality at LRU-level, SRU-level, and lower level among major architecture elements.
- Establish design requirements for operational environment (e.g. pressure differential effects on structure, 0-g, human factors, number of closeout fasteners).
- Keep all hardware to be maintained internal – minimize EVA.
- Eliminate avionics LRU boxes – implement rack-mounted boards (trade – e.g. mass impacts/benefits, TCS impact, smoke/fire detection and protection, etc.).
- Minimize tools (ISS tool kit: almost 500 items).
- Maximize commonality and standardization (enables wide use and minimizes tools).
  - Avionics boards
  - Fasteners
  - Connectors
  - Other components (e.g. pumps, power supplies, fans)
  - Piece parts
- Robust diagnostics and post-repair verification: quick, unambiguous fault isolation to designated repair level (BIT, BITE, standalone).
- Build for maintainability (e.g. access, number of fasteners).
- Do not combine English and metric hardware (reduces tool requirements).
- Design for upgrade and adaptation.

Supportability Technology Analysis

Goal

- Crews will be autonomous for maintenance and repair operations.
- Mass and volume required to support maintenance and repair will be substantially reduced from current requirements.
- Mass and volume requirements for crew clothing will be substantially less than current.
- Inventory management process will be transparent to crew.

Gaps

- Need enhanced Built-in-Test capabilities in system hardware.
- Need enhanced standalone system diagnostic capabilities available to crew.
- Need capability to repair hardware at component level to minimize mass and volume of spares. Requires significantly increased component commonality and standardization.
- Need capability to fabricate structural and mechanical replacement components as needed.
- Need to provide crew with information required to support these more robust repair capabilities.
- Need clothes laundering capability to minimize total quantity of clothing.
- Need hands-off inventory system (e.g. radio frequency identification tags).

Supportability TRL Summary

			Near Earth						
			Lunar L1 Gateway	Lunar Transfer Vehicle	L1 Lunar Habitat Lander	L1 Lunar Lander	Mars	THREADS WBS Element	Roadmap?
		Supportability							Yes
$									
Y	In-Situ Fabrication								
Y		Solid Freeform Fabrication			3		3	2.1.3	
R		Machining			5		5	2.1.3	
R		Metrology			3		3	2.1.3	
R		NDE			3		3	2.4.4	
Y	Electronics Repair								
Y		Diagnostics/Verification			2		2	2.4.5	
R		Rework			4		4	2.4.5	
R	Structural Repair								
R		Metals			4		4	2.4.5	
R		Composites			4		4	2.4.5	
R		Inflatables	1				1	2.4.5	
Y	Fiber Optics Repair		4		4		4	2.4.5	
R	Fluid Line Repair								
R		Lines	4	4	4	4	4	2.4.5	
R		Connectors	4	4	4	4	4	2.4.5	
Y	System Health Assessment								
R		Structure	4	4	4	4	4	2.4.4	
R		Bearings	4	4	4	4	4	2.4.4	
R		Cables	4	4	4	4	4	2.4.4	
Y		Leak Detection	4	4	4	4	4	2.4.4	
Y	Maintenance Information Management								
Y		Interactive/Integrated Electronic Technical Manuals	6	6	6	6	6		
Y		Component Design Library	6	6	6	6	6		
R	Crew Support Systems								
R		Clothes Laundering Capability	2		2		2	2.3.4	
R		Advanced Inventory Management System	3	3	3	3	3	2.3.4	

Supportability

Current Maintenance Technology Development Activities

– ***Reduced-g Soldering: component-level repair of avionics***

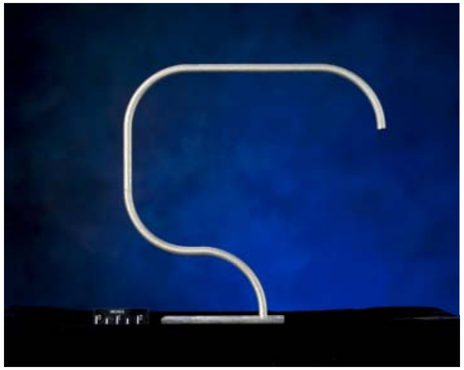
- Collaboration with GRC and NCMR
- Almost 600 samples produced during KC-135 parabolas (includes a limited number of 1/6-g parabolas and 1/3-g parabolas), plus 1-g control samples
- Analysis continuing – initial results show increased porosity in low-g, attempting mitigation approaches

– ***Potential collaboration with NAVAIR: component-level repair of avionics***

- Advanced diagnostic capabilities
- Surface mount device soldering repair

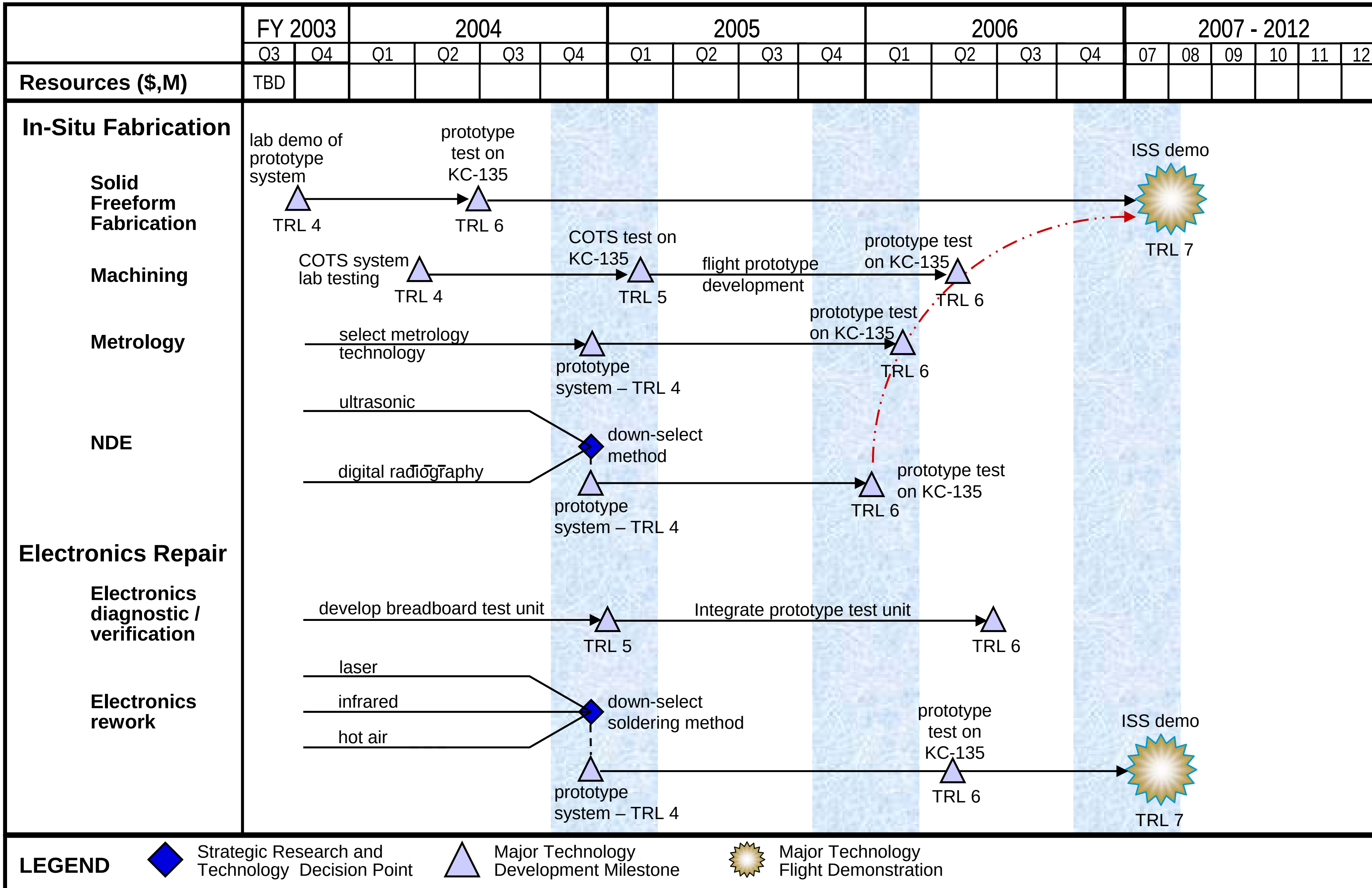
– ***Solid Freeform Fabrication: in-situ fabrication of spares***

- Collaboration with Langley
- Developing innovative process/system
- Provisional patent application submitted by JSC and Langley
- NASA and DoD forming SFF Interagency Coordinating Committee (includes ONR, NRL, NAVSEA, Army TACOM, Army Research Lab, Air Force Research Lab)

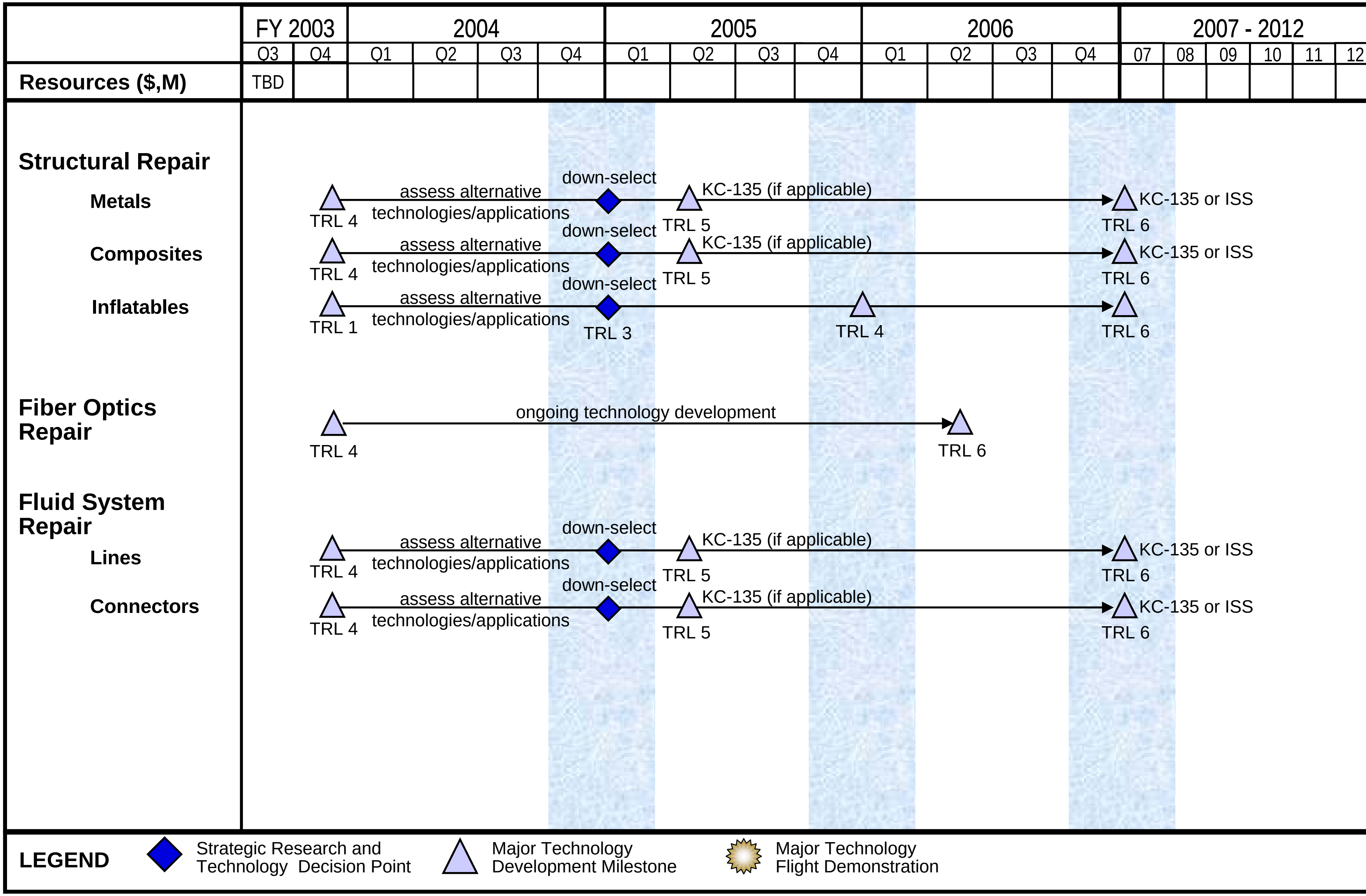


Thin-wall hollow tube produced by Lockheed Martin Tactical Aircraft Systems with laser Solid Freeform Fabrication process.

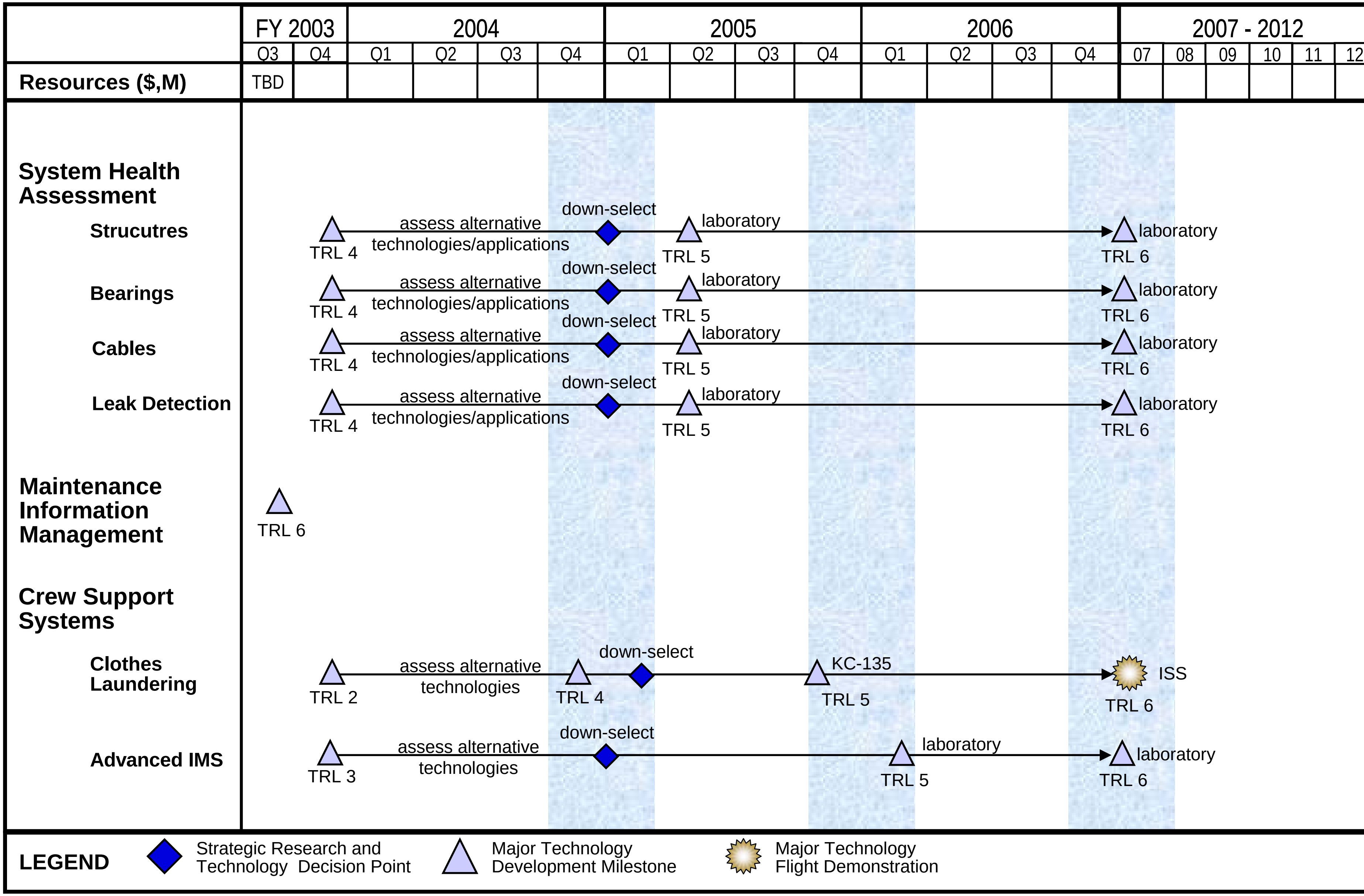
Supportability



Supportability



Supportability



Advanced Concept Analysis in Support of the Integrated Space Plan

Section 5.0

Technology Roadmaps

November 2002

Technology Overview

- Objectives of Technology Assessment
- Assumptions for Technology Assessment
- State of Technology
- Blueprint Summary Key Technologies
  - Technology long poles
    - Earth's Neighborhood
    - Mars
- Recommendations
  - To Agency (In work)
  - To Enterprises (In work)
  - To Architecture team
  - To Design Team

Objectives of Technology Assessment

- Focused Agency technology investments today provides the potential for conducting new missions and building future systems with better performance to meet defined requirements. Independent of specific architectures, there are several key fundamental core technologies, that if developed will put the agency in a good posture for decision making in the near future.
  - The technology focus investment strategy proposes to implement the following:
    - Derive the research and technology development needs from evolving architectural concepts and develop roadmaps for their accomplishment.
    - Identify and endorse programs that are currently addressing the research and technology development needs.
    - Identify gaps in existing programs that need to be augmented or refocused to address the research and technology development needs.
    - Identify and recommend new initiatives to fill gaps in research and technology development needs.
    - Periodically reassess evolving architectures and provide updated recommendations to technology development programs.
    - Periodically assess technology development programs to assure progress towards meeting the defined needs.

Assumptions for Current Technology Assessment

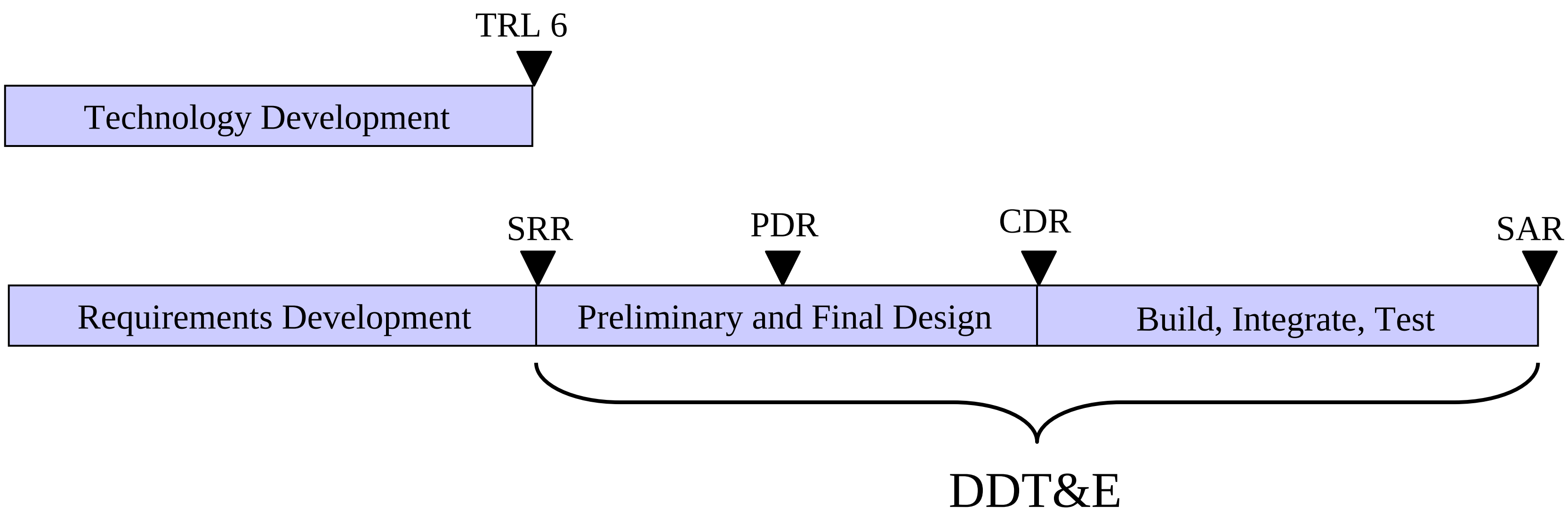
- Funding would begin in the first quarter of CY 2003.
  - Made it possible to determine how long it would take to develop the technologies required for beyond-LEO exploration, if reasonable funding was turned on immediately.
- DDT&E phases for each element would be 6 years.
  - The actual DDT&E schedules for the individual elements are not known at this point in time.
  - Allowed the assessment team to derive the required date for the technologies to achieve Technology Readiness Level (TRL) 6.
- Initial launch date of first Earth's Neighborhood element is in 2012.
- Assumed infrastructure development / mission sequence
  - L_1 capability $\rightarrow$ Short duration lunar surface missions $\rightarrow$ Long duration lunar surface missions $\rightarrow$ Mars missions

State of Technology

- A **<u>SEVERE</u>** GAP in technology development exists between the basic research TRLs (1-3) and the qualified technology TRLs (7-9).
  - Funding for the middle TRLs (4-6) for technologies critical to Human/Robotic Exploration beyond LEO have had limited investment over the last several years.
  - This gap was identified in the technology review of the Earth's Neighborhood element studies.

Blueprint Summary Key Technologies

- Given the previous assumptions, the list of critical technologies have been divided into three categories:
  - Category 1: If technologies achieve TRL 6 <u>after</u> the elements' DDT&E Phase is scheduled to begin.
  - Category 2: If technologies achieve TRL 6 at <u>approximately the same time</u> the elements' DDT&E Phase is scheduled to begin.
  - Category 3: If technologies achieve TRL 6 <u>before</u> the elements' DDT&E Phase is scheduled to begin.



Blueprint Summary Key Technologies

- Earth's Neighborhood "Category 1" Technologies and Areas of Research
  - EVA Suit and Personal Life Support System (PLSS)
    - Suit: Materials; Flexible, robust joints; heated, flexible gloves
    - PLSS: Materials; packaging; mass reduction
    - CO_2 removal system
    - Thermal control system
    - Information management systems
    - Electrical systems: High energy density power storage; low power sensors
  - High energy density fuel cells
  - Liquid H_2 cryocoolers
  - Inflatable structures: Habitats and Airlocks
  - Robotic systems for L_1 telescope construction
    - Earth-based control systems of L_1-based robotics
    - Robotic systems capable of working together to complete a task
    - Robotic systems capable of handling connection of electrical and fluid interfaces
  - Bio-astronautics
    - Ionizing Radiation
      - Analysis tools to evaluate crew dosages during architecture and element design phases
      - Innovative methods of protecting crew against ionizing radiation

Blueprint Summary Key Technologies

- Mars Long-lead Technologies and Areas of Research
  - Closed-loop life support systems
    - Closed air revitalization system
    - Liquid processing and recycling
    - Solid waste processing and recycling
  - In-situ propellant production systems
  - Nuclear power systems – Surface power & In-space propulsion
  - Bio-astronautics
    - Micro-g countermeasures
      - Artificial-g environment created by spacecraft
      - Medical countermeasures coupled with exercise devises
    - Ionizing Radiation
      - Ability to evaluate crew dosages during architecture and element design phases
      - Methods of protecting crew against ionizing radiation

Recommendations To Architecture Team

- **Analyze whether identified long pole technologies can be eliminated by modifying the architecture elements.**
- **Identify science-driven requirements that will require technology development (e.g. Excavation equipment, mobility systems, sensors etc.).**
- **Be more specific in quantifying architectural and element level requirements.**
- **The following technologies were identified as potentially critical or mission enhancing. Future studies should evaluate the following technologies for their criticality in the trade space:**
  - In-Situ Resource Utilization
  - Communication Requirements
  - Inter-Vehicular Health Monitoring
  - Logistics – (e.g. Consumables re-supply)
  - Supportability
  - Nuclear Power (surface & in-space)
  - Software Development
  - Computer and data management systems
  - MEMS applications

Recommendations to the Design Team

- A detailed study should be performed utilizing the techniques employed by the design team to identify cross-cutting sub-system component technologies.
  - The review demonstrated that there are a number of common component level technologies that when pushed will satisfy the needs of a variety of critical path systems such as light weight radiators, Cryocoolers, high density power, etc.
  - This information would be used to develop component level requirements such that a particular technology would be designed to satisfy the requirements of several different systems and to determine investment priorities.
- Study should be performed to determine if existing EVA suits could satisfy early L_1 missions.
- An integrated architectural level approach should be kept in mind while designing the elements.
  - It was found during the technology assessment that there were several different designs used across many of the elements for the same system (e.g. Thermal control leads used three different coolants in three different elements, which was found to be unnecessary.)

Integrated Technology Roadmaps
Element Legend

ALL	All elements in Near Earth & Mars architecture apply
GW	Gateway
KICK	Kickstage
LHAB	L1 Lunar Habitat Lander
LL	L1 Lunar Lander
MHAB	Mars Habitat Lander
ML	Mars Lander
MTV	Mars Transfer Vehicle
SEP	Solar Electric Power (SEP) Stage
XTV	Exploration Transfer Vehicle

Advanced Concept Analysis in Support of the Integrated Space Plan

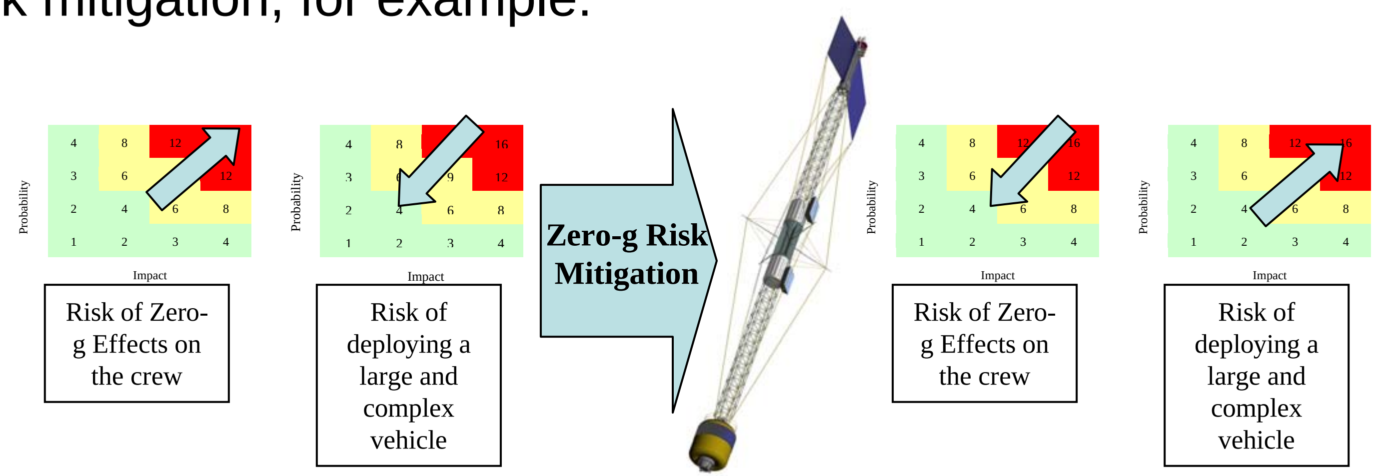
Section 6.0

Risk Assessment

November 2002

Risk Assessment

- Risk Assessment Documentation
  - A Draft Exploration Blueprint risk assessment plan is completed - Defines practice of risk management in the formulation phase.
  - Preliminary risks using the continuous risk management process
  - Probabilistic risk assessments (PRA) will be conducted as reference mission architectures are developed in the formulation phase.
- There will continually be tradeoffs between mission performance and risk mitigation, for example:



PRA Modeling Technique

End States	Events	Time (sec)	Week	Events
4	1	2400	1	HL/DAV SEP Launch (Magnum 1)
4	2	60		HL/DAV SEP Solar Array Deploy and Checkout
4	3	602340		HL/DAV SEP Orbit Operations
4	4	604800	2	HL/DAV SEP Orbit Operations
4	5	604800	3	HL/DAV SEP Orbit Operations
4	6	604800	4	HL/DAV SEP Orbit Operations
4	7	2400	5	HL1 Launch (Magnum 2)
4	8	259200		SEP/HL1 Auto Rendezvous and Dock
4	9	343200	604800	HL1/SEP Orbit Operations

Event Sequence

		Week	1			2	3	4	5
		time (sec)=>	2400	60	602340	604800	604800	604800	2400
		time (hours)=>	0.67	0.02	167.32	168.00	168.00	168.00	0.67
		Prob of Success	0.94554	1.00000	0.99997	0.99997	0.99997	0.99997	0.94553
		Loss of Crew and Equipment							
		Mission Delay - Loss of Equipment	0.0545	0.0000	0.0000	0.0000	0.0000	0.0000	0.0545
		Mission in Mars Orbit							
		Crew Stranded on Planet							
		Crew Stranded in Mars Orbit							
	Redundancy	Failure Rates (fpmh)	1	2	3	4	5	6	7
HL/DAV Solar Electric Propulsion									
Solar Array Deployment Mechanism	1	10.9700	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Structure	1	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Thermal Protection System	2	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
System Engines	2	0.2490	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propulsion System	2	0.2490	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tankage (Xe)	2	0.1280	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
RCS	2	0.2490	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
PMAD	2	13.6512	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Power Generation	2	0.0107	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Avionics	3	7.4755	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Control System	3	7.4755	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Event-System Matrix

Event Trees and End States

HL/DAV Solar Electric Propulsion	Redundancy	Failure Rate	Source
Solar Array Deployment Mechanism	1	10.97	NPRD-95/2-131 (Linkage, and Mechanism)
Structure	1	1.0000	NPRD-95/2-194 (Structural section)
Thermal Protection System	2	1.0000	NPRD-95/2-194 (Structural section)
System Engines	2	0.249	NPRD-95/2-89 (engine, turbine, rocket)
Propulsion System	2	0.249	NPRD-95/2-89 (engine, turbine, rocket)
Tankage (Xe)	2	0.128	NPRD-95/2-213 (Tank, Fuel, Engine)
RCS	2	0.249	NPRD-95/2-89 (engine, turbine, rocket)
PMAD	2	13.6512	NPRD-95/2-153 (power supply, summary)
Power Generation	2	0.0107	NPRD-95/2-189 (solar cell)
Avionics	3	7.4755	NPRD-95/2-88 (electronic assembly, missile)
Control System	3	7.4755	NPRD-95/2-88 (electronic assembly, missile)

Elements and Systems

Mission Success	0.5446312
Degraded Mission in Mars Orbit (MIMO)	0.0016737
Crew Return - Failed TMI	0.0068597
Mission Delay - Loss of Equipment	0.2425068
Loss of Shuttle Equipment	0.0009534
Crew Stranded in Mars Orbit	0.0000005
Crew Stranded on Planet	0.0000182
Loss of Shuttle Crew and Equipment	0.0001163
Loss of Crew and Equipment	0.2032401

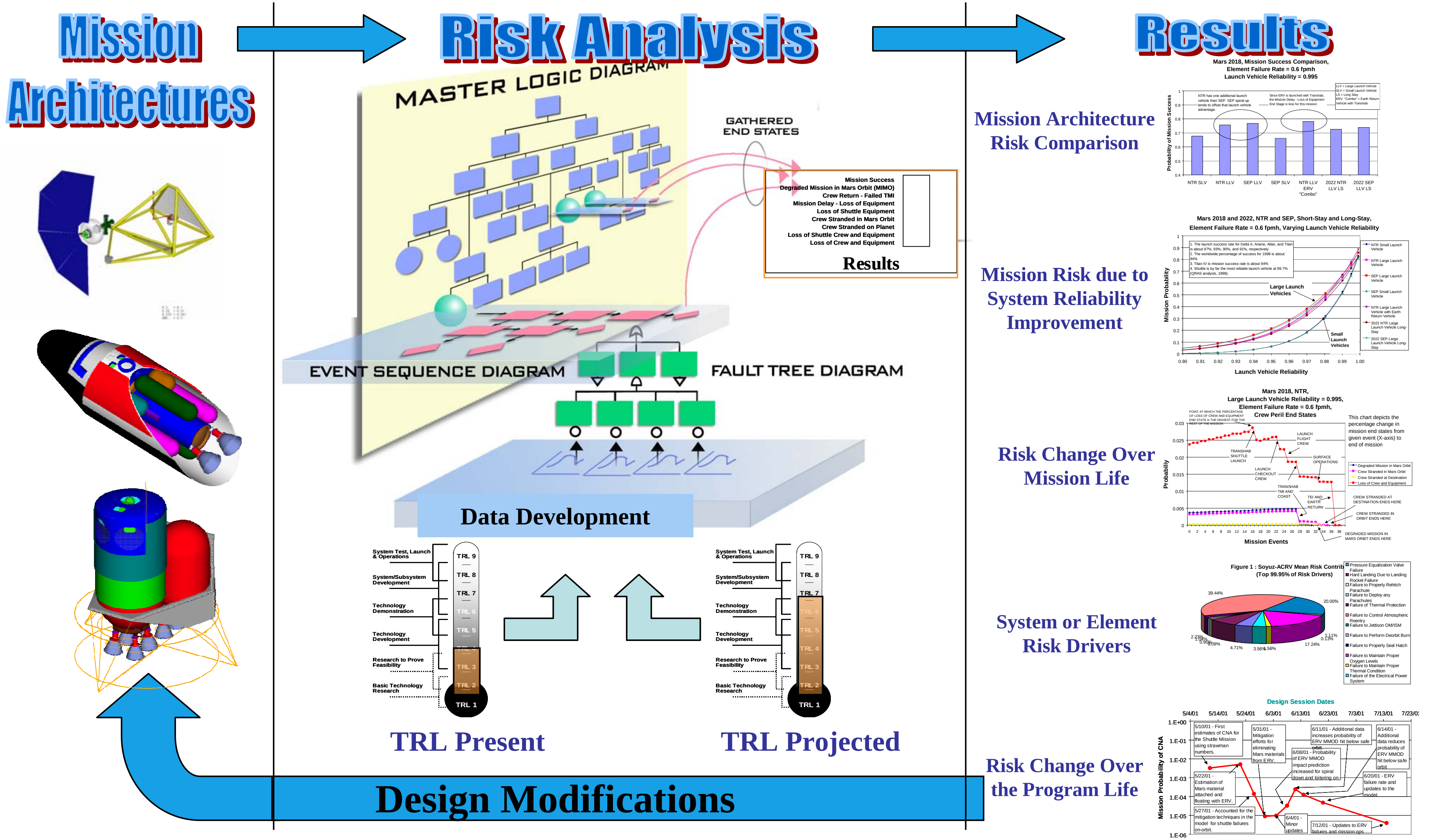
Results

Mission End States

- Mission Success
- Degraded Mission in Planetary Orbit (failure to land)
- Crew Return – (failed Trans-planetary injection)
- Mission Delay - Loss of Equipment
- Crew Stranded in Planetary Orbit
- Crew Stranded on Planet
- Crew Stranded in Heliocentric Orbit
- Loss of Crew and Equipment

Crew peril

Probabilistic Risk Assessment Plan



Exploration Mission Expected Results

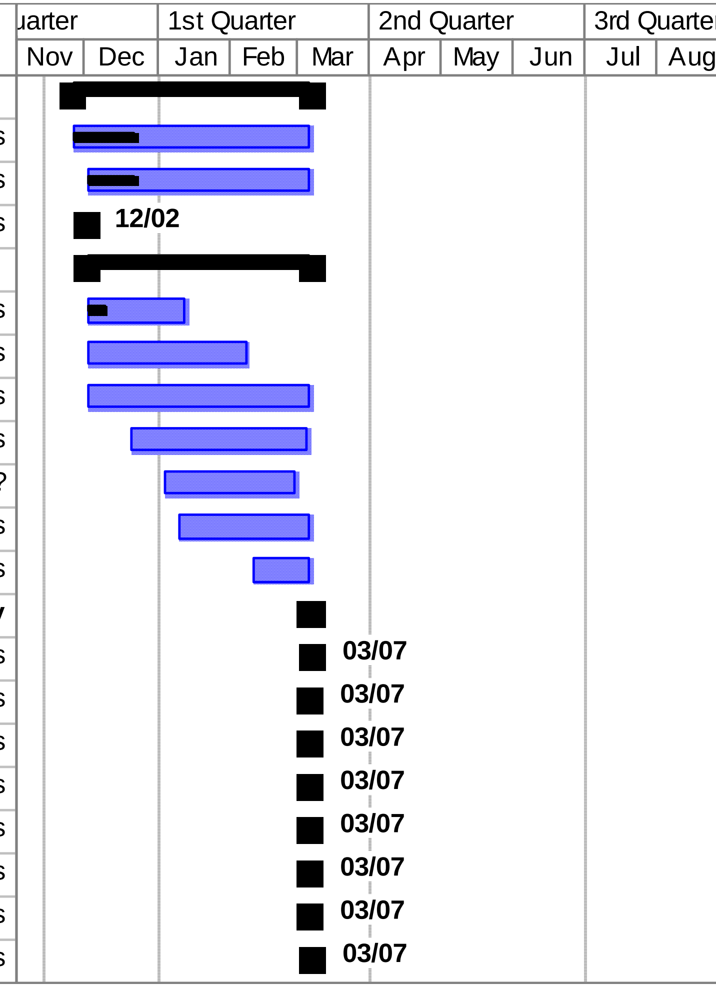
- For a given mission architecture:
  - Which end states drive the risk?
  - Which elements, systems, or components drive the risk?
  - Where in the mission are the riskiest events?
  - When are systems the most susceptible to failure?
  - What environmental conditions have the greatest effect on probability of failure on an element, a system or component, or the crew?
  - Given a set of conditions, what failure modes are most or least likely to occur?
  - How does risk change over the mission life?
  - How do changes in the design or improved data uncertainty change the results?

Probabilistic Risk Assessment

- Probabilistic Risk Assessment Overview
  - Define Mission Architectures (L1, Lunar, Mars)
  - Define Mission End States
  - Define Initiating Events
  - Assess Pivotal Events
  - Conduct Data Mining and Development Based on TRLs
  - Conduct Sensitivity Studies Based on TRLs and Projected Improved Reliabilities
- Perils and Pitfalls
  - Beware of Biased and Skewed Data (There is Hidden Agenda Everywhere!)
  - Ensure the Concurrence of Assumptions by all Interested Parties
  - Mission Failure Values of $1\text{x}10^{-4}$ (1/10,000) and Less are Generally Not Believable (for Space Missions)

Probabilistic Risk Assessment Plan

ID		Task Name	Duration
1		**Probabilistic Risk Assessment for L1 Gateway Mission**	**74 days?**
2		Review Results of Past Exploration Risk Assessme	74 days
3		Mission Architecture Familiarization	70 days
4		Mission Architecture Selection	0 days
5		**Model Development**	**70 days?**
6		Event Sequence Diagram Development	31 days
7		Identification of Risks (for Mission Architectures	50 days
8		Analyzation of Risks	70 days
9		Database Development	55 days
10		Model Exercise with Strawman Data	41 days?
11		Population of the Risk Models	41 days
12		Model Exercise and Sensitivity Studies	20 days
13		**Model Results**	**1 day**
14		End states which drive the risk	0 days
15		Elements, systems, or components which drive the	0 days
16		Mission riskiest events	0 days
17		Systems the most susceptible to failure	0 days
18		Environmental conditions that have the greatest effe	0 days
19		Failure modes are most or least likely to occur	0 days
20		Rrisk change over the mission life	0 days
21		Changes in results due to changes in design over p	0 days



System Safety Precedence

(There are variations to these criteria that say essentially the same thing. Sources: Mil-Std-882C, NHB 5300.4, NHB 1700.1, NSTS 22254, NSTS 07700, Vol. X)

1. Design for minimum risk. Hazards should be eliminated by design wherever possible.
2. Known hazards which cannot be eliminated by design should be reduced to an acceptable level by the use of safety devices as part of the system.
3. Where it is not possible to preclude the existence or occurrence of a known hazard devices shall be employed for the timely detection of the condition and the generation of an adequate warning signal.
4. Where it is not possible to reduce the magnitude of an existing or potential hazard by design, or the use of safety or warning devices, special procedures shall be developed to counter the hazardous condition.

PRA Talking Points

- **You will hear many buzz words regarding tools for probabilistic and other types of risk assessment; here are your talking points:**
  - **The probabilistic risk assessment methodology is a suite of graphical techniques for assessing risk. These include:**
    - Event Trees,
    - Fault Trees,
    - Reliability Block Diagrams;
    - Rarely used are digraphs, petri nets, root cause analysis, and statistical process control.
  - **PRA Computer Tools**
    - **QRAS** – (***Q**uantitative **R**isk **A**ssessment **S**ystem*),
      - An Event Tree and Fault Tree editor and evaluator.
      - Designed and developed by the University of Maryland for NASA HQ (Code Q).
      - Previous versions did not have a fault tree editor. Limited use at MSFC for Shuttle PRA. New version available Dec. '02

PRA talking points

– **PRA Computer Tools (continued)**

- **SAPHIRE** – *(**S**ystems **A**nalysis **P**rograms for **H**ands-on **I**ntegrated **R**eliability **E**valuations)*.
  – An Event Tree and Fault Tree editor and evaluator.
  – Designed and developed for the U. S. Nuclear Regulatory Commission by Idaho National Engineering and Environmental Laboratory (INEEL).
  – Currently used in Shuttle and ISS PRA activity; has some innocuous bugs.
- **Other Computer Tools Used at NASA**
  – ECTree: An Excel-based Event Tree Editor developed by SAIC on a government (NASA) contract.
  – Galileo ASSAP: (***A**dvanced **S**ystem **S**afety **A**nalysis **P**rogram*) Developed by the University of Virginia for dynamic risk assessments on a government (NASA) contract.
  – RAPTOR: Reliability Block Diagram Editor originally developed by the Air Force, now owned by RELIASS
- **Commercial tools** (many commercial fault tree and event tree computer tools $$$)
  » CAFTA package
  » RELEX
  – @Risk and Crystal Ball – Monte Carlo simulators

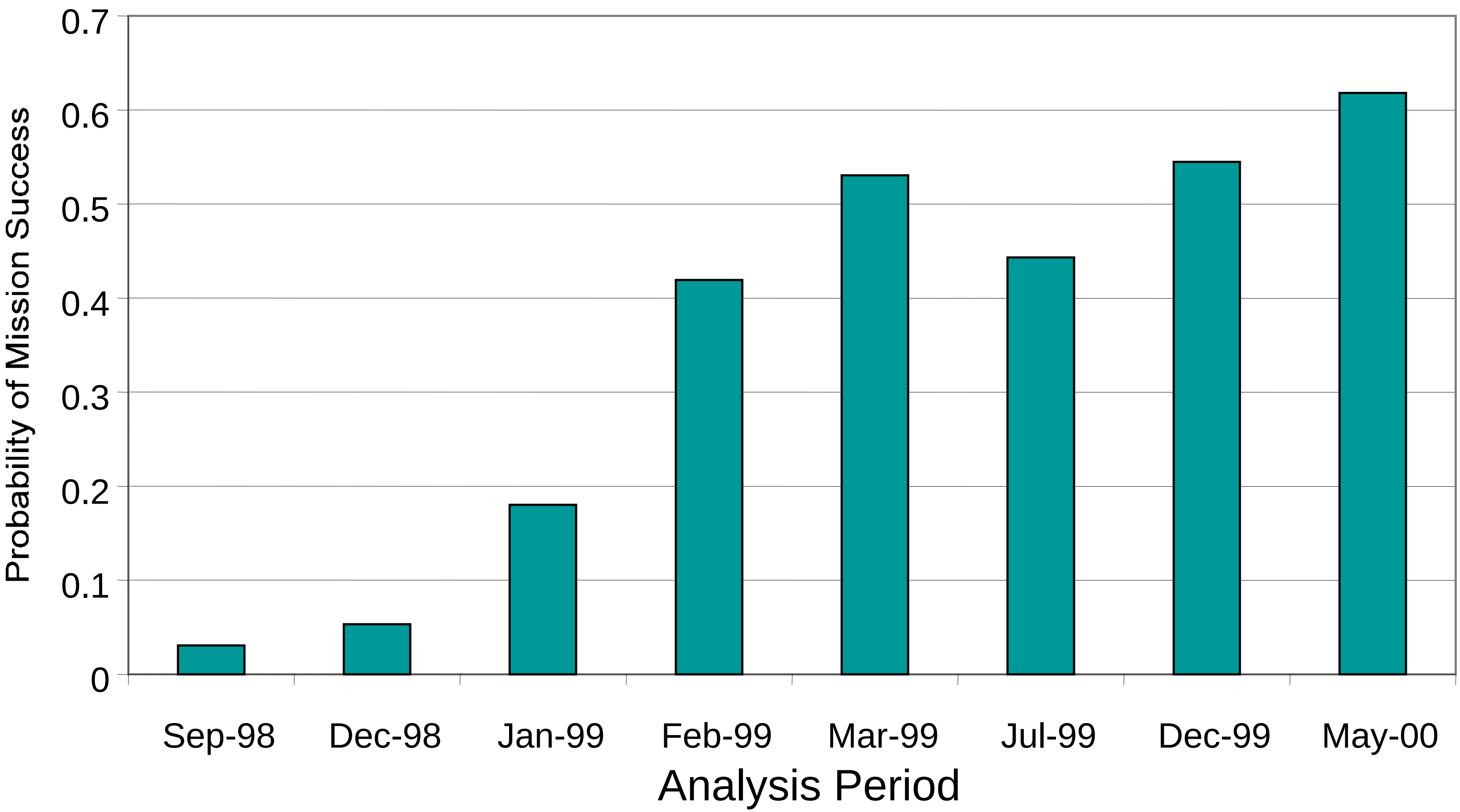
PRA talking points

- **Which one do we recommend?**

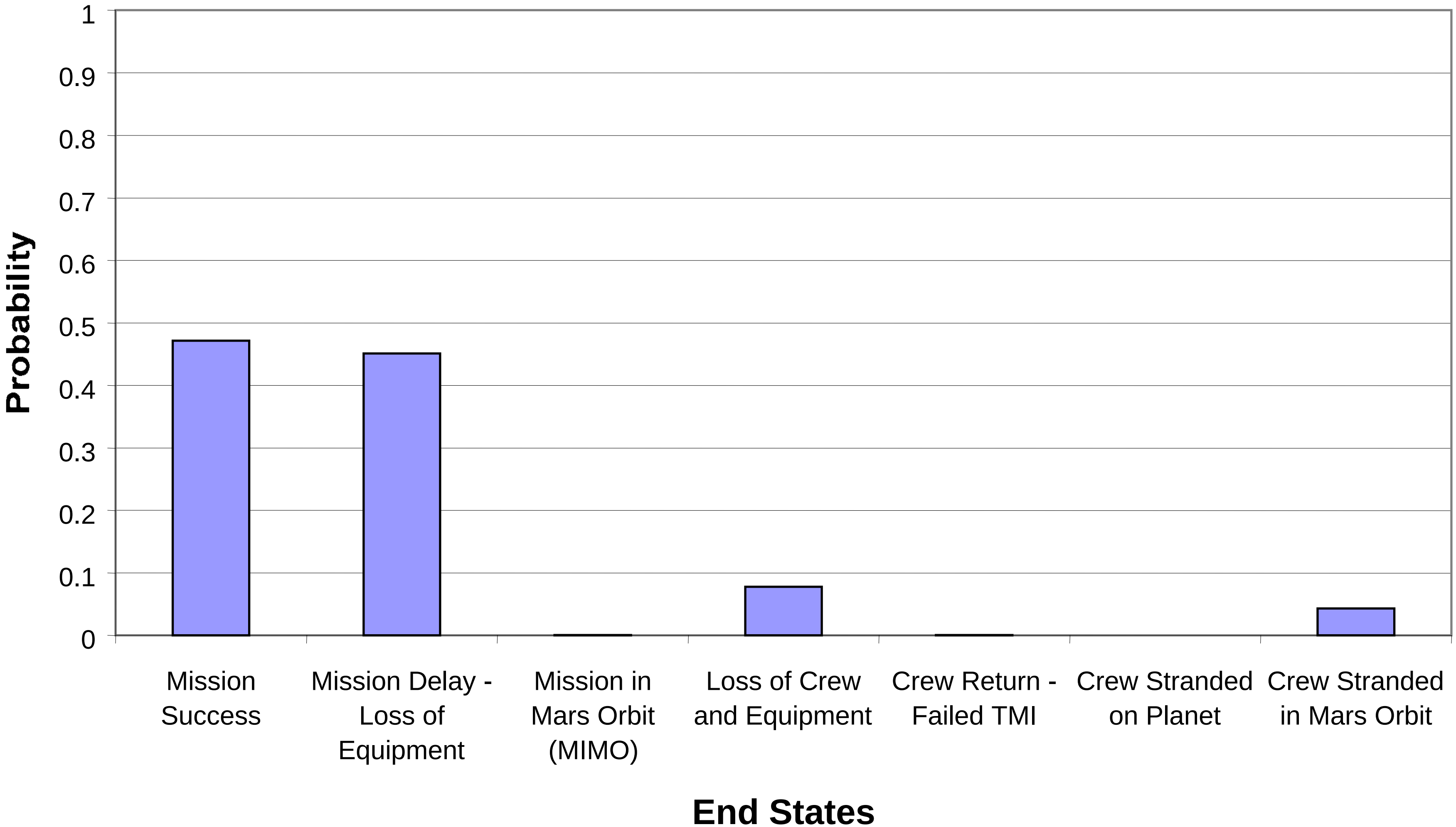
- All of them, but SAPHIRE is probably the best overall since most of the local practitioners have been trained on it. Current versions of all of these tools will likely be obsolete in a couple of years.
- Many local analysts use a combination of the previous chart.
- Bottom-line: It doesn't matter what tool you use; it only matters that the analysis represents the system.

Previous Risk Assessments on Exploration Missions

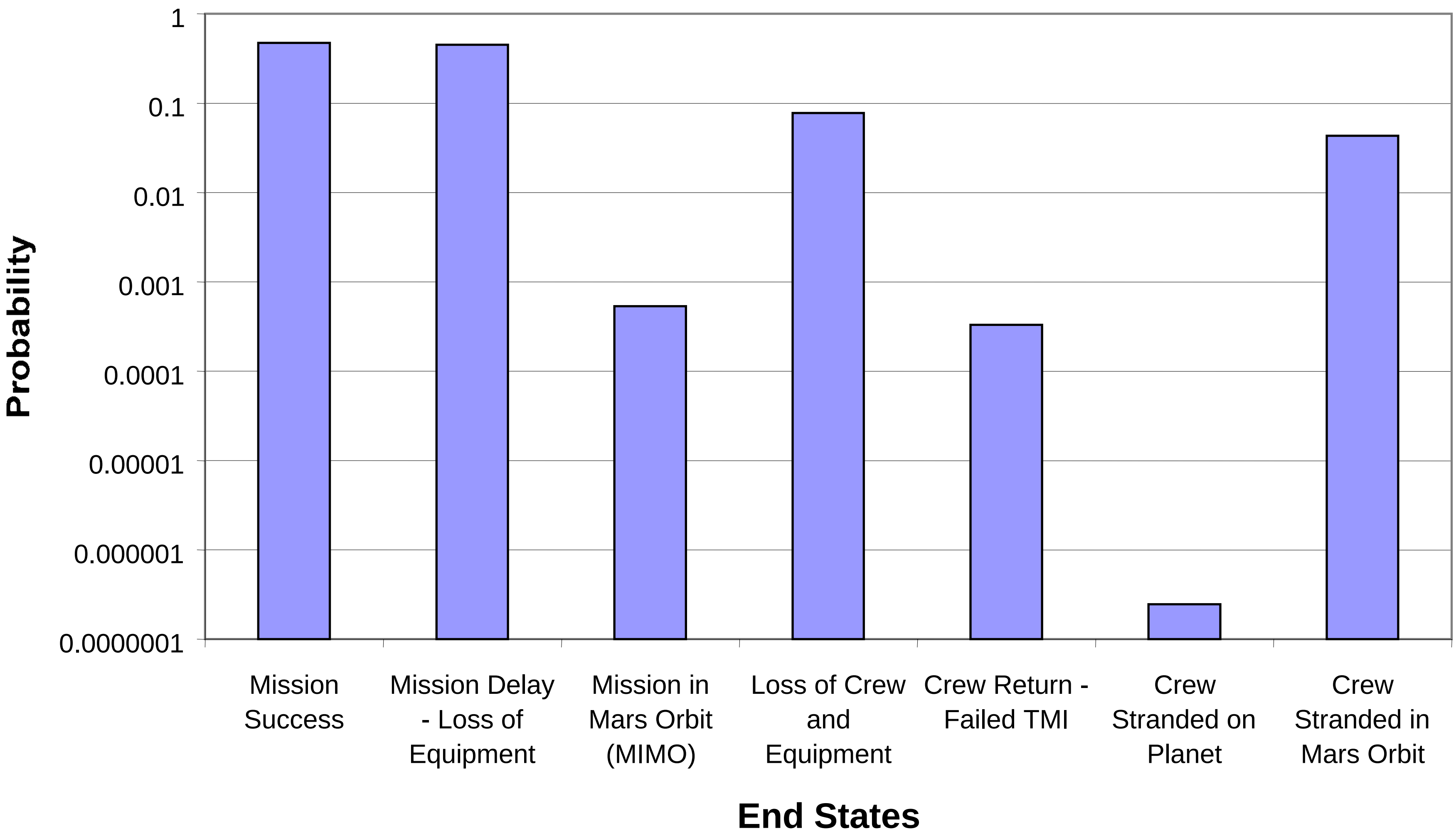
Human Mars Mission Success Results (SEP Dual Lander)



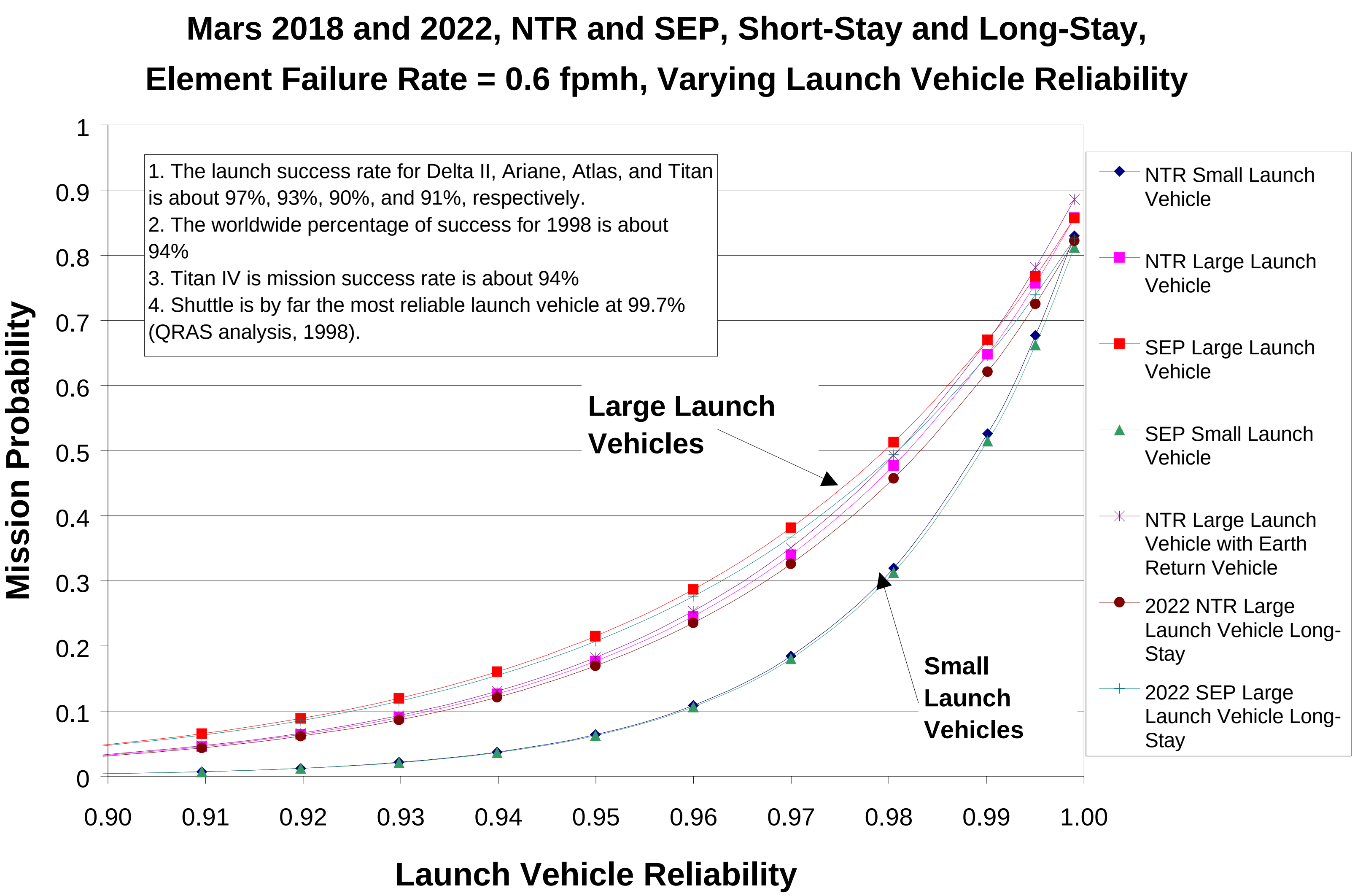
Nuclear Thermal Reactor/ Split Dual Mission Risk



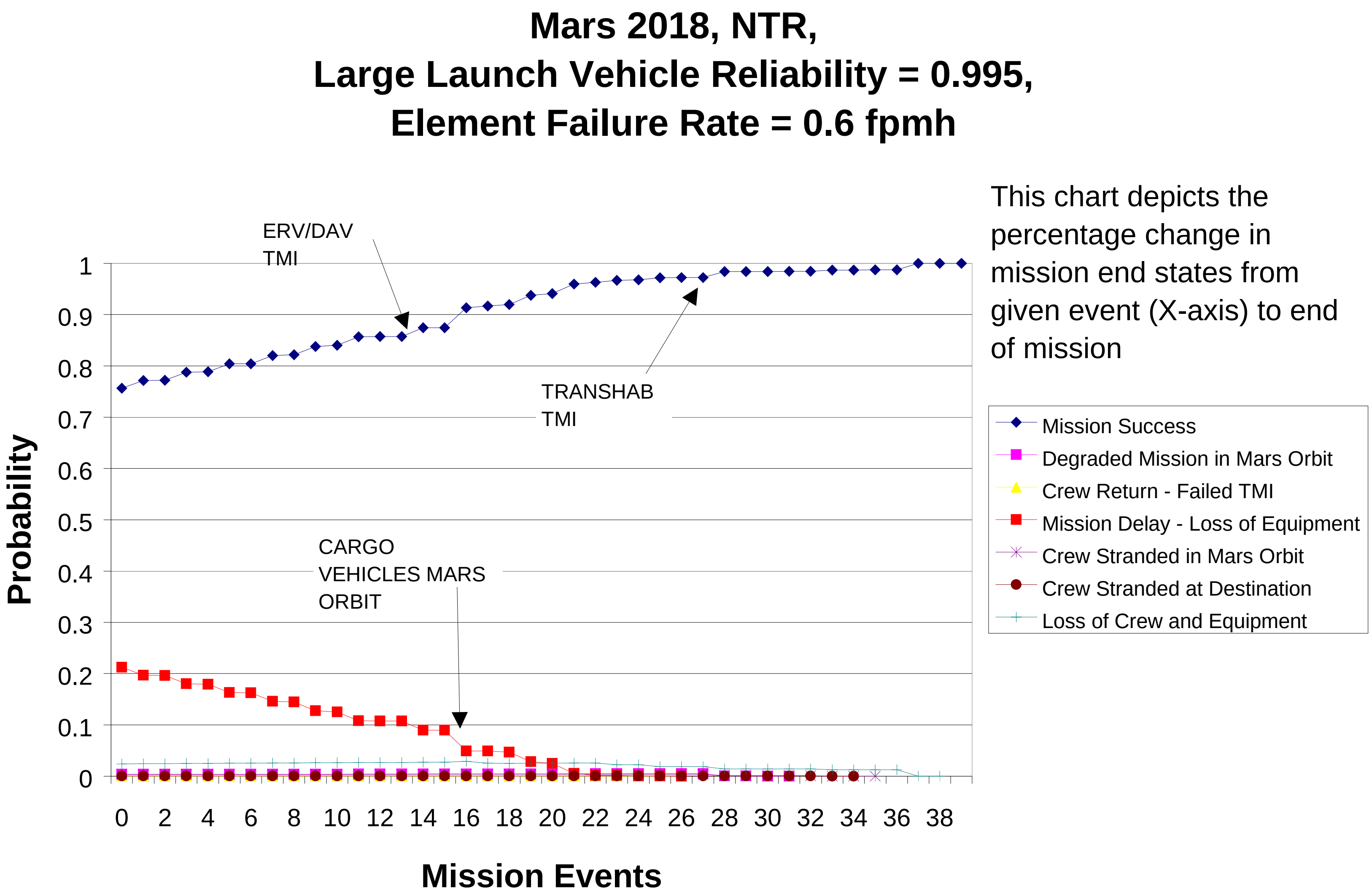
Nuclear Thermal Reactor/ Split Dual Mission Risk (log Probability scale)



Previous Exploration Studies



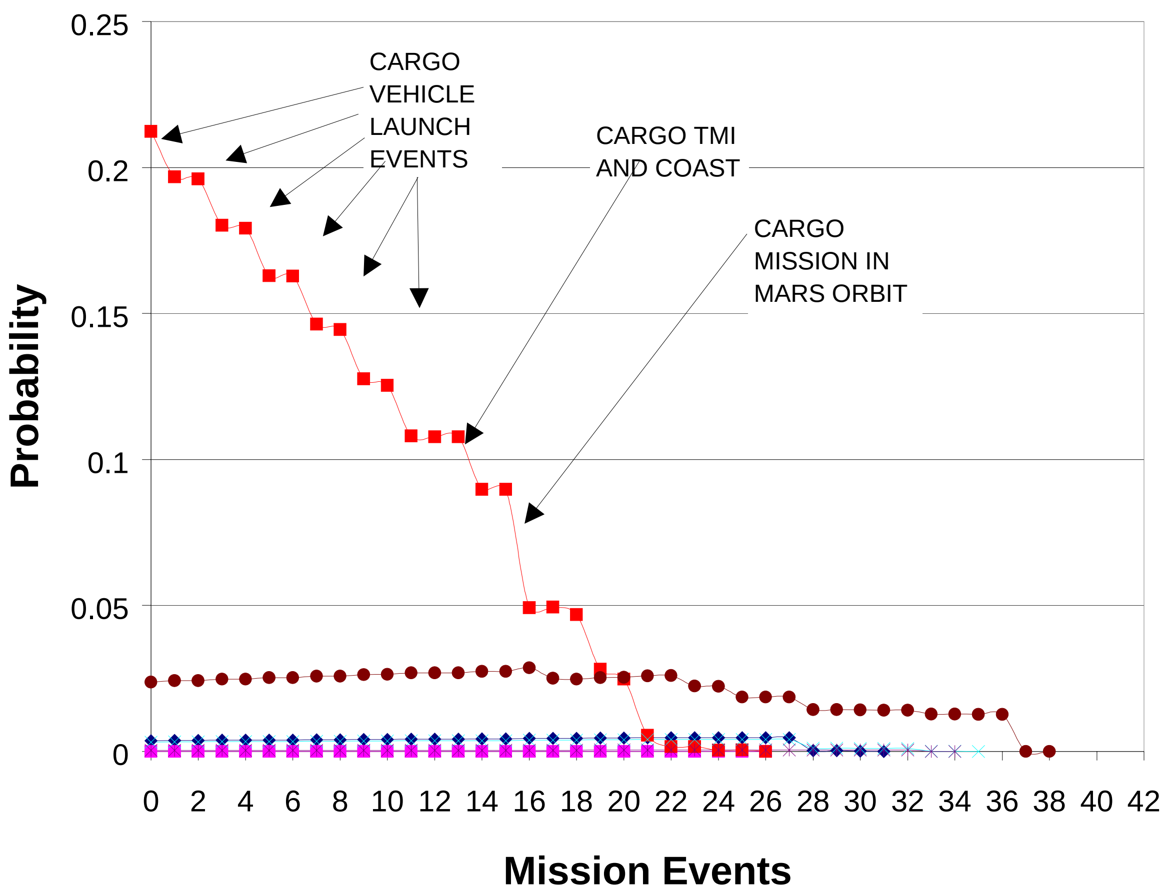
Previous Exploration Studies



This chart depicts the percentage change in mission end states from given event (X-axis) to end of mission

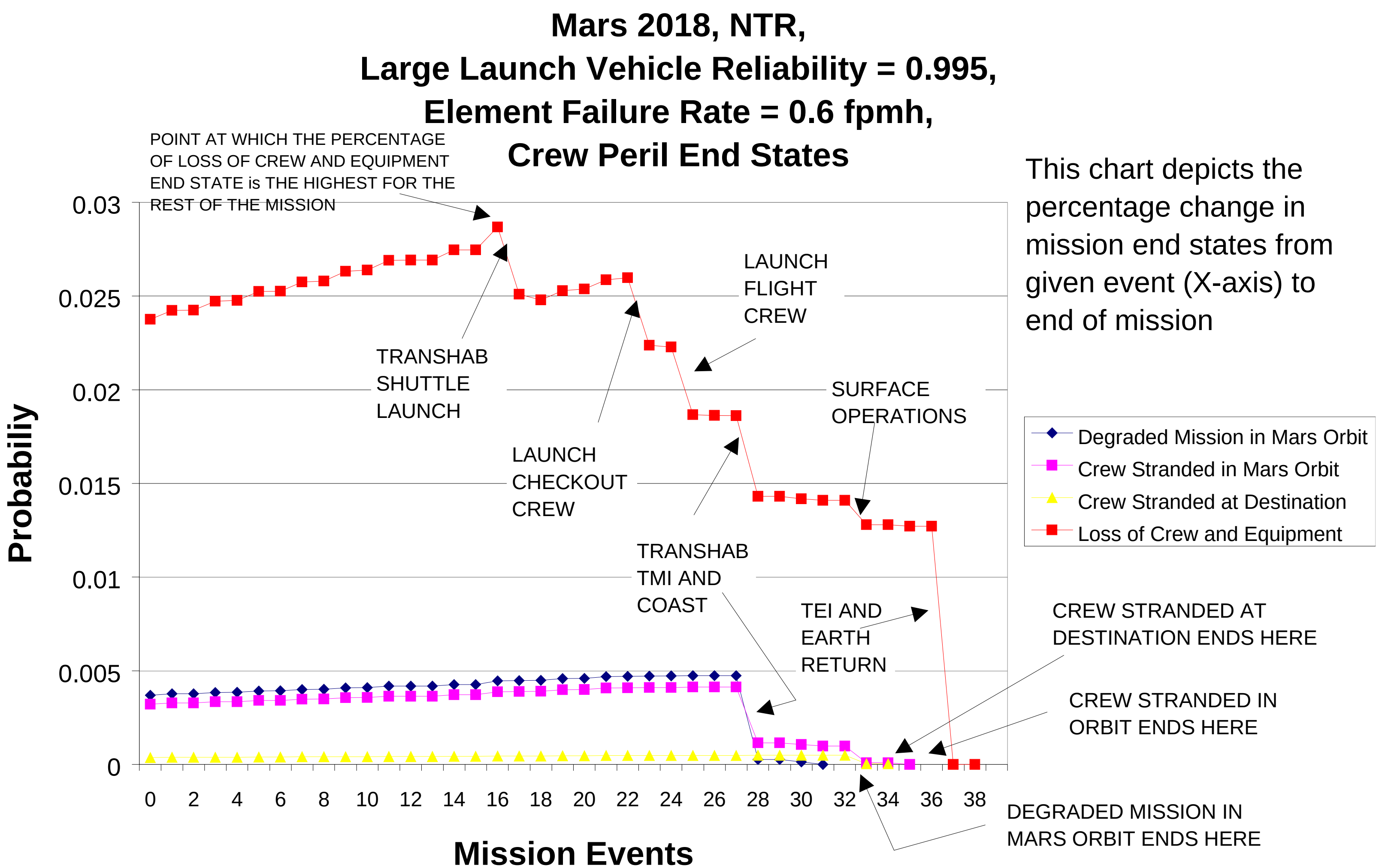
Previous Exploration Studies

Mars 2018, NTR, Large Launch Vehicle Reliability = 0.995, Element Failure Rate = 0.6, End-of-Mission End States



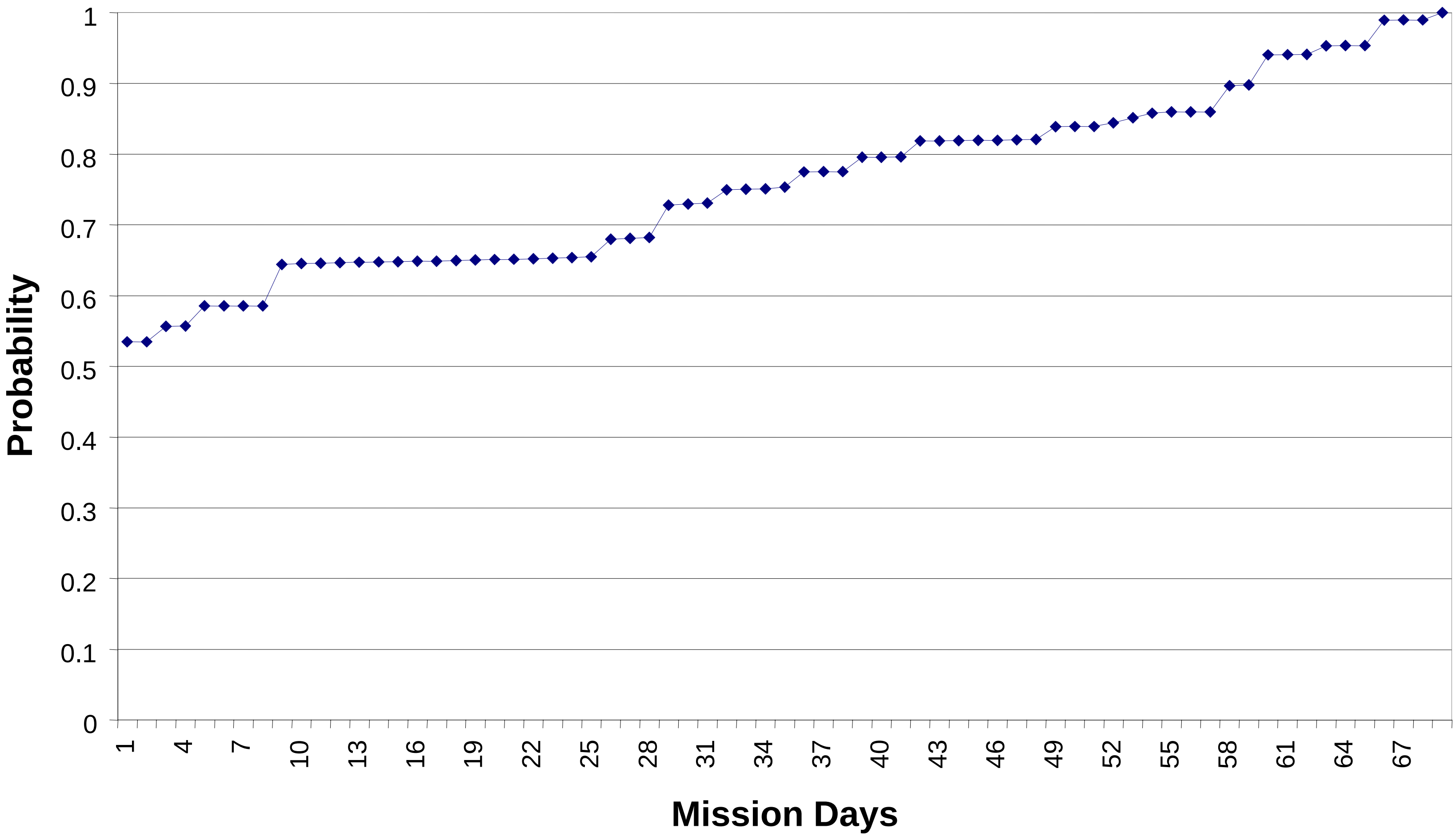
This chart depicts the percentage change in mission end states from given event (X-axis) to end of mission

Previous Exploration Studies

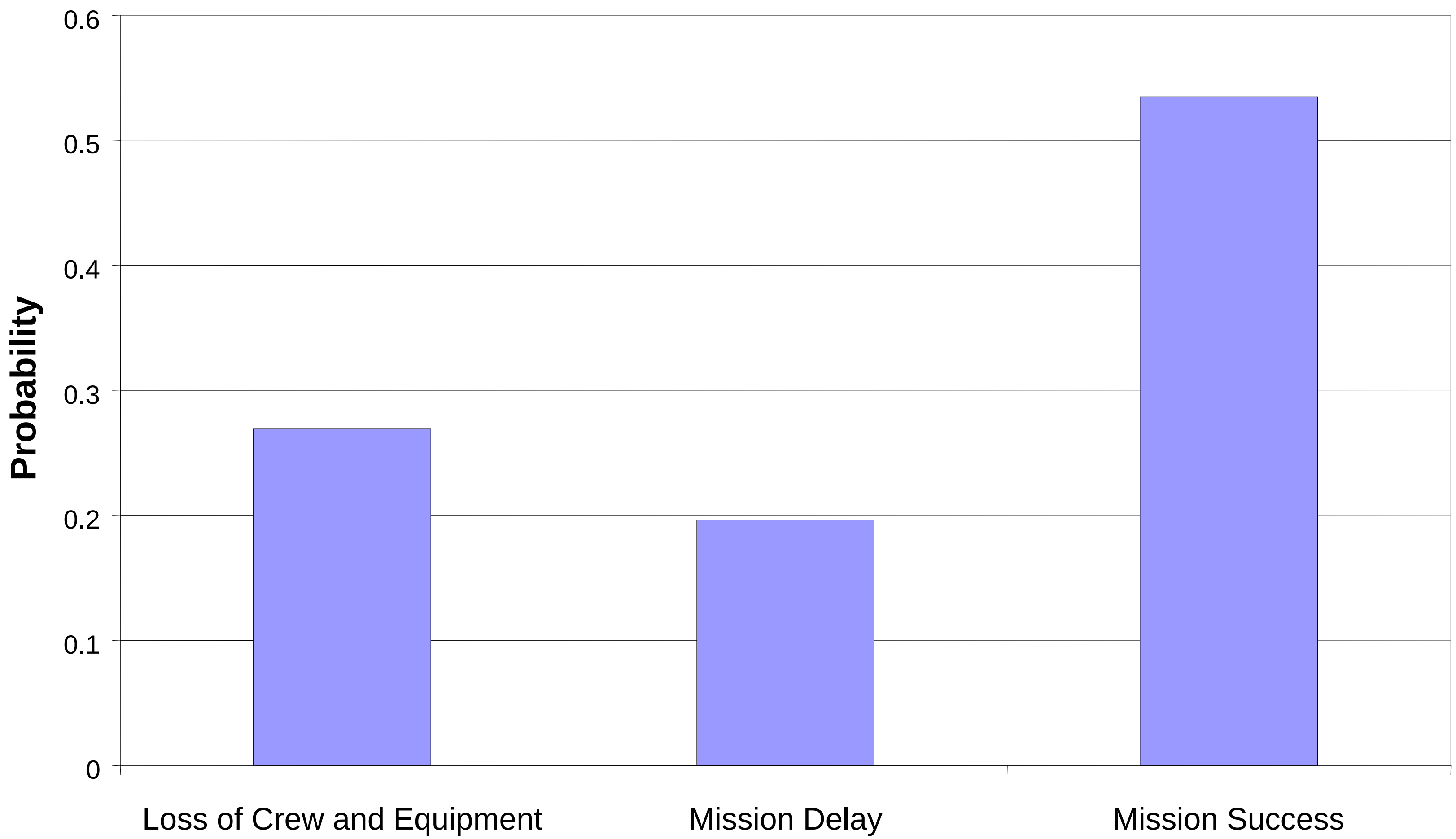


This chart depicts the percentage change in mission end states from given event (X-axis) to end of mission

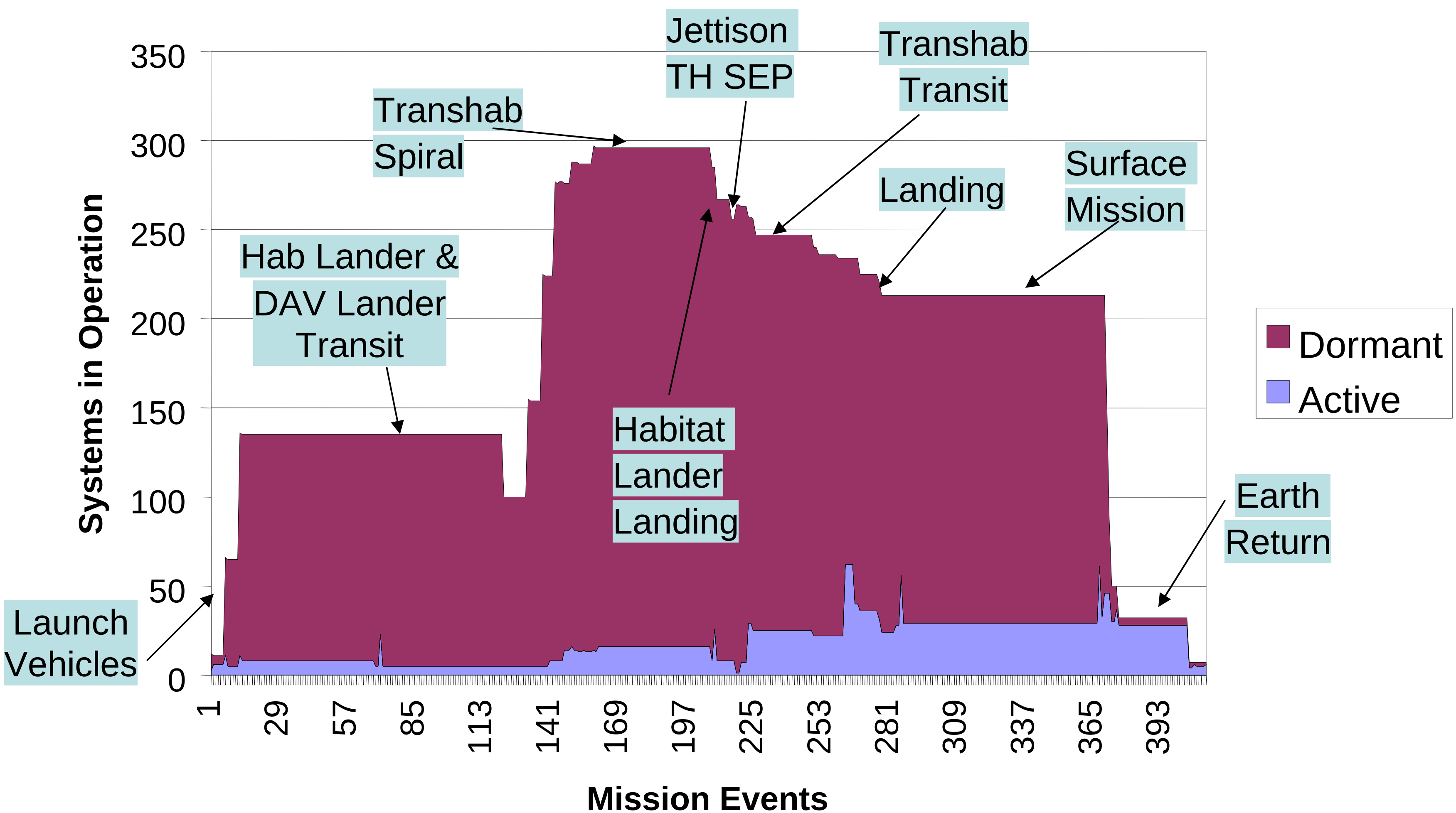
Lunar Landing via L1



Lunar Landing Mission End States



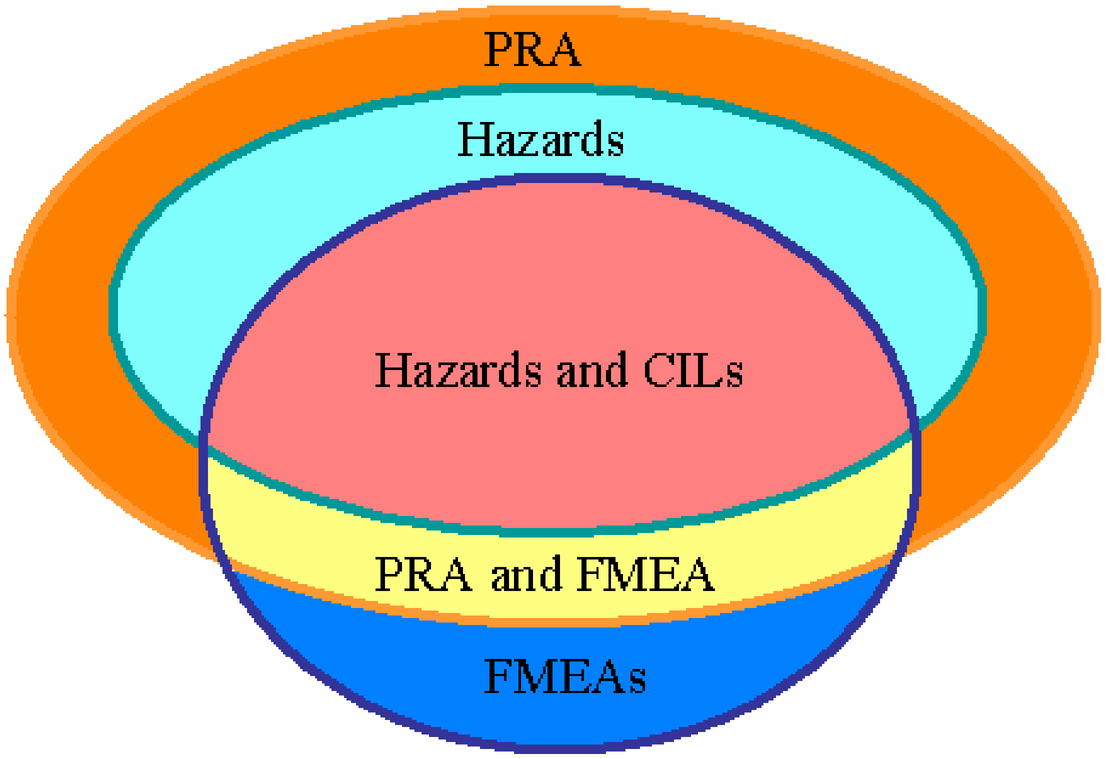
Mars Mission
Dormant/Active Comparison



Mission Risks for Human Exploration (from previous quantitative studies 1998-2000)

- **Launch vehicle reliability must be improved** – The existing launch vehicle reliability runs from ~0.9 to ~0.97 with Shuttle at ~0.996 (best in the industry). Recommend a cargo launch vehicle reliability no worse than Shuttle. This architecture assumes a launch vehicle probability of 0.997.
- **Pre-deploying redundant vehicles decreases the probability of mission success, but decreases the probability of loss of crew.**
- **Deploying the cargo and manned vehicles in a "combo" mission increases the probability of mission success, but increases the probability of loss of crew.**
- **The difference in NTR vs. SEP mission success probabilities –** Presently, both configurations have essentially the same mission risk. The additional NTR launch vehicle cancels out (approximately) the SEP time of system operation during spiral-up to HEO.

Risk Planet



Advanced Concept Analysis in Support of the Integrated Space Plan

Section 7.1

Common Core Crew Vehicle Requirements

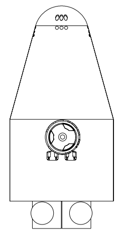
November 2002

Common Core Crew Vehicle Requirements

- **Objective:**
  - Establish the requirements for a common core crew vehicle which can satisfy multiple, Agency-wide, needs.
- **Approach:**
  - Initiate a process for coordinating the needs and requirements for the next generation crew vehicles in order to establish a common set of requirements
  - Crew vehicle requirements should include needs for:
    - ISS Crew Return Vehicle (from low-Earth orbit)
    - Crew Transfer Vehicle (to and from low-Earth orbit)
    - Exploration Transfer Vehicles (beyond low-Earth orbit and return)
- **Recommendation:**
  - Initial assessment of common core crew vehicle requirements include the following:
    - Reconfigurable pressurized volume for 4-7 deconditioned crew
    - One day mission duration independent from a service module
    - Enable autonomous / manual operations
    - Provides propulsive orbital maneuvering capability
    - Controlled aerodynamic flight
    - Primary landing mode shall be on dry land

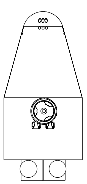
Common Crew Vehicle Design Capture

Core Crew Vehicle



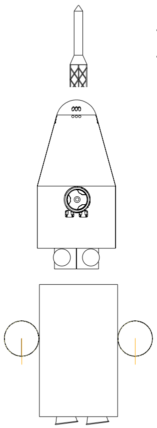
- Common crew element satisfying multiple mission capabilities
- Key Design Requirements :
  - Re-configurable for 4-7 crew
  - Independent one day mission duration
  - Autonomous / manual operations
  - Propulsive orbital maneuvering
  - Controlled aerodynamic flight

ISS Crew Return



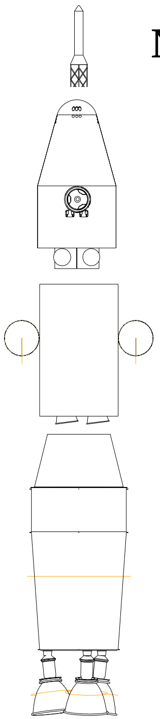
- Provides safe and expeditious recovery of astronauts from low-Earth orbit
- Core Vehicle Configuration Changes:
  - Configured for 4 deconditioned crew
  - Medical emergency provisions
  - Emergency undock capability
  - ISS interfaces and six-month to two-year on-orbit stay
- Key Issues:
  - EELV launch compatibility including automated delivery to ISS
  - Degree of vehicle reusability

LEO Crew Transfer



- Crew transfer to low-Earth orbit and return
- Core Vehicle Configuration Changes:
  - Crew escape for aborts
  - Configured for 5 crew (3 ISS transfer)
  - 12 day mission duration for ISS support
- Service Module for extended mission duration (propulsion, power, thermal control, life support consumables)
- Key Issues:
  - EELV launch compatibility and human rating
  - Degree of vehicle reusability

Near-Earth Transfer



- Transport crew to lunar vicinity and return to Earth
- Core Vehicle Configuration Changes:
  - Configured for 4-6 crew (mission dependent)
  - Crew escape for aborts
  - 12+8 day mission
  - Deep-space environmental conditions
- Service Module for extended mission duration (propulsion, power, thermal control, life support consumables)
- Injection stage for trans-lunar injection
- Key Issues:
  - Lunar return velocities
  - Large launch vehicle
  - Degree of vehicle reusability

Core Crew Vehicle Notional Design Approach

- **Function: Common crew element which satisfies multiple mission capabilities**
- **Key Design Philosophy :**
  - **The system shall provide a reconfigurable pressurized volume for 4-7 deconditioned crew**

    Rationale: Mission requirements for the various mission modes vary from 4-7 (ISS crew return), 5 (for ISS crew transfer), to 6 (for lunar science servicing and Mars). Providing a pressurized volume which is reconfigurable allows for a single design to accommodate anticipated modes for both Low-Earth-Orbit and exploration missions. Emphasis should be placed on maximizing reconfiguration of subsystems in order to accommodate varying mission modes.
  - **The system shall provide a one day mission duration independent from a service module**

    Rationale: Mission durations on the order of one day captures the common requirement between the crew emergency return from ISS, final phase of lunar return, and Mars return. Mission durations greater than this core mission duration can be accomplished with a supplemental service module which provides additional power, consumables, and thermal control.
  - **The system shall enable autonomous / manual operations**

    Rationale: Providing the capability of operating autonomously without relying upon means of external control (such as from Earth control centers), with appropriate manual override is necessary for the missions and time delays expected for the various mission modes.
  - **The system shall provide a propulsive orbital maneuvering capability of 300 m/s**

    Rationale: All mission modes require on-orbit orbital maneuvering capabilities including orbital phasing maneuvers, attitude control, and de-orbit. Additional propulsive capabilities for larger maneuvers can be accomplished with a supplemental service module.
  - **The system shall provide controlled aerodynamic flight**

    Rationale: Providing entry cross range capability increases landing site availability, landing opportunities, as well as landing site targeting.
  - **The primary landing mode shall be on dry land**

    Rationale: Landing on land increases crew safety, reduces recovery operational costs, and enhances vehicle reusability potential. Emphasis should be placed on developing a common vehicle shape (slender body mid-L/D outer mold line) with an appropriate level of vehicle reusability.

Summary

- **Defining the requirements on a multipurpose vehicle requires consideration of all potential mission modes.**
- **Strategies exist that can satisfy the top-level requirements which are common between mission modes.**
- **Further analysis of the impacts of the mission modes on the multipurpose vehicle is required in order to finalize core requirements**

Proposed Process

Overview

- The following presentation provides an approach and process for defining the requirements for the next generation crew vehicles.

- This is an initial step in that process.

- Further coordination and integration between programs across the Agency is required before a final set of requirements for a common core crew vehicle can be established.

Approach

1. **Compare the primary functional needs and requirements for the next generation crew vehicles including:**
   - ISS Crew Return Vehicle
   - Crew Transfer Vehicle (including assured access to ISS)
   - Exploration Transfer Vehicle (including transfers to high earth orbit for potential Mars mission concepts)
   - Entry Vehicle for Mars missions

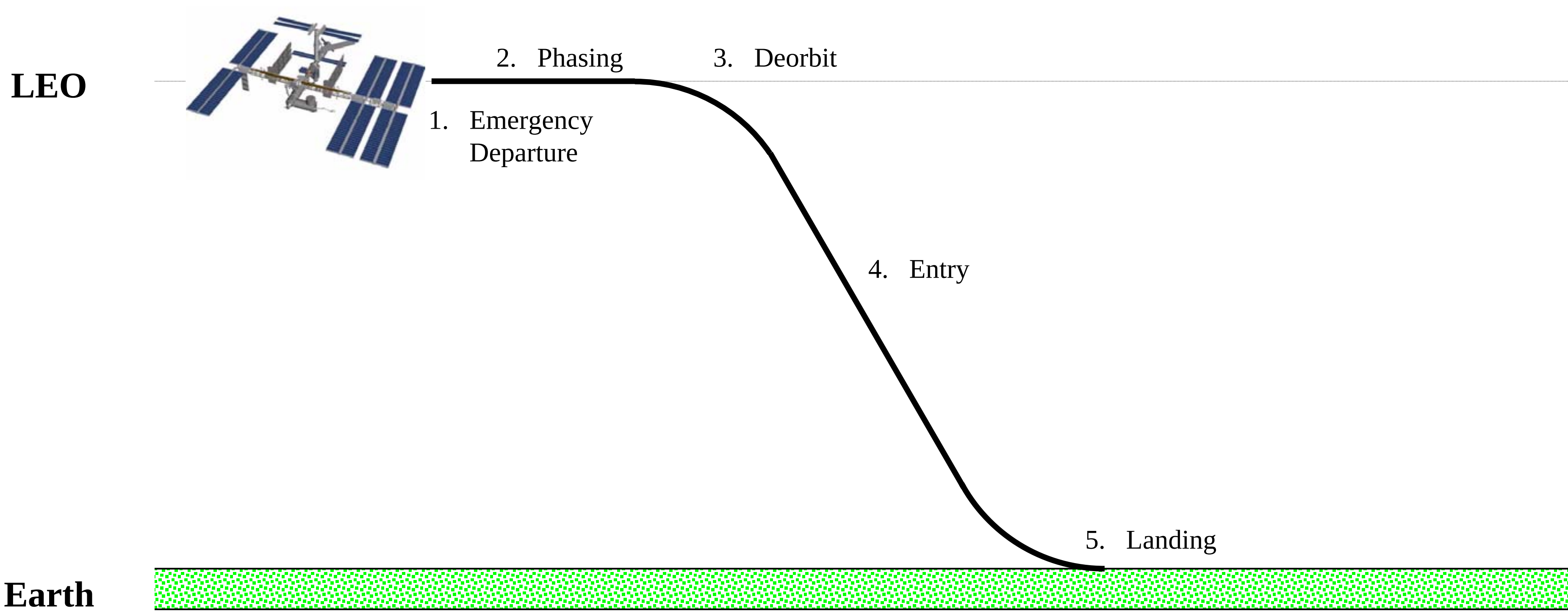
2. **Begin to establish the set of requirements for a common core crew vehicle which satisfies the above mission modes.**

ISS Crew Return Vehicle

- **Primary CRV function is the expeditious return of crew from ISS due to:**
  - Crew medical emergencies
  - ISS emergency situations
  - Grounded Shuttle fleet

- **Key functional needs which drive the CRV design:**
  - Capability to return 4 crew (7 desired)
  - Capability for a quick departure from an uncontrolled ISS
  - Capability to return a sick or injured crewmember
  - Total mission duration less than one day
  - Capability to be stored for a long duration (2-years) (TBD) at ISS
  - The desire for the system to be reusable
  - The CRV shall perform a soft runway landing (wings and wheels)

Notional Mission Profile
ISS Crew Return

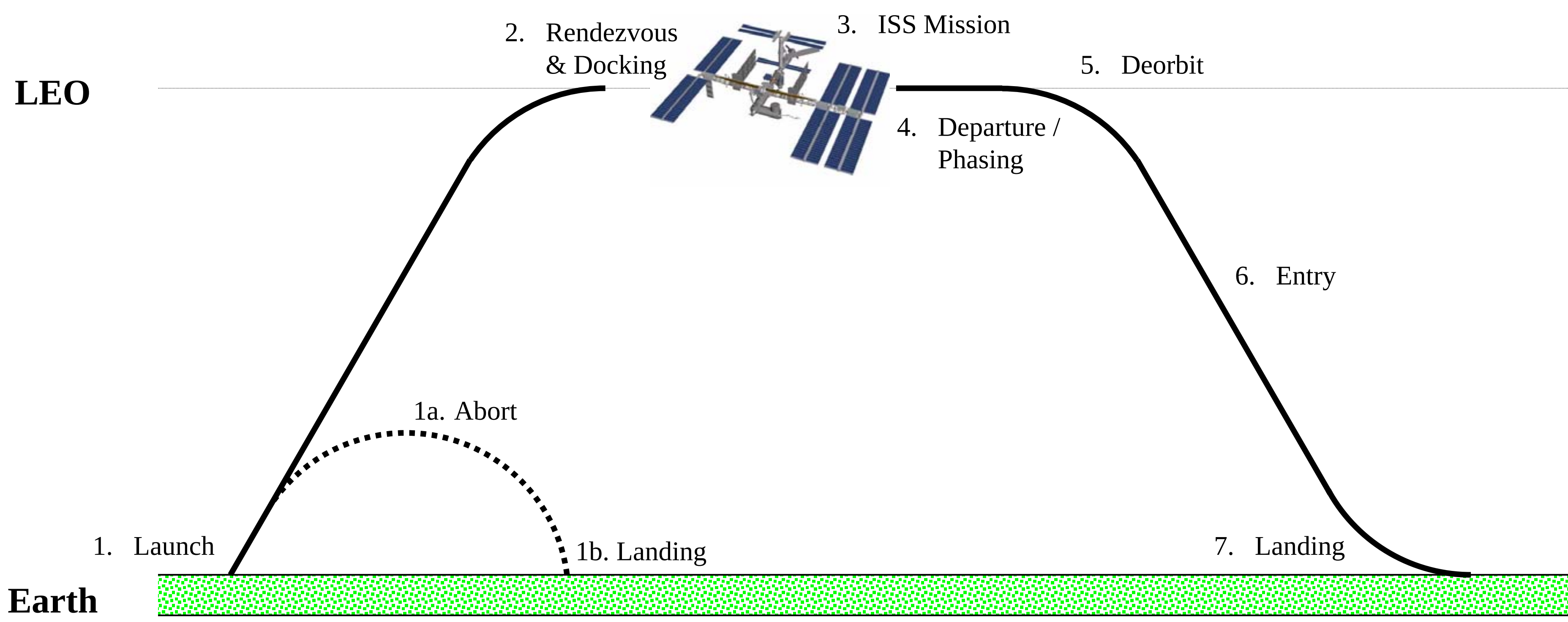


Crew Transfer Vehicle

- **The Crew Transfer Vehicle (CTV) provides an alternate crew delivery and return capability to and from low-Earth orbit:**

- **Key functional needs which drive the CTV design:**
  - Capability to exchange 3 ISS crew (implies a total crew complement of 4-5 depending on operational requirements)
  - Capability to be launched on US EELV-H launch vehicles
  - Capability to be launched on future US launch vehicles (reusable launch vehicle)
  - Provide adequate crew escape methods during ascent
  - Total mission duration of 12 days for ISS crew exchange missions
  - System should be reusable and able perform a soft runway landing (wings and wheels)
  - The CTV shall be capable of performing other missions, such as satellite servicing, when combined with other (additional) mission elements.

Notional Mission Profile
Crew Transfer Vehicle

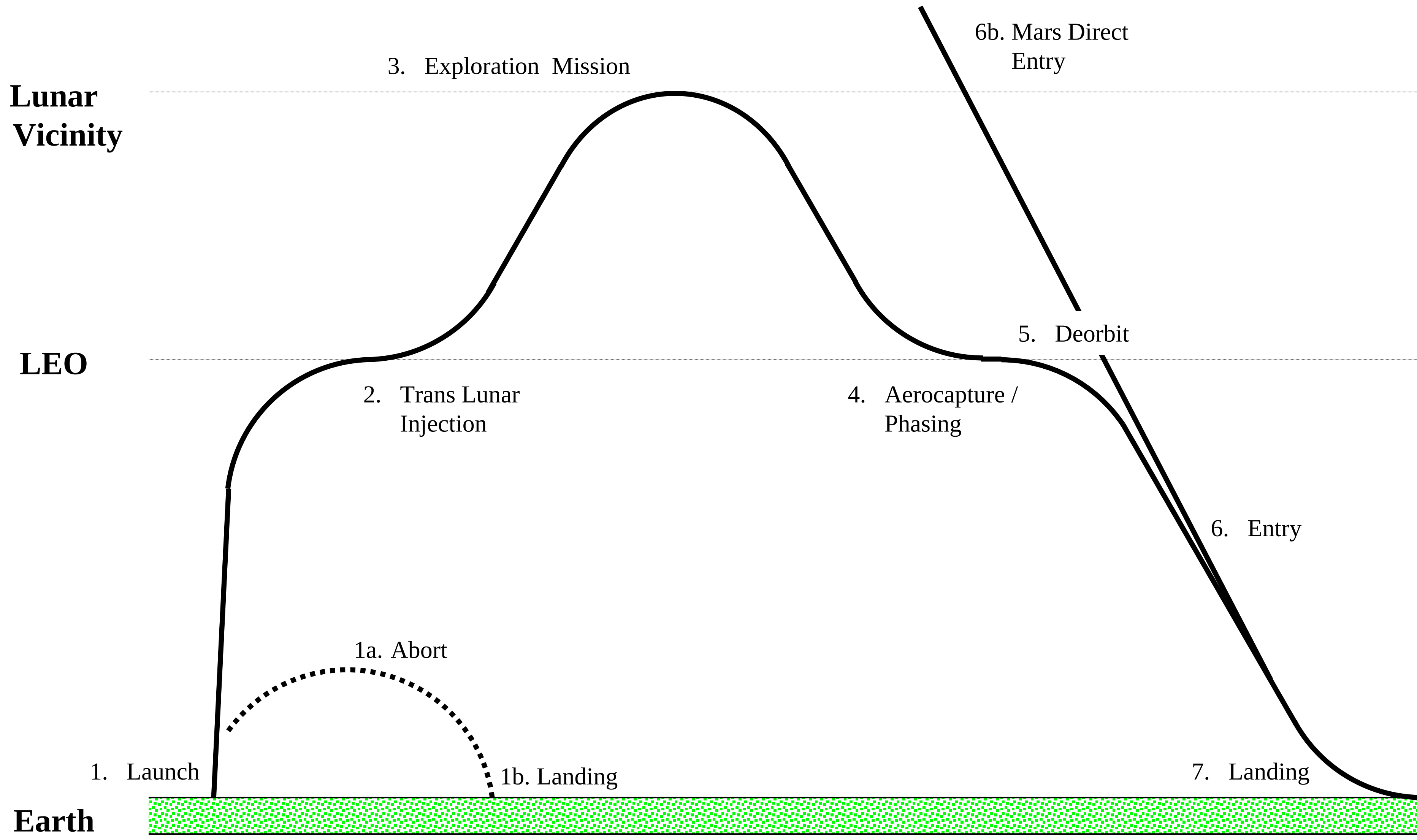


Exploration Transfer Vehicle

- **Provides the capability to transfer mission crew from Earth, to the lunar vicinity, and return back to Earth:**
- **Includes capability for transfers to high earth orbit for potential Mars mission concepts**
- **Key functional needs which drive the XTV design:**
  - Capability to support up to 6 exploration mission crew
  - Total mission duration of 12 days
  - The desire for the system to be reusable
  - Capability to accommodate lunar return velocities

- **Provides the capability to return exploration mission crews from Mars return trajectories to the surface of the Earth:**
- **Key functional needs which drive the Mars Earth Return Vehicle design:**
  - Capability to support up to 6 exploration mission crew
  - Capable of being stored in a dormant state during the Mars mission
  - Total active mission duration of one day
  - Capability to accommodate Mars return velocities

Notional Mission Profile
Exploration Mission



Key Crew Vehicle Key Functional Needs Summary

Crew Emergency Return from ISS

- Expeditious recovery of crew from ISS
  - **Undock < 10 min** [1]
  - **Medical < 24 hrs** [2]
  - All attitudes, **2°/sec** [3]
- 4 crew (7 desired)
- Shirt Sleeve Environment
- Autonomous or manual operation
- Orbital maneuvering and controlled aerodynamic flight
- **Soft runway landing (day or night)** [4]
- ISS compatible
- Simultaneous space / ground communications
- **Long-term storage at ISS (2 years)** [5]
- Reliability 0.999
- Probability of no penetration (MMOD) <.9953 [A6]
- **Reusable** [6]
- Evolvable to a CTV

Crew Transfer to ISS

- Crew transfer to and from ISS
- **EELV launched** [7]
- 5 crew
- **Crew escape system** [8]
- Autonomous or manual operation
- Orbital maneuvering and controlled aerodynamic flight
- **Soft runway landing (day or night)** [4]
- ISS compatible
- Simultaneous space / ground communications
- **Total mission duration ~ 12 days** [9]
- Reliability (TBD)
- N/a
- **Reusable** [6]

Lunar Orbit or L1 Mission

- Crew transfer to lunar vicinity and **return** [10]
  - Earth-Moon L1
  - Lunar orbit
  - Lunar surface
- 4 & 6 crew
- Shirt Sleeve Environment
- Autonomous or manual operation
- Orbital maneuvering and controlled aerodynamic flight
- Land landing (day)
- (N/A)
- Simultaneous space / ground communications
- **Mission duration ~12 days active / 8 days dormant** [11]
- Reliability (TBD)
- N/a
- Reusability desired

Crew Return From Mars Missions

- Crew return from **Mars return trajectories** [12]
- 6 crew
- Shirt Sleeve Environment
- Autonomous or manual operation
- Orbital maneuvering and controlled aerodynamic flight
- Land landing (day)
- (N/A)
- Simultaneous space / ground communications
- Total mission duration ~ 1 day
- Reliability (TBD)
- N/a
- Reusability desired

The Strategy of a Common Core Crew Vehicle

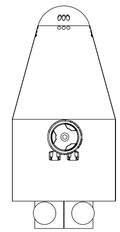
- **The crew vehicle requirements for all current and future mission modes should be considered when developing the requirements for the next generation crew vehicle**

- **Comparison of the key functional requirements between mission modes results in the following common core requirements:**
  - Re-configurable for 4-7 crew
  - Independent one day mission duration
  - Autonomous / manual operations
  - Propulsive orbital maneuvering
  - Controlled aerodynamic flight
  - Land landing

- **Capabilities beyond the scope of the core requirements can be met with additional systems such as:**
  - Service modules for consumables, power, thermal control
  - Injection stages for larger propulsive maneuvers

Common Crew Vehicle Design Capture

Core Crew Vehicle



- Common crew element satisfying multiple mission capabilities
- Key Design Requirements :
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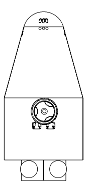
  - Controlled aerodynamic flight

ISS Crew Return



- Provides safe and expeditious recovery of astronauts from low-Earth orbit
- Core Vehicle Configuration Changes:
  - Configured for 4 deconditioned crew
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  - Emergency undock capability
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- Key Issues:
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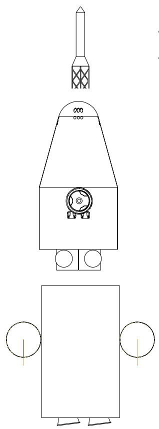
  - Degree of vehicle reusability

LEO Crew Transfer



- Crew transfer to low-Earth orbit and return
- Core Vehicle Configuration Changes:
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  - 12 day mission duration for ISS support
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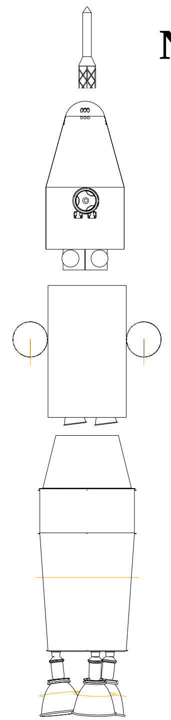
Near-Earth Transfer



- Transport crew to lunar vicinity and return to Earth
- Core Vehicle Configuration Changes:
  - Configured for 4-6 crew (mission dependent)
  - Crew escape for aborts
  - 12+8 day mission
  - Deep-space environmental conditions
- Service Module for extended mission duration (propulsion, power, thermal control, life support consumables)
- Injection stage for trans-lunar injection
- Key Issues:
  - Lunar return velocities
  - Large launch vehicle
  - Degree of vehicle reusability

Vehicle Shape Issues

- **Are wings and wheels required?**
  - Many of the mission modes (CRV and CTV) derive a requirement for soft runway landings, which implies wings and wheels, in order to satisfy multiple higher-level requirements including:
    - Cross range as one approach to meeting loss of crew requirements
    - Landing accelerations for medical and system certification purposes
    - Quick turnaround between flights
  - Wings are incompatible for missions beyond low-Earth orbit
    - Peak heating limits nose and wing radius of curvature – thus eliminating wings from consideration
  - Maintaining pressure in wheels for long periods in space may be an issue
  - Wings may be incompatible for launch modes where the vehicle is exposed to the free air stream.
  - Source of this requirement researched – not a hard requirement
- **If wings are considered a strong Level I requirement, then an additional requirement should be added:**
  - The system shall be capable of accommodating outer mold lines of multiple vehicles
    - With this approach, the common core vehicle requirements would be contained within a common crew cabin or reduced to common system components

Core Crew Vehicle Notional Design Approach

- **Function: Common crew element which satisfies multiple mission capabilities**
- **Key Design Philosophy :**
  - **The system shall provide a reconfigurable pressurized volume for 4-7 deconditioned crew**

    Rationale: Mission requirements for the various mission modes vary from 4-7 (ISS crew return), 5 (for ISS crew transfer), to 6 (for lunar science servicing and Mars). Providing a pressurized volume which is reconfigurable allows for a single design to accommodate anticipated modes for both Low-Earth-Orbit and exploration missions. Emphasis should be placed on maximizing reconfiguration of subsystems in order to accommodate varying mission modes.
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  - **The system shall provide controlled aerodynamic flight**

    Rationale: Providing entry cross range capability increases landing site availability, landing opportunities, as well as landing site targeting.
  - **The primary landing mode shall be on dry land**

    Rationale: Landing on land increases crew safety, reduces recovery operational costs, and enhances vehicle reusability potential. Emphasis should be placed on developing a common vehicle shape (slender body mid-L/D outer mold line) with an appropriate level of vehicle reusability.

Summary

- **Defining the requirements on a multipurpose vehicle requires consideration of all potential mission modes.**
- **Strategies exist that can satisfy the top-level requirements which are common between mission modes.**
- **Further analysis of the impacts of the mission modes on the multipurpose vehicle is required in order to finalize core requirements**

Backup

Crew Vehicle Key Functional Needs Notes

1 Providing the capability to quickly undock from ISS from a dormant state significantly impacts all system response times. Requires system architecture which can autonomously perform quick system checks and startup including position and attitude determination.

2 Basic medical capabilities should be provided on all crew vehicles. Providing a dedicated medical emergency function is unique CRV requirements. This includes such functions as providing a dedicated crew medical officer station, unique medical accommodations (pure oxygen, seats, restraints, isolation, etc.). Providing a core vehicle with a reconfigurable pressurized volume can enable this capability.

3 Separation from a rotating space station at 2°/sec is a unique CRV requirement which drives docking mechanisms and vehicle control system response authority.

4 Soft runway landing is an implementation rather than a requirement which should be driven by other higher level requirements such as medical landing accelerations, operational costs, crew safety, etc. Soft implies that there is an acceptable vertical speed at touchdown which is not specified. Runway implies that the CRV will have wings and/or wheels. Wings cannot be used for missions beyond low Earth orbit due to peak heating limits. Other approaches exist which can maximize, if not enable, vehicle reusability including steerable parachutes (parafoils) and non-steerable parachutes (round) with landing attenuation devices (strokable struts, air bags, retro-rockets).

5 Long-term storage at ISS is a unique CRV requirement. The two-year storage requirement drives technology selections, redundancy and maintenance strategies, and operational servicing and checkout strategies. The strategy of rotating a new CRV every 2 years, as this requirement implies, should be traded against a CRV with a shorter (6-month) life which is swapped during each crew rotation mission such as Soyuz. System impacts for long-term storage include elimination of cryogenic fluids (propulsion and power), micro-meteroid protection, propulsion system stability and isolation, thermal and environmental conditioning.

Crew Vehicle Key Functional Needs Notes

6 Vehicle reusability is driven primarily by technology selections, system architecture designs, and most importantly landing conditions. Vehicle reusability usually implies soft runway landings utilizing wings and wheels which are incompatible for missions beyond low Earth orbit due to peak heating requirements. Strategies which focus on selective reusability, rather than total system reuse, can be accommodated within beyond LEO missions.

7&8 Providing a crew transfer capability independently from the STS by utilizing EELV launchers will limit the overall crew transfer vehicle design and size. Key drivers include maximum vehicle mass (approximately 20 mt), vehicle diameter (approximately 4.5 m), and vehicle shape (limited area and lift). EELV control authority issues may be inconsistent with the desire to utilize wings on the crew transfer vehicle. In addition, human rating issues may require EELV modifications as well as incorporation of crew escape systems for ascent aborts. Developing a core vehicle without wings can allow commonality across mission modes as well as enable multiple delivery modes (STS and EELV).

9 This mission duration is driven by ISS crew transfer missions as well as on-orbit servicing missions. System drivers for longer missions are primarily habitable volume requirements and consumables (power and life support).

10 Lunar return missions will drive the overall thermal protection system and vehicle shape. Thermal protection systems which can accommodate much higher peak heating are required due to the higher entry velocities (11.0 km/s for lunar return versus 7.5 km/s for low Earth orbit). This necessitates vehicle shapes which limit leading edge radius of curvature (no wings such as slender bodies with mid-L/D) and incorporation of ablative thermal protection systems for areas of high peak heating at stagnation points. Reusable thermal protection systems can be substituted for ablators for low-Earth orbit only missions.

11 This mission duration is driven by lunar missions which include approximately 12 days of transfer and orbital operations and 8 days of dormancy during satellite servicing (performed from independent mission assets) or lunar exploration missions.

12 Thermal protection systems and vehicle shapes must accommodate Mars return entry speeds of approximately 13.0 km/s.

Advanced Concept Analysis in Support of the Integrated Space Plan

Section 7.2

Bioastronautics Critical Path Roadmap: Reducing the Risks for Human Exploration-Class Missions

November 2002

Some Physiological Risks and Impacts of Extended Space Flight (L1/Lunar Missions)

Physical tolerance of stresses during aerobraking, landing and launch phases, and strenuous surface activities

Bone loss

- no documented end-point or adapted state
- countermeasures in work on ground but not yet flight tested

Cardiovascular alterations

- pharmacological treatments for autonomic insufficiency in work

Muscle atrophy

- basic mechanisms under study
- resistive exercise in work

Neurovestibular adaptations

- vehicle modifications, including centrifuge under consideration
- may require auto-land capability

Space Medicine - Routine and Contingency Ops must cope with these issues.

Mars – All the above, plus radiation effects, both acute and chronic

Bioastronautics Issues

- **Risks and critical questions have been identified and prioritized for mission scenarios**
  - **Radiation concerns limit deep-space exposure: most susceptible person < ~50 days; least susceptible person < ~270 days (NCRP, 2000: 3% excess cancer, based on age and gender)**
  - **Neurological, cardiovascular concerns about precision piloting for Earth return after ~20 days**
  - **Medical response plan to be determined by risk level to be accepted, mission requirements (potential for injury, etc.)**
    - **TRL varies inversely with available resources (such as: mass/volume available; presence of trained care-giver)**

BCPR Background

- Joint NASA JSC/NSBRI undertaking, initiated 1997
- Twelve joint Risk Area Teams in three categories

- Habitation Systems:
  - Advanced Life Support (ALS)
  - Environmental Health (EH)
  - Food and Nutrition (F&N)
  - Human Behavior and Performance (HB&P)
- Health Care Systems:
  - Clinical Capabilities
  - Multi-system Alterations
- Human Adaptation and Countermeasures:
  - Bone Loss
  - Cardiovascular Adaptations (CV)
  - Human Behavior & Performance (HB&P)
  - Immunology, Infection and Hematology (II&H)
  - Muscle Atrophy & Alterations (MA)
  - Neurovestibular Adaptations (NVA)
  - Radiation Effects

BCPR Background

- Assessed Mars DRM
  - Produced set of 55 risks, ~250 critical questions (CQ)
- Now analyzing subsets of risks, etc., specific to 180-day ISS, 30-day STS, 3 & 30-day lunar surface missions, etc.
- Countermeasure tracking
- Risk quantification activity

Risk Resolution Timeline: Bad News

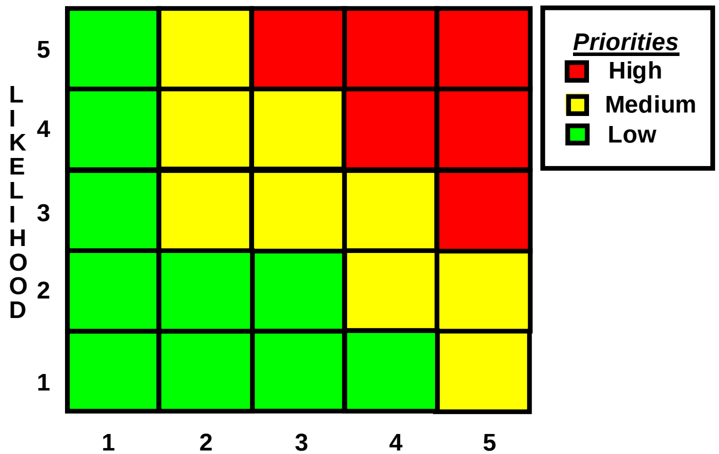
- 55 risks identified for Mars DRM.
  - Subset of 43 risks (not including ECLSS) tentatively identified for lunar surface 3-day and 30-day missions.
- 248 CQs identified for Mars DRM
  - 185 required studies
    - Ground-based data: 108
    - Requiring in-flight data: 77
      - SWAG: 130 “trials” @ 7 crewmembers/trial (optimistic!!)
      - All 55 risks by 2010 => 79% too few ISS <u>7-person</u> crews
      - Lunar subset of 43 risks by 2010 => 27% too few ISS <u>7-person</u> crews

Risk Resolution Timeline: Good News

- Not ALL risks must be resolved before Go/No Go.
  - Every single risk resolved reduces overall threat to crew for mission and lifetime.
  - Periodic reassessment by BCPR to track overall risk level.
- BCPR is being applied to Code U NRAs
  - Ground-Based Research in Space Radiation Biology and Space Radiation Shielding Materials (NRA-02-OBPR-02), proposals due 25 Nov. 02.
  - Research Opportunities in Space Biological Sciences, Advanced Human Support Technology Program 2002 (NRA-02-OBPR-01), June 2002.
  - Others

Bioastronautics Risk Mitigation Definitions

LIKELIHOOD	What is the likelihood the risk will occur?		
	Level	*Probability*	*. . . probability of occurrence . . .*
	5	Very High	95 – 100%
	4	High	75 – 95%
	3	Moderate	25 – 75%
	2	Low	5 – 25%
	1	Very Low	0 – 5%



CONSEQUENCE	*What is the worst case consequence (Crew or Mission) if the risk occurs with the current level of mitigation?*					
	Level	1	2	3	4	5
	Crew Health, Safety, Performance	No impact to crew	Short- term, minor injury, illness, incapacitation, or impairment to crewmember	Serious injury, illness, incapacitation or impairment but not long term	Significant and long term impairment, but not permanent	Irreversible, catastrophic impairment, or death
	Mission Success	No impact to mission whatsoever; no loss of mission objectives	Relatively small impact to mission; loss limited to only a few of the mission objectives	Considerable impact and considerable loss of mission objectives	Significant mission impact; many mission objectives lost, however mission is not aborted	Significant mission impact; total loss of mission objectives; Mission aborted

BCPR Risks and Risk Areas for Mission Scenarios (1of 4) **PRELIMINARY**

ID	Risk Title	Risk Area	STS EVO	ISS	Moon surface via L1		Mars DRM
			30 days	180-215 days	3 (18) days	30 (44) days	30 months
28	Loss of Skeletal Muscle Mass, Strength, and/or Endurance	Muscle	3Green	3Green	2Yellow	1Red	1Red
29	Inability to Adequately Perform Tasks Due to Motor Performance, Muscle Endurance, and Disruption in Structural and Functional Properties of Soft & Hard Connective Tissues of the Axial Skeleton	Muscle	2Yellow	2Yellow	2Yellow	1Red	1Red
43	Trauma and Acute Medical Problems	Clinical	3Green	3Green	2Yellow	1Red	1Red
46	Illness and Ambulatory Health Problems	Clinical	2Yellow	2Yellow	2Yellow	2Yellow	1Red
14	Impaired Response to Orthostatic Stress	CVA	2Yellow	2Yellow	2Yellow	2Yellow	1Red
17	Impaired Cardiovascular Response to Exercise Stress	CVA	2Yellow esp. Earth return	2Yellow	2Yellow esp. Earth return	2Yellow esp. Earth return	1Red
19	Human Performance Failure Because of Sleep and Circadian Rhythm Problems	HB&P	2Yellow	2Yellow	2Yellow	2Yellow	1Red
31	Propensity to Develop Muscle Injury, Connective Tissue Dysfunction, and Bone Fractures Due to Deficiencies in Motor Skill, Muscle Strength and Muscular Fatigue	Muscle	3Green	3Green	2Yellow	2Yellow	1Red
30	Inability to Sustain Muscle Performance Levels to Meet Demands of Performing Activities of Varying Intensities	Muscle	3Green	2Yellow	2Yellow	2Yellow	1Red
33	Disorientation and Inability to Perform Landing, Egress, or Other Physical Tasks, Especially During/After G-Level Changes (Acute spontaneous & provoked vertigo, nystagmus, oscillopsia, poor dynamic visual acuity)	NVA	1Red	2Yellow	2Yellow esp. Earth return	2Yellow esp. Earth return	1Red
36	Vestibular Contribution to Cardioregulatory Dysfunction (Post landing orthostatic intolerance, sleep and mood changes)	NVA	2Yellow esp. Earth return	2Yellow esp. Earth return	2Yellow esp. Earth return	2Yellow esp. Earth return	1Red
34	Impaired Neuromuscular Coordination and/or Strength (Gait ataxia, postural instability)	NVA	2Yellow esp. Earth return	2Yellow	2Yellow esp. Earth return	2Yellow esp. Earth return	1Red
39	Damage to Central Nervous System from Radiation Exposure	Radiation	2Yellow	2Yellow	2Yellow	2Yellow	1Red

BCPR Risks and Risk Areas for Mission Scenarios (2 of 4) **PRELIMINARY**

ID	Risk Title	Risk Area	STS EVO	ISS	Moon surface via L1		Mars DRM
			30 days	180-215 days	3 (18) days	30 (44) days	30 months
44	Toxic Exposure	Clinical	3Green	3Green	2Yellow	2Yellow	2Yellow
35	Impaired Cognitive and/or Physical Performance Due to Motion Sickness Symptoms or Treatments, Especially During/After G-Level Changes (Including short term memory loss, reaction time increase, drowsiness, fatigue, torpor, irritability, ketosis)	NVA	2Yellow esp. Earth return	2Yellow esp. Earth return	2Yellow esp. Earth return	2Yellow esp. Earth return	2Yellow
42	Radiation Effects on Fertility, Sterility, and Heredity	Radiation	2Yellow	2Yellow	2Yellow	2Yellow	2Yellow
47	Development and Treatment of Space-Related Decompression Sickness	Clinical	2Yellow	2Yellow	2Yellow	2Yellow	2Yellow
45	Altered Pharmacodynamics and Adverse Drug Reactions	Clinical	3Green	3Green	2Yellow	2Yellow	2Yellow
49	Post-landing Alterations in Various Systems Resulting in Severe Performance Decrements and Injuries	Multisystem	3Green	3Green	2Yellow esp. Earth return	2Yellow esp. Earth return	2Yellow
7& 53 & 54 & 55	Inadequate Nutrition (Malnutrition) & …Due to Inability to Provide and Maintain a Bioregenerative System & Difficulty of Rehabilitation Following Landing Due to Nutritional Deficiencies & Human Performance Failure Due to Nutritional Deficiencies	Food & Nutrition & ALS	2Yellow (7&53) 3Green (54,55)	2Yellow (7&53) 3Green (54,55)	3Green	2Yellow	1Red
23 & 38	Carcinogenesis	IIH Radiation	2Yellow	2Yellow	3Green	2Yellow	1Red
11	Injury to Soft Connective Tissue, Joint Cartilage, & Intervertebral Disc Rupture w/ or w/o Neurological Complications	Bone Loss	2Yellow	2Yellow	3Green	2Yellow	2Yellow
12	Renal Stone Formation	Bone Loss	2Yellow	2Yellow	3Green	2Yellow	2Yellow
13	Occurrence of Serious Cardiac Dysrhythmias	CVA	2Yellow	2Yellow	3Green	2Yellow	2Yellow
16	Manifestation of Previously Asymptomatic Cardiovascular Disease	CVA	2Yellow	2Yellow	3Green	2Yellow	2Yellow

ID	Risk Title	Risk Area	STS EVO	ISS	Moon surface via L1		Mars DRM
			30 days	180-215 days	3 (18) days	30 (44) days	30 months
25	Altered Wound Healing	IIH	3Green	3Green	3Green	2Yellow	2Yellow
26	Altered Host-Microbial Interactions	IIH	3Green	3Green	3Green	2Yellow	2Yellow
3	Inadequate Supplies (including maintenance, emergency provisions, and edible food)	ALS	2Yellow	2Yellow	3Green (see ECLSS)	3Green (see ECLSS)	1Red
8	Unsafe Food Systems	Food & Nutrition	2Yellow	2Yellow	3Green (see ECLSS)	3Green (see ECLSS)	1Red
10	Fracture & Impaired Fracture Healing	Bone Loss	3Green	3Green	3Green	3Green	1Red
9	Acceleration of Age-Related Osteoporosis	Bone Loss	2Yellow	2Yellow	3Green	3Green	1Red
18	Human Performance Failure Because of Poor Psychosocial Adaptation	HB&P	3Green	2Yellow	3Green	3Green	1Red
24	Altered Homodynamic and Cardiovascular Dynamics caused by Altered Blood Components	IIH	3Green	2Yellow	3Green	3Green	1Red
37	Possible Chronic Impairment of Orientation or Balance Function Due to Microgravity or Radiation (Imbalance, gait ataxia, vertigo, chronic vestibular insufficiency, poor dynamic visual acuity)	NVA	2Yellow	2Yellow	3Green	3Green	1Red
41	Early or Acute Effects from Radiation Exposure	Radiation	2Yellow	2Yellow	3Green	3Green	1Red
40	Synergistic Effects from Exposure to Radiation, Microgravity and other Spacecraft Environmental Factors	Radiation	3Green	2Yellow	3Green	3Green	1Red
2 & 52	Inability to Provide and Recover Potable Water & … Due to Environmental Health Contaminants	ALS	2Yellow	2Yellow	3Green (see ECLSS)	3Green (see ECLSS)	2Yellow

PRELIMINARY

ID	Risk Title	Risk Area	STS EVO	ISS	Moon surface via L1		Mars DRM
			30 days	180-215 days	3 (18) days	30 (44) days	30 months
1 & 51	Inability to Maintain Acceptable Atmosphere in Habitable Areas & … Due to Environmental Health Contaminants	ALS & EH	2Yellow	2Yellow	3Green (see ECLSS)	3Green (see ECLSS)	2Yellow
4	Inability to Maintain Thermal Balance in Habitable Areas	ALS	2Yellow	2Yellow	3Green (see ECLSS)	3Green (see ECLSS)	2Yellow
6	Inadequate Stowage and Disposal Facilities for Solid and Liquid Trash Generated During Mission	ALS	3Green	3Green	3Green (see ECLSS)	3Green (see ECLSS)	2Yellow
5	Inability to Adequately Process Solid Wastes	ALS	2Yellow	2Yellow	3Green (see ECLSS)	3Green (see ECLSS)	2Yellow
48	Difficulty of Rehabilitation Following Landing	Clinical	3Green	2Yellow	3Green	3Green esp. Earth return	2Yellow
20	Human Performance Failure Because of Human System Interface Problems & Ineffective Habitat, Equipment, Design, Workload, or In-flight Information and Training Systems	HB&P	3Green	3Green	3Green	3Green	2Yellow
22	Immunodeficiency/Infections	IIH	3Green	3Green	3Green	3Green	2Yellow
27 & 50	Allergies and Hypersensitivity Reactions Allergies and Hypersensitivity Reactions from Exposure to the Enclosed Spacecraft & Other Environmental Factors	IIH EH	3Green	3Green	3Green	3Green	2Yellow
32	Impact of Deficits in Skeletal Muscle Structure and Function on Other Systems	Muscle	3Green	3Green	3Green	3Green	2Yellow
21	Human Performance Failure Because of Neurobehavioral Dysfunction	HB&P	3Green	3Green	3Green	3Green	2Yellow
15	Diminished Cardiac Function	CVA	3Green	3Green	3Green	3Green	3Green

Bioastronautics

- Bioastronautics Endorses the following:
  - Science-driven mission selection
  - Mission-driven technology development
  - OBPR Priorities ranked as 1^{st} and 2^{nd} Priority by REMAP
  - Expanded application of Bioastronautics Critical Path Roadmap in guiding funding of tasks for risk reduction
    - Ground-based radiobiology research towards countermeasures
  - Artificial gravity development
    - Ground-based studies of acceptable AG limits
    - Earliest possible human-rated short-radius AG testbed in space
    - Earliest possible delivery of animal centrifuge to ISS
    - Continued development of concept for Artificial Gravity spacecraft providing up to 1-g

Bioastronautics

- Bioastronautics advocates these Augmentations:
  - Increase ISS crewmember throughput for biomedical investigations
    - Increase crew size
    - Decrease increment duration
    - *Reduce crew workload to increase research opportunities on ISS*
  - *Develop and* demonstrate advanced medical care capabilities consistent with mission and risk
    - "Stand-and-fight" on-board provisioning *vs*. abort to Earth
    - On-board medical autonomy as a standard practice
  - Use ground analogs (*BNL*, INTEGRITY, NEEMO, *lab*, *bed rest studies*, etc.) to augment flight opportunities
    - *Biological effects of radiation dose, advanced life support and monitoring, countermeasure effectiveness, behavior and performance tools, etc*.
  - Evaluate future vehicles' systems on ISS
    - Improve crew safety, health, and habitability

Bioastronautics

- Bioastronautics makes these Recommendations:
  - Manifest STS & ISS missions for specific risk-reduction activities
    - *Examples:*
      - » *Medical Ops – procedures and tools*
      - » *Countermeasures – procedures and tools*
      - » *Environmental monitoring – procedures and tools*
      - » *BCPR Research – some risks addressable on short flights*
  - Place humans at center of future vehicle and mission design efforts
    - Humans as critical systems instead of as supplements to all other systems
    - Human requirements to be defined, integrated — and implemented!
    - *Human Rating Standards: NASA Std 3000, SMACs, NPG-8705 (in work), JSC-28354 (approved) (Human Rating Req'ts for Space Flight Systems), SSP 50260 (MORD), SSP50480 (ISS Med Ops Implementation Plan)*

Advanced Concept Analysis in Support of the Integrated Space Plan

Section 7.3

Human Exploration Requirements for Future Nuclear Systems

November 2002

Contents

- Roadmap Objectives
- NExT Requirements Document
- Human NEP Requirements
- Human Surface Power Requirements

Nuclear Roadmap Overview

- **Where-when-&-how nuclear "fits" into exploration strategies is highly dependent on how architectures develop over next few weeks**
- **Nuclear technology is challenging & expensive – need to use where makes sense (enabling or highly enhancing)**
- **Nuclear surface power "shines" for one or more of the following:**
  - **Little sunlight (significant night-times or far from sun)**
  - **Higher power levels & durations**
  - **Repeated or extended visits to same place (a base vs. Apollo sorties)**
- **Related System Applications can be "roadmapped" together:**

• **Lunar, Mars nuclear surface power**	**10's kWe**
• **NEP for outer planets science missions**	**100's kWe**
• **SEP for near-earth tugs**	**500-2,000 kWe**
• **NEP for human Mars missions**	**6,000+ kWe**

- **Related constituent technologies can be also mapped:**
  - **Reactor fuels, materials, power conversion, radiators, electric thrusters, … etc.**
- **References for requirements, end-point systems to be "blueprinted":**
  - **"Human Exploration Requirements for Future Nuclear Systems"; Draft 5 recently completed**
  - **Architecture & System studies underway**
- **Related activity underway to "roadmap" low power NEP to high power commissioned by Gary Martin (Code M) and Ray Taylor (NSI)**

Space Nuclear Roadmap

Goal: **Chart a unified space fission power and propulsion vision for the agency's next 2 decades of exploration**

Objectives:

- **Identify desired system/concepts and requirements**
- **Identify primary technology and infrastructure options, pros & cons**
- **Assess cross-applicable technology options and common infrastructure options**
- **Develop a roadmap that can link technology and infrastructure developments, downselects, and system developments leading to desirable missions**

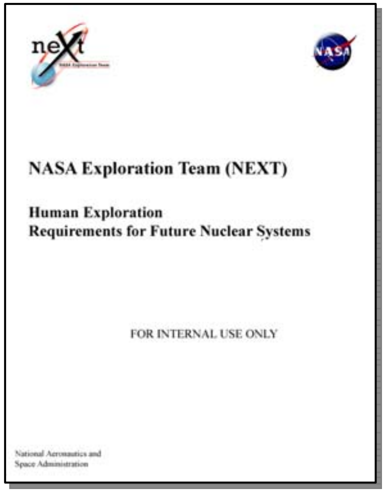
Groundrules:

- **Strategy should address projected robotic and human needs of the agency over the next two decades**
- **An early robotic science mission in the 2010 timeframe will pathfind the program**
- **Resulting fission systems should enable new mission capabilities relative to non-fission approaches (or why bother?)**
- **Technology and infrastructure approaches should be mature enough to support IOC's w/ fair degree of confidence**
- **System Requirements come from:**
  - **Robotic: Recent NSI studies**
  - **Human: "NExT Human Exploration Requirements for Future Nuclear Systems"**

Contents

- Roadmap Objectives
- NExT Requirements Document
- Human NEP Requirements
- Human Surface Power Requirements

Background


NASA Exploration Team (NEXT)

Human Exploration
Requirements for Future Nuclear Systems

FOR INTERNAL USE ONLY

National Aeronautics and
Space Administration

Document Title:

"NEXT Human Exploration Requirements for Future Nuclear Systems",

Draft 5, 9/29/02

Purpose: "This document shall serve to consolidate and to communicate current needs and requirements for nuclear systems and technologies in support of advanced human exploration missions." (Section 1.1)

Objective: Influence ongoing technology programs, in particular NSI, to address human nuclear needs

Out-of-Scope: "Nuclear needs and requirements for robotic exploratory missions are explicitly considered out-of-scope for this document, as this issue is being actively and extensively pursued elsewhere within the agency." (1.2)

Requirements Background, Cont.

Caveats: "current best understanding… subject to future change" (start of a living document - not carved in stone) (1.2)

- Not intended to include detailed DRM descriptions (other document) (1.2)
- Compromise in mission approach: Started w/ rigorous linkage to single architectural scenario - ended up blending different approachs
- Compromise in "Level": First out of gate (w/ SLI) - includes some mixing of different level requirements (mission, system, technology)
- Compromise between Requirements Doc. And White Paper (to communicate and rationalize need)
- Does focus on two important applications (see below).
- Does not specify constituent technologies.
- Does not specify internal system design or implementation.

Requirements Background, Cont.

***Scope (Section 2.2-2.4*)**:**

- **Current Most Immediate Interest:application to "First Wave" of advanced human missions beyond LEO**
- **First Selection Criterion - Enabling Performance (or why bother with nuclear at all?)**
- **Second Selection Criterion - Near-Term Feasibility and Maturity (lower risk to achieve ~10-15 year implementation)**

Focussed Applications (Section 2.5):

- **NEP Missions for Humans and Cargo beyond Earth Orbit**
- **Fixed Surface Nuclear Reactor Power Systems for Moon, Mars, and Asteroids**

Contents

- Roadmap Objectives
- NExT Requirements Document
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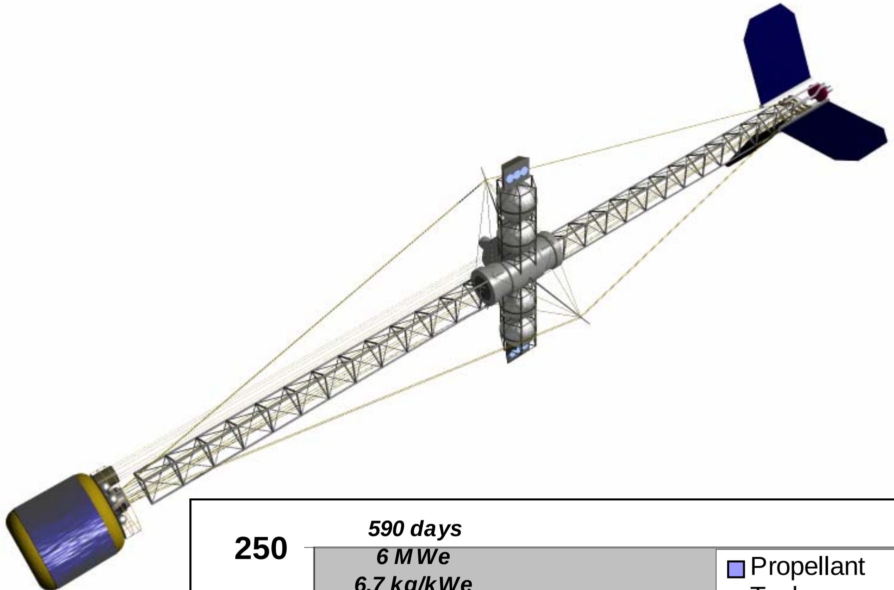
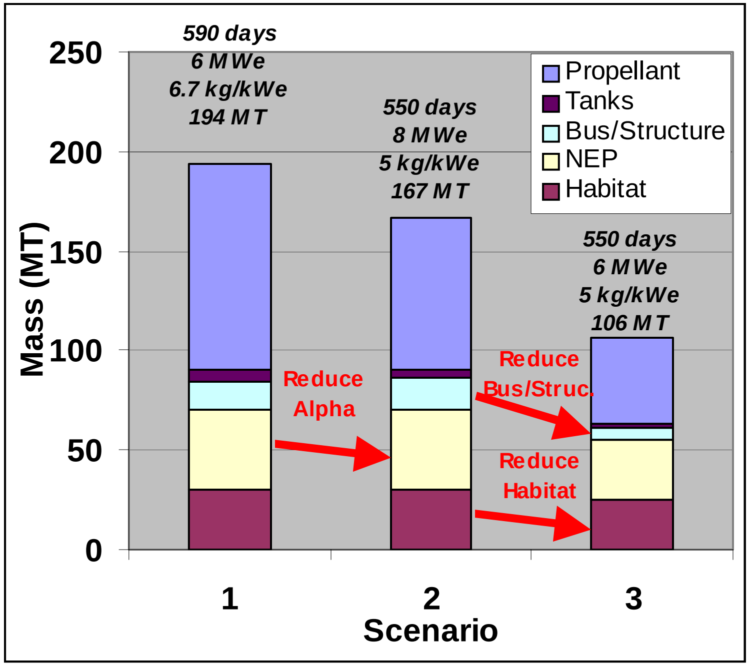
- Human Surface Power Requirements

Nuclear Electric Propulsion Advantages

- High propulsive performance
  - Captures energetically challenging Mars missions in all opportunities (for ~ same prop mass)
- High power availability
  - Robust power for crew, spacecraft systems (<1% of propulsion requirements)
- Potential technology convergence with advanced robotic exploration and NSI
  - Reactor, power conversion, thrusters
  - Human exploration nuclear power requirements ready to submit to Nuclear Space Initiative
- Potential convergence with technology development of surface nuclear power
  - Moon - > 14 days (non-polar) at fixed location
  - Mars – "long" stay
- *Allows Sustainable, Evolvable Exploration Capability*
  - High reactor energy content and low prop mass fraction allows high degree of vehicle reusability for Mars missions
  - Evolution of power/propulsion possible to even more ambitious missions

NEP Enables New Human Exploration Capabilities





- Nuclear Electric Propulsion enables new class of "medium surface stay" (few month) human Mars missions
  - Factor of ~3-5 longer stay and higher productivity than past opposition missions
  - Reduces infrastructure and technology to support multi-year conjunction missions
- ~1.5 year total mission
- 3 month stay at Mars
- 110-190 MT wet piloted NEP vehicle
- No LEO Nuclear Ops. via staging from earth-moon libration point
- Lander predeployed to high Mars orbit
- 6 MWe Nuclear Power
- 4000-7000 sec Isp Electric Propulsion
- 1.0 g artificial gravity aids
  - Crew health & safety
  - "Hardware" testing & certification
  - Power and fluid technology & design

Human NEP Function

Function: **The NEP system transports crew and/or cargo in support of human exploration missions. The NEP system also provides primary onboard power for habitat and vehicle subsystems. The NEP system may also provide primary attitude control during thrusting periods.**

Functional Allocation of NEP System Elements: **The NEP system shall be comprised of the following elements and subsystems:**

- ***Nuclear Power System*** **– provides conditioned electrical power. Includes reactor, shield, control, power conversion, heat rejection, and power management and distribution subsystems.**
- ***Electric Propulsion System*** **– converts electrical power into kinetic jet power and thrust. Includes electric thruster, power processing, thrust vector control, thermal, and propellant feed subsystems.**
- ***Tankage*** **– stores and thermally controls propellant.**
- ***Propellant*** **– serves as reaction mass for vehicle propulsion, and may vary with specific thuster type and specific impulse range.**
- ***Bus Module*** **– contains all remaining vehicle support and infrastructure subsystems such as structure, mechanisms, command and data handling (C&DH), attitude control, etc.**
- ***Payload Modules*** **– the mission specific payload, such as crew habitats, science instruments, landers, etc.**

Human NEP Design Goals and Objectives

- Enable *fast transits* to reduce crew exposure to harm.
- Allow demanding missions to be performed for *reduced launch mass*.
- Entail multi-mission savings through *reuse* and *low resupply mass*.
- Exhibit robust operation and *high reliability* over the design lifetime.
- Provide *enhanced abort* options for a variety of scenarios over broad segments of the mission.
- Enhance *mission flexibility* thru widened departure windows.
- Provide a *power rich* environment for crew subsystems.
- Perform primary vehicle *attitude control* during thrusting periods.
- Where practical, *common* nuclear power and electric propulsion *technologies* should be used across human and robotic system applications.
- Where practical, *common* subsystems and *components* should be used across human and robotic systems.
- While meeting requirements for performance and safety, the system should be based on technologies of *sufficient maturity* to ensure successful and cost-effective development.
- The system should *facilitate* ground *testing*, and minimize need for new or complex facilities.
- The system should *facilitate* integration, packaging, storage, and approval for *launch*.
- The system should feature *minimal deployment* needs, and be easily integrated on orbit.
- The system should *facilitate* stable *operation*, and autonomous, crew, or ground control.

NEP Survey

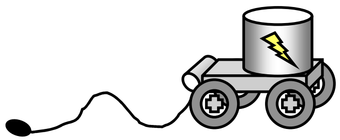
Table 1. Survey of Human Mars Missions Utilizing NEP.

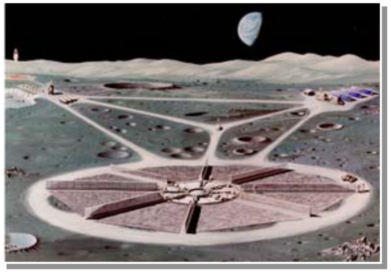
REFERENCE	Electrical Power (MWe)	Full Power Life (yr)	Number Missions	Specific Mass (kg/kWe)	Mission Class	Artificial Gravity?	Stay Time (days)	Total Mission Duration (days)	Initial Mass (metric tons)
DRM 2002	6	4	3	6.7	Opposition	Yes	90	590	194
DRM 2002	8	4	3	5	Opposition	Yes	90	550	167
Clark, 1994	8	5	2	11.1	Conjunction	No	550	960	283
George, 1992	10	2	1	7.3	Opposition	No	30	418	265
George, 1992	15	2	1	4.7	Opposition	No	30	367	285
George, 1993	10	2	1	7.3	Conjunction	No	626	899	286
McD/Doug, 92	10	-	-	10	Conjunction	Yes	489	887	576
Boeing, 1991	40	-	-	4	Conjunction	Yes	600	1090	561

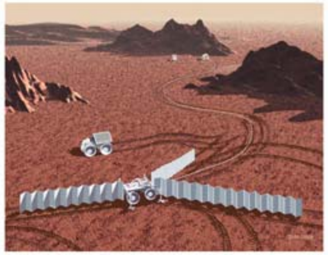
Requirements Summary
(Draft 5, 9/29/02)

Human NEP			Surface Power		
No.	Subject	Value	No.	Subject	Value
4.1	Power	6-20 MWe	6.1	Power	30, 60, 90 kWe
4.2	Life	4 yr	6.2	Life	15 yr
4.3	Specific Impulse	4000-7000 sec	6.3	(reserved)	---
4.4	Thruster Efficiency	>50%	6.4	(reserved)	---
4.5	Specific Mass	4-7 kg/kWe	6.5	Mass	2000 kg
4.6	Restartable	see spec.	6.6	Restartable	see spec.
4.7	Throttleable	see spec.	6.7	Throttleable	see spec.
4.8	Microgravity	see spec.	6.8	(reserved)	---
4.9	Artificial Gravity	see spec.	6.9	(reserved)	---
4.10	(reserved)	---	6.10	(reserved)	---
4.11	Reliability	see spec.	6.11	Reliability	see spec.
4.12	Earth Release	see spec.	6.12	Earth Release	see spec.
4.13	Dose to Crew	5 rem/yr	6.13	Dose to Crew	5 rem/yr
4.14	Fissile Material	U-235	6.14	Fissile Material	U-235
4.15	Initial Criticality	see spec.	6.15	Initial Criticality	see spec.
4.16	Inadvertent Criticality	see spec.	6.16	Inadvertent Criticality	see spec.
4.17	Disposal	see spec.	6.17	Disposal	see spec.
4.18	(reserved)	---	6.18	Lunar Environment	see spec.
4.19	(reserved)	---	6.19	Mars Environment	see spec.
4.20	(reserved)	---	6.20	Asteroid Environment	see spec.
4.21	Contamination	see spec.	6.21	Contamination	see spec.

Contents







- ***Function***: The nuclear surface power system provides primary power generation and distribution for human exploration missions to the surface of the Moon, Mars, and asteroids.

- ***Functional Allocation of Surface Power System Elements***: The nuclear surface power system shall be comprised of one or more of each of the following elements:

- ***Nuclear Power Element*** – provides unconditioned electrical power. Includes reactor, shield, control, power conversion, and heat rejection subsystems.

- ***Primary PMAD Element*** – provides control, regulation, and distribution of electrical power to (possibly remote) users.

- ***Deployment Element*** – provides all necessary deployment services between landing and initial startup. May include surface transport to a remote location, radiator deployment and other assembly, transport and connection of power distribution cables, and construction or excavation of in-situ radiation shielding.

Surface Nuclear Power Design Goals and Objectives

- Provide a *power rich* environment for human surface missions.
- Exhibit robust operation and *high reliability* over the design lifetime.
- Allow for a *low incremental* increase in crew *radiation dose* through time, distance, and shielding.
- Exhibit simple, stable *operation* capable of autonomous *control*.
- Design for ease of *deployment* with minimal required assembly or construction.
- Be compatible with the varied thermal and chemical *environments* of the Moon, Mars, and expected asteroid environment
- Exhibit modest *mass*.
- Exhibit modest packaged *volume*.
- Where practical, *common* nuclear power *technologies* should be used across human and robotic system applications.
- Where practical, *common* subsystems and *components* should be used across human and robotic systems.
- While meeting requirements for performance and safety, the system should be based on technologies of *sufficient maturity* to ensure successful and cost-effective development.
- The system should *facilitate* ground *testing*, and minimize need for new or complex facilities.
- The system should *facilitate* integration, packaging, storage, and approval for *launch*.

Surface Power Survey

Table 2. Survey of Power Needs for Human Surface Missions.

REFERENCE	Destination	Day Average Power (kWe)	Night Average Power (kWe)	Technology
First Lunar Outpost (Ref. 8)	Moon	13	9	PV/RFC
DRM 1.0; ISRU only (Ref. 9)	Mars	60	60	Nuclear
DRM 1.0; Habitat only (Ref. 9)	Mars	25	25	Nuclear
DRM 3.0 ; ISRU only (Ref. 10)	Mars	45	45	Nuclear
DRM 4.0; Habitat, Rovers (Ref. 11)	Mars	37	9	PV/Battery/RFC

Requirements Summary
(Draft 5, 9/29/02)

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4.19	(reserved)	---	6.19	Mars Environment	see spec.
4.20	(reserved)	---	6.20	Asteroid Environment	see spec.
4.21	Contamination	see spec.	6.21	Contamination	see spec.

Advanced Concept Analysis in Support of the Integrated Space Plan

Section 7.4

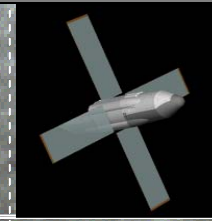
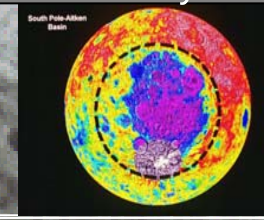
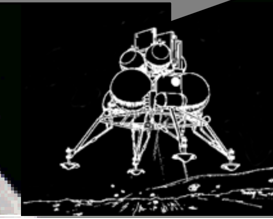
Lunar (EN) Precursor Mission

November 2002

Lunar (EN) Robotic Precursors to Future Human Missions

- **Lunar robotic precursor missions will acquire new data sets, demonstrate technologies and emplace infrastructure in advance of human missions**
- **No lunar robotic missions are currently planned by NASA**
  - NRC “New Frontiers” report has elevated the interest in a South Pole-Aitken Sample Return mission
  - ESA’s 2003 SMART-1 mission will map the lunar south pole demonstrate advanced technologies
  - Japan’s 2005 SELENE mission will acquire orbital data
- **Science data and technology precursor requirements could be filled with 2-3 focused orbiters and landers**
  - Polar mapping orbiter – south pole mapping and propulsion technology demonstration
  - Shadowed south pole crater lander – astrobiology, landing GN&C technologies, mobility, ISRU, survivability
  - South Pole-Aitken sample return – precursor to Mars sample return (sampling operations, sample protection, Earth targeting and entry

Lunar Precursors

	Planned / in development			Proposed		
	2003	2004	2005 / 2006	200x	200y	20zz
						
	LUNAR-A (Japan) - 2003	**SMART-1 (ESA)- March 2003**	**SELENE-A and SELENE-B (Japan) - 2005/6**	**Lunar Mapping Orbiter**	**Permanently Shadowed Crater Lander-Rover**	**South Pole-Aitken Sample Return**
SCIENCE	• Nearside and farside antipode penetrators • Seismometer • Heat flow probe • Accelerometer • 30 m resolution monochromatic camera (comm orbiter)	• Miniature high resolution camera (AMIE) • Near-infrared spectrometer (SIR) • X-ray spectrometer (D-CIXS) • Radio science experiment (RSIS)	• Surface Imaging • Far side gravitational mapping • X-ray spectrometer • Gamma ray spectrometer • Terrain camera • Laser altimeter • Radar sounder • Magnetometer • Plasma imager • Charged particle spectrometer	• 1 meter imaging of landing sites • Remote sensing of potential landing sites • Lunar year survey of lunar pole shadow and lighting • Global altimetry • Synthetic aperture radar mapper	• Vertical and lateral distribution of ice in permanently shadowed craters • Drilling • Ice abundance and composition measurement • Astrobiology	• Return of surface and subsurface samples • Landing site characterization
TECHNOLOGY	• High impact acceleration systems	• SEP flight test (Hall thruster) • Low-thrust spiral trajectory • 15-17 month weak stability boundary transfer • Advanced solar array • Deep space optical communications experiment • X- and Ka band telemetry experiment (KaTE)	SELENE-B: • Lunar soft lander • Precision landing • Hazard avoidance • Lunar night survival	• Solar electric propulsion • Low thrust trajectories • Advanced solar arrays • High bandwidth communications • Libration point (L1) transfer orbit	• Remote drilling • ISRU experiment (lunar water) • Surface mobility • Low temperature thermal control and survivability • System health monitoring • Robotics • Lander-based GN&C • Hazard avoidance • Precision landing	Mars Sample Return precursor: • Surface sample operations • Earth targeting • Earth entry • Sample protection • Autonomous rendezvous and docking (if required) • Electric propulsion (Earth return) • Farside communications relay • Farside radio science antenna

Robotic Missions Precursor Science Measurements

- **Prior lunar missions have created a large data set, <u>except in the lunar polar regions</u>**
- **Additional data required:**
  - Science
    - South Pole-Aitken returned samples
    - High resolution (<10 m) compositional mapping (some data will be generated by the SMART-1 and SELENE missions)
    - Multi-station, long-duration (10 year) seismic network
    - Far side gravity field mapping (may be addressed by SELENE-A)
    - High-resolution polar imagery and global topography (some data will be generated by the SMART-1 and SELENE-A missions)
  - Resources
    - Determine the nature and distribution of hydrogen concentrations at the lunar poles
    - Search for ice in the permanent shadows
  - Prepare for human exploration
    - High-resolution imagery (<1 m) -critical at highly shadowed polar sites
    - Geochemical and mineralogical mapping for site selection

Lunar (EN) Robotic Precursors Technology Demonstrations

- **Technologies can be demonstrated in Earth's Neighborhood which will decrease the risk of future human missions**
  - Electric propulsion, low-thrust trajectories, Libration point trajectories
  - Advanced solar arrays
  - High bandwidth, deep space communications
  - Automated drilling
  - Water extraction and in-situ resource utilization
  - Surface mobility, robotic sampling
  - Autonomous surface operations
  - Precision landing and hazard avoidance
  - Surface thermal control and thermal cycle survivability
  - Advanced system health monitoring
- **Lunar South Pole-Aitken Sample Return can also serve as a technology and operational precursor to Mars Sample Return**
  - Surface sampling operations
  - Autonomous rendezvous and docking
  - Sample preservation
  - Earth targeting
  - Earth entry

Backup Charts

- Requirements

Requirements to Other Programs – Lunar Robotic Precursors

1. **A lunar robotic precursor program shall <u>provide lunar environmental data sets</u> which pose the greatest risk to future human missions (references: LExSWG report, 1992, and M. Duke, 2002)**
   a. Orbital or landed missions shall map the landing operations area for humans in sufficient detail to identify hazards
   b. Orbital missions shall gather <1 meter resolution imagery of the highly shadowed polar sites
   c. Orbital missions shall provide geochemical and mineralogical mapping for site selection
   d. Orbital or landed missions shall measure the nature and distribution of hydrogen concentrations at the lunar poles
   e. Orbital or landed missions shall search for ice in the permanent shadows
   f. Samples shall be returned from the South Pole-Aitken Basin for study in Earth laboratories
   g. Orbital missions shall provide <10m resolution compositional mapping data
   h. Landed missions shall emplace a multi-station, long-duration (10 year) seismic network
   i. Orbital missions shall map the far side gravity field
   j. Orbital missions shall provide high-resolution polar imagery and global topography

2. **A lunar robotic precursor program shall <u>demonstrate key technologies</u> in order to reduce the risk to future human missions (reference: tbd)**
   a. Landers shall demonstrate terminal phase hazard avoidance and precision landing
   b. Landed experiments shall demonstrate water extraction, ISPP (propellant production) and ISCP (consumable production)
   c. Missions shall demonstrate electric propulsion, low-thrust trajectories, and Libration point trajectories
   d. Missions shall demonstrate advanced solar arrays
   e. Missions shall demonstrate high bandwidth, deep space communications
   f. Missions shall demonstrate automated drilling
   g. Missions shall demonstrate surface mobility
   h. Missions shall demonstrate autonomous surface operations
   i. Missions shall demonstrate surface thermal control and thermal cycle survivability
   j. Missions shall demonstrate advanced system health monitoring
   k. Missions shall demonstrate autonomous rendezvous and docking
   l. Missions shall demonstrate sample preservation
   m. Missions shall demonstrate Earth targeting
   n. Missions shall demonstrate Earth entry

Requirements to Other Programs – Lunar Robotic Precursors

3. **A lunar robotic precursor program shall <u>deliver infrastructure</u> necessary for the accomplishment of future human missions (reference: tbd)**
   a. Orbital missions shall emplace high data rate communication infrastructure for continuous communications support of future human missions
   b. Orbital and landed missions shall carry navigation infrastructure to support precision entry, descent and landing of future human missions.
   c. Landed missions shall emplace high capacity power systems

Advanced Concept Analysis in Support of the Integrated Space Plan

Section 7.5

Mars Precursor Missions

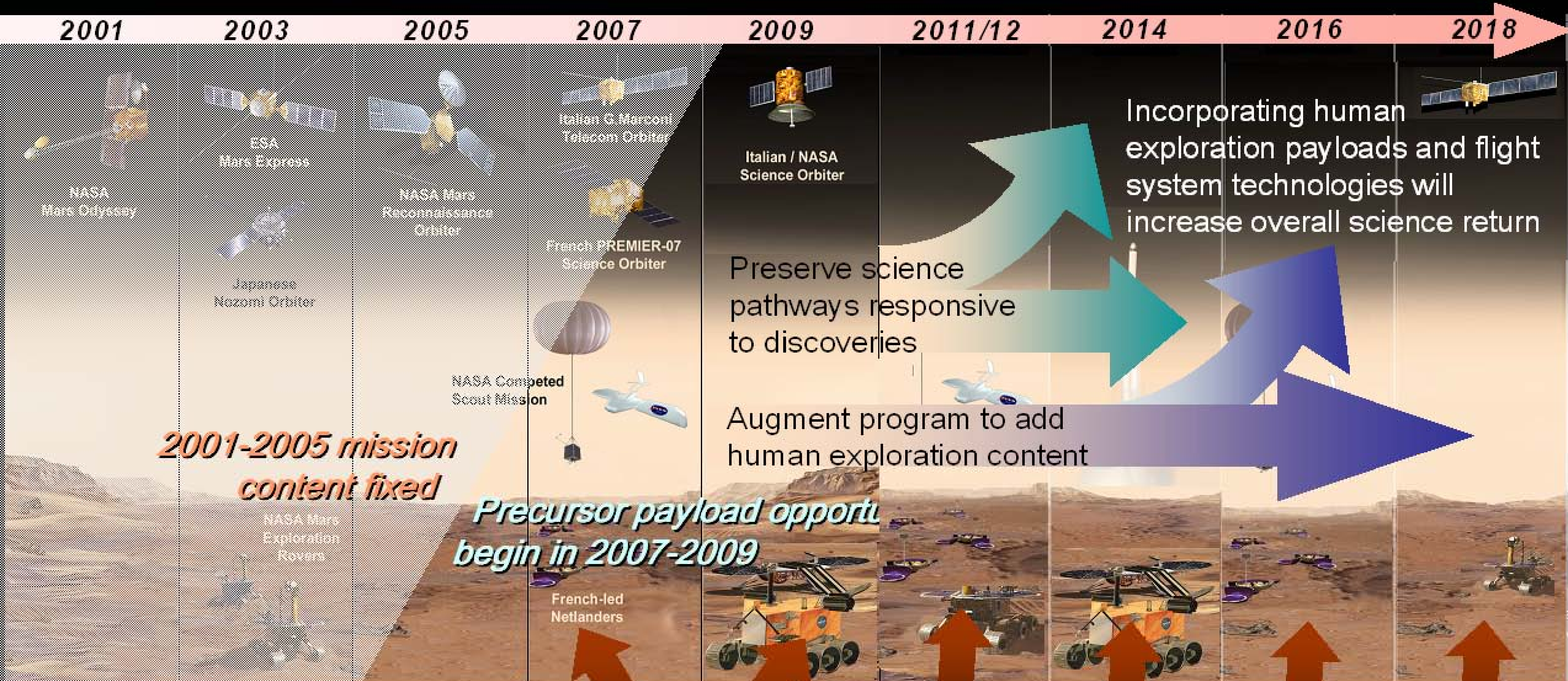
November 2002

Mars Robotic Program Augmentation for Future Human Missions

- **NASA's Mars Exploration Program (MEP) features a science-driven mix of orbital and landed missions**
- **Opportunities for human exploration experiments begin with the 2007-2009 opportunities.**
  - Scout missions
  - 2009 Mars Science Laboratory
- **Augmentation of the MEP is required to support human exploration precursor activities**
  - Development of miniaturized instruments to acquire highest priority data sets (surface radiation, soil properties, landing site surveys)
  - Development of enabling flight system technologies (hazard avoidance, precision landing, Mach 3 parachutes, mid-L/D aeroentry, nuclear surface power)
  - Acceleration of Mars Sample Return

Robotic Support of Human Exploration

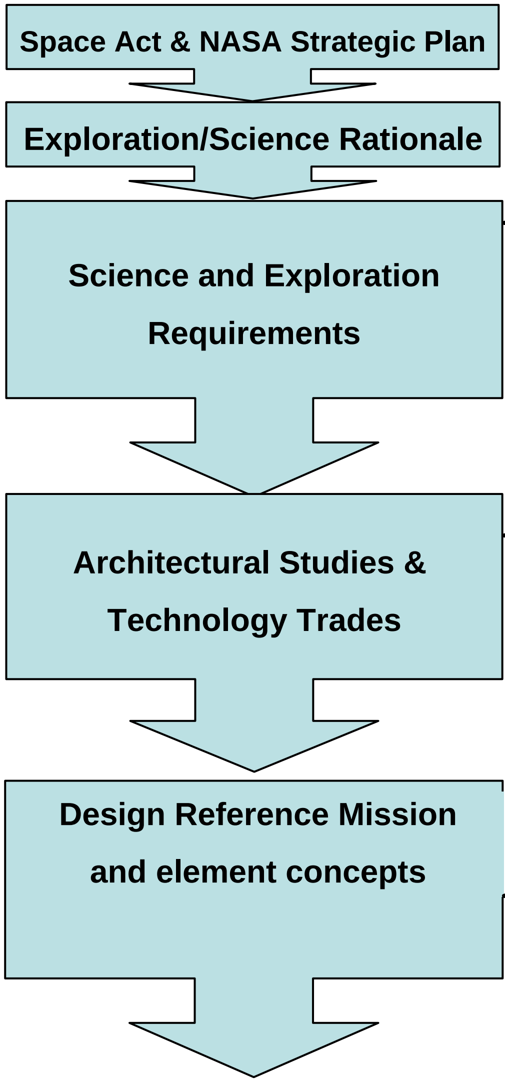
Launch Year



Mission Opportunities:	• 2007 Scout	• 2009 MSL	• 2011/12 Scout	• Mars Sample Return	•Site Survey Mission • 2016 Scout	• Next Generatio Science Lab • Comsat
	• Potential Dedicated 2007/9/12 Precursor Mission					
Potential Human Exploration Content :	• Hazard avoidance and precision landing • Advanced entry shapes (mid L/D) • High Mach parachute • Measure Cr VI, Ph and buffer capacity • Measure organic carbon • Measure surface radiation • Measure mechanical and adhesive properties of soil and dust • Deep drilling			• Sample return (required if organic carbon found by in-situ measurement) • Technology inheritance from 2009 mission	• Landing site characteri-zation • ISPP, ISCP • Water recovery	• Comm. and navigation infrastructure • Additional site survey

Backup Material

- Exploration Roadmap precursor mission product coordination



Earth's Neighborhood

- Earth's Neighborhood precursor science and exploration requirements
- Earth's Neighborhood technology requirements
  - new technology requirements to THREADS
  - precursor technology demos
- Earth's Neighborhood precursor mission concepts
- Experiment concepts

Mars (and beyond)

- Mars precursor science and exploration requirements (NRC, MEPAG)
- Mars technology requirements
  - MTP augmentation
  - new technology requirements to THREADS
  - precursor technology demos
- Mars precursor mission concepts
- Experiment concepts
- Opportunities to augment existing missions
- Stand-alone NEXT Mars precursor mission concept

Mars Precursor Science and Exploration Requirements

Requirements to Other Programs – Mars Robotic Program

1. **The Mars Exploration Program (Code S Robotic Mars missions) shall <u>provide Mars environmental data sets</u> which pose the greatest risk to future human missions (references: NRC "Safe on Mars" report, 2002 and MEPAG August 2001 report "Mars Exploration Program Scientific Goals, Objectives and Investigation Priorities")**
   a. Landed missions shall measure the radiation level (charged particles and neutrons) on the Martian surface (highest priority, ref: NRC "Safe on Mars" report, 2002)
   b. Orbital or landed missions shall map the landing operations area for humans in sufficient detail to identify hazards
   c. Landed missions shall measure certain mechanical and adhesive properties of Martian soil and dust
   d. Landed missions shall measure the concentrations of certain hazardous heavy metals (Cr VI)
   e. Landed missions shall measure soil Ph and buffer capacity
   f. Landed missions shall determine the presence and concentration of organic carbon

Mars Precursor Technology Demonstration Requirements

Requirements to Other Programs – Mars Robotic Program

1. **The Mars Exploration Program (Code S Robotic Mars missions) shall <u>demonstrate key technologies</u> in order to reduce the risk to future human missions (reference: MEPAG August 2001 report "Mars Exploration Program Scientific Goals, Objectives and Investigation Priorities")**
   a. Landers shall demonstrate terminal phase hazard avoidance and precision landing
   b. Entry systems shall demonstrate mid-L/D aeroentry/aerocapture vehicle flight
   c. Entry systems shall demonstrate high-Mach parachute deployment and performance
   d. Landed experiments shall demonstrate ISPP and ISCP (consumable production)
   e. Landed experiments shall demonstrate access to and extraction of water from soils, regolith, and groundwater systems
   f. Landed platforms shall demonstrate deep drilling

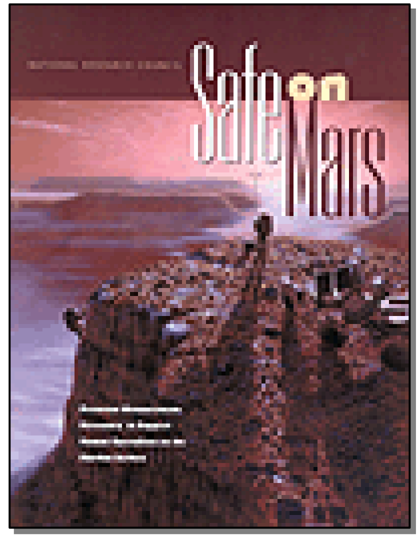
Requirements to Other Programs – Mars Robotic Program

2. **The Mars Exploration Program (Code S Robotic Mars missions) shall <u>deliver infrastructure</u> necessary for the accomplishment of future human missions (reference: MEPAG August 2001 report "Mars Exploration Program Scientific Goals, Objectives and Investigation Priorities")**
   a. Orbital missions shall emplace high data rate communication infrastructure for continuous communications support of future human missions
   b. Orbital and landed missions shall carry navigation infrastructure to support precision entry, descent and landing of future human missions.
   c. Landed missions shall emplace high capacity power systems

Mars Technology Program (MTP) Augmentation Requirements

Requirements to Other Programs – Mars Robotic Technology Program

1. **Augmentations to the Mars Technology Program (Code S Robotic Mars mission base and focused programs) <u>shall focus development efforts on technology programs that are mutually beneficial to robotic and human Mars missions</u>. (references: NRC "Safe on Mars" report, 2002 and MEPAG August 2001 report "Mars Exploration Program Scientific Goals, Objectives and Investigation Priorities")**
   a. The Mars Technology Program shall develop terminal phase hazard avoidance and precision landing systems
   b. The Mars Technology Program shall develop mid-L/D aeroentry/aerocapture systems
   c. The Mars Technology Program shall develop high-Mach parachute systems
   d. The Mars Technology Program shall develop human-scale rover systems
   e. The Mars Technology Program shall develop deep drilling systems
   f. The Mars Technology Program shall develop in-situ propellant and consumables production systems
   g. The Mars Technology Program shall develop systems to access to and extract water from soils, regolith, and groundwater systems
   h. The Mars Technology Program shall develop life detection instruments
   i. The Mars Technology Program shall develop ppm detectors for Cr VI, Cd, As
   j. The Mars Technology Program shall develop sub-ppb detectors for organic carbon



Safe on Mars – Precursor Measurements Necessary to Support Human Operations on the Martian Surface

National Research Council Report

(May 2002)

Summary Briefing

John Connolly/JSC

September 6, 2002

Summary Results

- **Highest priority is to measure radiation (charged particles and neutrons) on the Martian surface.**
  - “The committee recommends that this in-situ test be made a priority in the Mars program and conducted as soon as reasonable possible.”
- **Additionally:**
  - Map the landing operations area for humans in sufficient detail to identify hazards
  - Measure certain mechanical and adhesive properties of Martian soil and dust
  - Measure the concentrations of certain hazardous heavy metals (Cr VI)
  - Measure soil Ph and buffer capacity
  - Determine the presence and concentration of organic carbon
- **If the measurements recommended by the Committee can be performed in-situ on Mars surface, and if no organic carbon is detected above the life detection threshold, no sample return is required prior to the first human visit**

Background

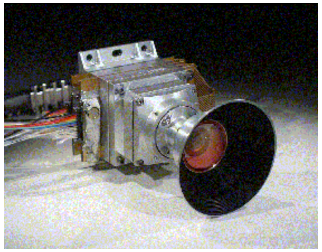
- **The NASA-sponsored Mars Exploration Program/Payload Analysis Group (MEPAG) produced a FY2000 document detailing the Martian environmental data sets required to prepare for human exploration of Mars**
- **The NRC was tasked by NASA to independently answer a similar question:**
  - Examine the role of robotic Mars exploration missions in assessing the risks to human exploration of Mars due to possible environmental, chemical and biological agents on the planet
  - Consider how the Mars robotic program can provide answers to mitigate these risks prior to a human mission
  - Document the measurements which <u>must</u> be made on Mars prior to the first human mission.
- **The new NRC report is a Mars-focused follow-on to the NRC's 1993 report "Scientific Prerequisites for the Human Exploration of Space"**
- **The committee presented only the requirements "essential" for NASA to pursue in order to mitigate possible hazards to the first humans to Mars**
- **The committee presented the results of this report to Orlando Figueroa, John Rummel, HQ Code M and S reps on April 29th, 2002**

NRC Study Recommendations

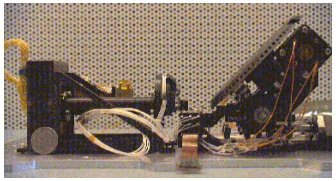
- **The recommendations were divided into three categories:**
  - Physical Environment Hazards
  - Chemical Environment Hazards
  - Potential Biological Environment Hazards
- **Additional comments were offered on two other topics:**
  - Rover Technologies and Robotics
  - Risk Standards
- **“The requirements identified in this report are indeed the only ones essential for NASA to pursue in order to mitigate potential hazards to the first human missions to Mars”**

Physical Environment Hazards

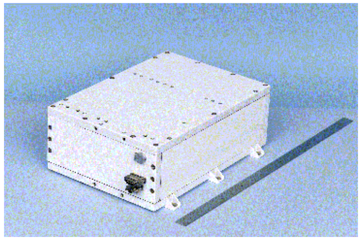
Recommendation	Recommended implementation
Map the 3-dimensional terrain morphology of landing operation zones for human missions.	Imaging from orbit
Determine rock size distribution and shape in-situ at the (human mission) landing site.	Surface in-situ measurement
Characterize the range of mechanical properties of the Martian regolith at the landing site or comparable terrain. Specifically, perform experiments to determine the regolith's aggregate strength, stability, bearing strength, bulk modulus, yield strength, and internal friction angle.	Surface in-situ measurement
Determine the adhesive properties of Martian soil and airborne dust.	Surface in-situ measurement
Perform experiments to measure the absorbed radiation dose in a tissue-equivalent material on Mars at a location representative of the expected (human mission) landing site. These experiments should be made a priority in the Mars Exploration Program.	Surface in-situ measurement



Mars Descent Imager. Built for 2001 lander mission



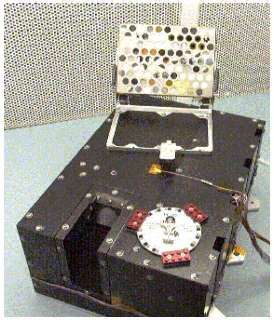
Mars Environmental Compatibility Assessment (MECA) experiment. Microscope built for 2001 lander mission



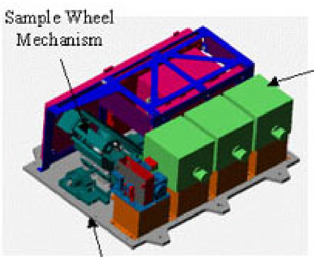
Mars Radiation Environment Experiment. Built for 2001 lander mission.

Chemical Environment Hazards

Recommendation	Recommended implementation
Conduct a precursor in-situ measurement to determine if hexavalent chromium is present in the Martian soil or airborne dust at more than 150 ppm. This measurement may take place anywhere on Mars where well-mixed, uniform airborne dust is present. If such a measurement is not possible, a sample of airborne dust and fine particles of Martian soil must be returned to earth for evaluation.	Surface in-situ measurement; returned sample if in-situ measure-ment is not possible
Measure the pH and buffer capacity of soil and airborne dust either via an in situ experiment or on Earth with returned samples.	Surface in-situ measurement; return of environmentally preserved sample if in-situ measure-ment is not possible



MECA wet laboratory. Built for 2001 lander



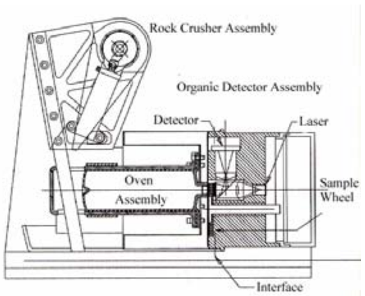
MOD/MECA/TEGA instrument proposed for 2003 lander.

Potential Biological Environment Hazards

Recommendation	Recommended implementation

- **Conduct a precursor in situ experiment at a location as reasonably close to the human mission landing sites as possible to determine if organic carbon is present.**
  - Measure materials from the surface and down to a depth to which astronauts may be exposed.
  - If no measurement technique can be used to determine if organic carbon is present above the life detection threshold (to be set by NASA, but 0.1 ppb example quoted), or if organic carbon is detected above that threshold, a sample should be returned to Earth for characterization prior to sending humans to Mars.
    - If experiments determine that organic carbon is present in concentrations greater than the life detection threshold the subsurface soil should be considered a toxic hazard until proven otherwise
    - NASA must then determine which compounds constitute the organic carbon by returning a sample from that specific location to Earth

Surface in-situ measurement; returned sample if in-situ measurement is not possible or if organic carbon is detected



Mars Organic Detector instrument selected for 2003 lander (1999). Cancelled following MPL failure.

Programmatic Topics

- **Rover Technologies and Robotics**
  - NASA's current focus on small, slow robotic rovers with short lifetimes and modest power supplies does not provide an adequate research base for the development of the rovers needed for the human exploration of Mars
    - The engineering knowledge being gained from the science rover experience will not scale up nor will it easily apply to human assistant rovers or larger human transport rovers

- Risk Standards
  - Because NASA has not allocated risk factors and reliability requirements for missions beyond Earth orbit, it should establish risk standards necessary to provide preliminary guidance to Mars mission planners and hardware designers.
- Technology Assumptions
  - Static discharge system
  - Filtration systems
  - Humidification systems
- "Press Ahead"
  - "The Committee believes that, even should a sample be required because organic carbon has been found, a baseline plan for a mission to Mars and even hardware development may still proceed under the assumption that a sample return will not find anything significant enough with regard to Martian biology to invalidate the baseline mission plan."

Sample Return ?

- **Is it necessary to return a Martian soil and/or airborne dust sample to Earth prior to the first human mission to Mars to assure astronaut health and safety?**
  - If the measurements recommended by this report can be performed in-situ on Mars surface, **and** if no organic carbon is detected above the life detection threshold, no sample return is required prior to the first human visit
  - If a precursor in-situ organic carbon experiment indicates the presence of organic carbon on Mars above the life detection threshold, a sample must be returned to Earth from the location and depth where the organic carbon is discovered if no suitable life-form confirmation technologies are available

Map to MEPAG (1)

MEPAG	NRC

GOAL IV: PREPARE FOR HUMAN EXPLORATION

A. Objective: Acquire Martian environmental data sets

1. Investigation: Determine the radiation environment at the Martian surface and the shielding properties of the Martian atmosphere.

Measurements

a. Measure charged particle spectra, at the surface and in orbit, accumulated absorbed dose and dose rate in tissue as a function of time over time, particulary at solar maximum and solar minimum.

b. Determine the radiation quality factor, determine the energy deposition spectrum from 0.1 keV/um to 1500 keV/um, and separate the contributions of protons, neutrons, and HZE particles to these quantities.

c. Measure neutron energy spectrum from 100 keV to 50 MeV or above. The ability to obtain information on the source of the neutrons (depth in soil, atmosphere) is a strongly desirable feature and therefore provisions for assessing direction of incidence of the neutrons is required.

d. Simultaneous surface and orbital measurements are required to determine the shielding component of the atmosphere..

e. Simultaneously measure the atmospheric pressure at the surface of Mars and the atmospheric dust loading.

f. Measure the natural radioactivity of the planet's surface materials (soil and rocks).

NRC:

- **Highest priority NRC recommendation**
  - Measure radiation at surface (charged particles and neutrons) in a tissue-equivalent material
- Energy spectrum not specified
- Simultaneous measurement from orbit inferred by the detailed description of transport code calibration?
- No requirement for atmospheric pressure or dust loading measurement

2. Investigation: Characterize the chemical and biological properties of the soil and dust.

Measurements

a. In situ determination of the toxic trace elements and mineral species including, but not limited to As, Be, Cd, Cl, F, and Pb.

b. Determine the toxic and genotoxic potential of dust and soil to biological cell analogs (enzymes, lipids, nucleic acids, etc), to identify reactivity of quasi-cellular systems from which the potential for acute toxicity for human explorers could be inferred.

c. Determine the chemical reactivities with a sensitivity of ppm (of particular interest are changes in the reactivities upon heating, with exposure to humidity, and with emphasis on the identification and volatility of the gases evolved) and, up to a maximum depth of 150 cm. Understand the solubility in water of martian soil (total weight loss after water is equilibrated with the soil), the before and after composition of the soil, and the composition of the aqueous phase in equilibrium with Martian soil.

d. Determine the depth of the superoxidation zone at several locations.

e. *In situ* sensors or analytical tools to determine the content of carbon and complex organic compounds in wind-blown dust, surface soil, and materials from secluded environments to a sensitivity of 10 (?) PPM.

f. Biohazard assessment.

g. Determine physical properties (size, shape, hardness, adhesion) of representative dust samples.

NRC:

- NRC recommends measurement of Chromium VI concentration
  - Report also cites As, Cd and other cancer-causing compounds
- NRC recommends measurement of organic carbon to a depth which humans will be exposed
- NRC recommends measuring the Ph and buffer capacity of Martian soil and dust
- No requirement to measure mechanical properties of dust EXCEPT adhesive properties

Map to MEPAG (2)

MEPAG	NRC
3. Investigation: Understand the distribution of accessible water in soils, regolith, and Martian groundwater systems. Requires geophysical investigations and subsurface drilling and in situ sample analysis. ***Measurements*** a. Map the Martian subsurface for ice and liquid water reservoirs.. b. Measure the vertical distribution (and ultimately comprehensive 3-dimensional subsurface maps) of permafrost, water ice and liquid water with a vertical resolution of ~ 10 m at selected sites. c. Determine the adsorbed and bound water content of soil samples from several provenances (air-borne dust, surface fines, sand dunes) with precision of +/- 10% down to levels of 0.1%. Determine the release temperature of water over the range 0oC-600oC.	• No requirement to measure water accessibility
4. Investigation: Measure atmospheric parameters and variations that affect atmospheric flight. Requires instrumented aeroentry shells or aerostats. ***Measurements*** a. Measure and record pressure versus altitude, and temperature for all Mars entry vehicles during the E/D/L phase of the mission. b. Measure basic surface meteorology: temperature, pressure, wind speed and direction at different sites. c. Monitor global weather patterns from orbit. d. Measure the frequency and magnitude of dust storms selected surface locations; characterize the processes active in these storms in terms of the associated wind speeds, pressure changes, atmospheric dust loading. e. Detect local atmospheric vorticity in terms of frequency of local "dust devil" development, quantity of dust lofted, associated wind speeds and pressure differentials.	• No requirement to measure atmospheric parameters or weather
5. Investigation: Determine electrical effects in the atmosphere. Requires experiments on a lander. ***Measurements*** a. Measure the electrical properties of dust in the atmosphere and observe the consequences of dust electrification. b. Determine the atmospheric electrification due to turbulent motion in dust clouds and dust storms; determine the population of atmospheric ions and whether there is a diurnal variation; determine what types of discharges occur on Mars. c. Determine the electrostatic charge state (magnitude, sign, and longevity of charges) for both aerosols and soil particles up to 100 microns. d. Determine Paschen curves (electrical breakdown in gases) for Mars as a function of temperature, pressure, wind, dust load in atmosphere, and season for meteorological use and as a tool for designing and safeguarding equipment for Mars exploration.	• No requirement to measure electrical properties of the atmosphere

Map to MEPAG (3)

MEPAG	NRC
6. Investigation: Measure the engineering properties of the Martian surface. Requires in-situ measurements at selected sites. ***Measurements*** a. Measure soil bearing strength and surface penetration resistance. b. Measure soil cohesion and angle of repose. c. Measure soil magnetic and electrostatic properties (adhesion potential, strength of adhesion and character of the charge). d. Measure surface temperature and touch temperature of surface features. e. Measure surface heat capacity. f. Measure surface albedo. g. Measure surface thermal conductivity/insulation properties. h. Determine the particle size and distribution, in the range 0.01 to 10.0 microns (0.01 to about 10 cm surface depth), with higher emphasis on particles much smaller than 1.0 micron. i. Determine the total columnar suspended load of dust in the atmosphere. j. Measure average surface sink temperature. k. Determine soil and dust chemical composition. l. Measure the conductivity, resistivity, dielectric constant, and piezoelectric properties of the subsurface to a depth of 10 m as a function of latitude, time of year, and geological environment. m. Measure subsurface distribution of ground ice.	• NRC recommends measuring the regolith's aggregate strength, stability, and sinkage properties, including bearing strength, bulk modulus, yield strength, and internal friction angle.
7. Investigation: Determine the radiation shielding properties of Martian regolith. Some of the in situ measured properties may be verified with a returned sample. ***Measurements*** a. Determine the radiation shielding characteristics of Martian regolith as a function of cover depth. Radiation sensors would be placed under various depth of regolith cover, and their readings correlated with an unburied sensor.	• No requirement to measure shielding properties of Martian regolith
8. Investigation: Measure the ability of Martian soil to support plant life. Requires in-situ measurements and process verification. ***Measurements*** a. Conduct in situ process verification of plant growth experiment through full plant growth, seed and re-germination cycle.	• No requirement to measure the ability to support plant life
9. Investigation: Characterize the topography, engineering properties, and other environmental characteristics of candidate outpost sites. Site certification for human outposts requires a set of data about the specific site that can best be performed by surface investigations. Specific measurements are listed in other investigations.	• NRC recommends mapping the 3-dimensional terrain morphology of landing operation zones • NRC recommends determining rock size distribution and shape in situ at the (human mission) landing site or on comparable terrain,
10. Investigation: Determine the fate of typical effluents from human activities (gases, biological materials) in the Martian surface environment. ***Measurements*** a. Determine the rate of reaction of typical materials exposed to the Martian environment. b. Monitor the rate of dispersion of analog materials in the Martian environment.	• No requirement to measure the ability to support plant life

Conclusions

- **The 2002 NRC study gives priority to the many measurements listed in the 2000 MEPAG document**

$$\text{NRC} \subset \text{MEPAG}$$

- **Characterizing the radiation at the surface of Mars continues to be the highest priority**
- **Organic carbon detection will determine if a sample return is needed prior to the first human mission**
- **Prior to MCO/MSL failures, a cooperative (Code S/U/M) program was in place to obtain these data sets**
- **Current Mars Exploration Program is not explicitly addressing these data needs**

Recommended Actions

- **In-situ radiation measurement at the earliest opportunity**
- **In-situ measurement of genotoxic elements and compounds (Cr VI, Cd, As)**
- **In-situ measurement of organic carbon**
- **Technology efforts required for:**
  - Instruments
    - Life detection
    - ppm detectors for Cr VI, Cd, As
    - ppm detectors for organic carbon
  - Human Systems
    - Static discharge system
    - Habitat filtration systems
    - Habitat humidification systems
    - Human-scale rovers

Launch Vehicle Capability Trade Study

Presented To:
Gary Martin

NASA Headquarters
April 25, 2003

Presentation Outline

Background and Study Overview (Charts 1 – 14)	Phil Sumrall
Launch Vehicles (Charts 15 – 20)	Phil Sumrall
Earth's Neighborhood Mission (Charts 21 – 32)	Jim Geffre
Accessible Planetary (Mars) Surface Mission (Charts 33 – 46)	Bret Drake
Wrap-up (Charts 47 – 49)	Phil Sumrall

Launch Vehicle Capability Trade Study

Background

- Doug Cooke requested on January 17, 2003 that a trade study of HLLV sizing for exploration missions be undertaken.
- Study should be MSFC-led and performed by an inter-center team, taking maximum advantage of existing data.
- Study should address delivery of complete assemblies, assembly on-orbit, fuel delivery, etc.
- Trades should consider cost, mission risk, and other figures of merit.
- Study scope and trade space should be planned to provide for a March, 2003 deliverable.

Launch Vehicle Capability Trade Study

Approach

- Two missions selected for study (data exists, represent wide scope of mission requirements):
  - Earth's Neighborhood (Sun-Earth L2 Telescope Mission)
  - Accessible Planetary (Mars) Surface (Human Mars Exploration Mission)
- Launch vehicle definitions will be taken from recently completed "Architecture Study Number One", ELVs, etc.
- Figures of Merit (FOM) will be derived for this study using NExT FOM as a point of departure.
- Independently assess the launch vehicle capabilities (performance, volume) against the reference missions to establish operational scenarios.
- Populate the FOM matrix to the extent possible within the study constraints.

Launch Vehicle Capability Trade Study

Products

- Assessment of EELV-Heavy and Heavy Lift Launch Vehicle (HLLV) capabilities with respect to two reference missions: Earth's Neighborhood and Accessible Planetary (Mars) Surface
- New FOM for ETO launch vehicles
- Assessment of gaps in current study and identification of future work to fill the gaps

Participants

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Ground Rules and Assumptions

- **Mission Requirements**
  - Earth's Neighborhood: 2 missions per year
  - Accessible Planetary (Mars) Surface : 1 mission every launch opportunity (26 months)
    - Utilize a 450 metric tons (mt) IMLEO Mars Mission
    - Assumes aggressive technology implementation
- **Launch Vehicle Assumptions**
  - EELV Heavy (Delta or Atlas)
  - Shuttle-Derived HLLV
  - Crew Transfer with OSP/EELV Heavy
- **All In-Space Mission Assembly Accomplished at ISS** (Assumed, not necessarily recommended)
- **Assess Launch Vehicle Trades thru Mission Assembly only**

Launch Vehicle Capability Assessment

Figures of Merit

Performance	Safety	Technology	Schedule	Cost
Provides the most flexibility for meeting future human exploration and development of space needs	Ensures crew safety and mission assembly completion	Entails lowest technology risk	Provides shortest assembly timeline and least schedule risk	Provides lowest initial and/or total life cycle costs
• Station utilization impact • Payload mass • Payload volume • Number of launches	• Launch reliability • Complexity of on-orbit assembly • Number of assembly flights • Number of supporting EVA's • Means of crew delivery	• Launch vehicle technologies required • Assembly and certification of complex interfaces (e.g. aerobrakes) • Architectural technology advancements required	• Launch rate • Launch processing • Test and checkout • On-orbit assembly • Launch window constraints • Launch reliability	• DDT&E & Recurring • Launch & Ground Operations • In-space Operations (Not quantified) • Additional Support Flights and Elements • Cost of unreliability • Synergy with other mission requirements

Launch Vehicle Capability Assessment

Performance

- Increased payload mass and volume and reduced number of launches is viewed as positive.
- Reduced number of assembly flights to the Station should have least impact on Station utilization.

Safety

- Increased launch reliability increases probability of mission success and crew safety.
- Increased number of assembly flights reduces probability of mission success and crew safety.
- Increased complexity of on-orbit assembly reduces probability of mission success.
- Increased number and complexity of supporting EVA's reduces crew safety.

Launch Vehicle Capability Assessment (cont.)

Technology

- Neither launch vehicle capability is viewed as having technology risks.

- Increased number of flights and complexity of assembly drives need for increased technology risk for mission assembly.

- The chosen Accessible Planetary (Mars) Surface Mission case assumes significant technology breakthroughs. Failure to achieve these technology breakthroughs increases other risks associated with reduced launch capabilities.

- Complexity of on-orbit assembly tasks and interfaces, e.g. aerobrakes, has a significant adverse impact on technology risk.

Launch Vehicle Capability Assessment (cont.)

Schedule

- Increased launch rates, launch processing, test and checkout, and on-orbit assembly increase schedule risks.
- Increased on-orbit assembly increases risk associated with launch window constraints.
- Reduced launch reliability increases schedule risk associated with mission assembly.

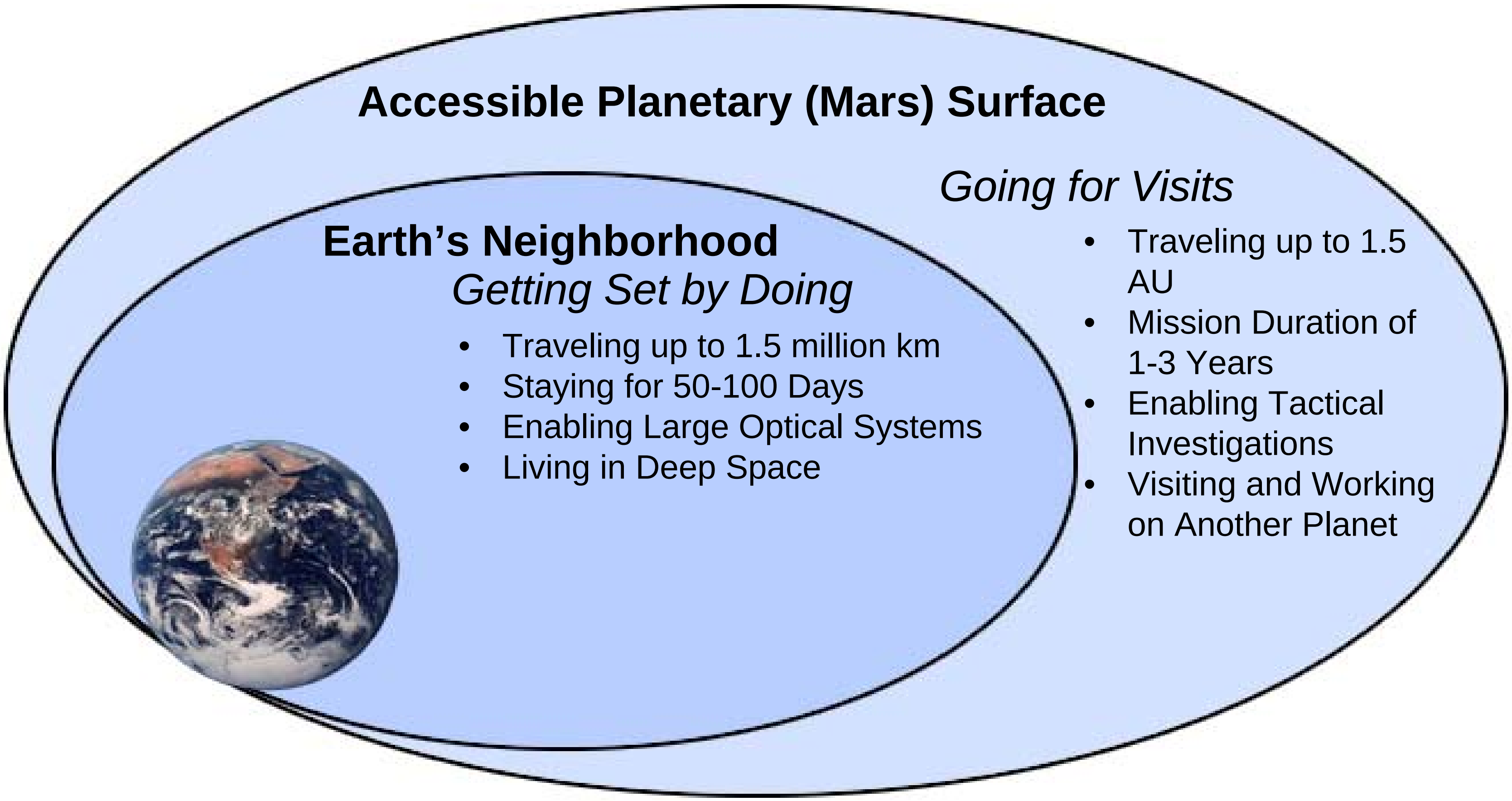
Costs

- DDT&E and Recurring
- Infrastructure: ground processing, production capacity, on-orbit assembly
- Support flights and elements
- Cost of unreliability
- Synergy with other mission launch requirements

On-Orbit Assembly Key Functional Requirements

- Provide capability to assemble, checkout, and maintain vehicle elements (either on the ground or in-space) prior to departure for exploration destinations
- Provide capability for housing transient mission crew, support crew, and mission equipment
- Provide capability to process exploration mission elements by supporting the following:
  - Vehicle mating/assembly and de-mating/disassembly
  - Space construction of elements
  - Element and integrated vehicle on-orbit check-out
  - Maintenance and servicing of elements
  - Provide housekeeping resources and services to elements and vehicles
  - Loading and unloading of mission equipment
- Provide capability to support on-orbit supply and re-supply of:
  - Life support consumables
  - Propellants
  - Mission equipment
- Provide debris protection for assembly elements and in-space vehicles while resident at the ISS

Mission Classes



Observations and Findings

Earth's Neighborhood Mission

- A heavy lift launch capability is favored by all Figures of Merit and is highly enhancing for this class of mission.
- Assessment of investment in on-orbit assembly vs heavy lift capability is needed.
- Number of launches of EELV-H to support Earth's Neighborhood is about the same as number of Heavy Lift launches needed to support the Accessible Planetary (Mars) Surface Mission.
- Investment costs of EELV-H borne by other mission applications.

Accessible Planetary (Mars) Surface Mission

- A heavy lift launch capability is enabling for this class of mission.
- Feasibility of using Station to support magnitude of on-orbit assembly highly uncertain.
- Feasibility of successfully assembling subassemblies into major elements such as aerobrakes, NEP, and habitats is highly uncertain.
- Risks and costs associated with unreliability is significant for launch rates associated with EELV-H vehicle class.

General

- Life cycle cost assessment incomplete for both mission classes and vehicle options.
- A vehicle trade study is needed to assess a range of vehicle and propulsion concepts to identify the preferred approach for a HLLV capability.

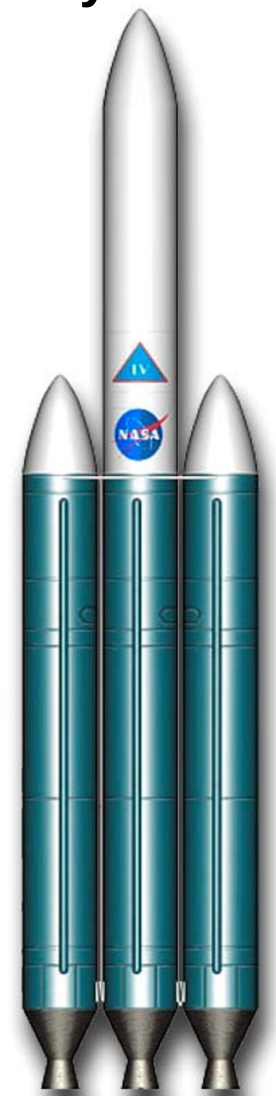
Heavy Lift Launch Vehicle (HLLV) Options

Shuttle-Derived HLLV Class

Shuttle-
Derived HLLV

EELV Heavy Class

Atlas V 552



Delta IV-H

Atlas V Heavy Launch Vehicle Configuration

Atlas V 552

Vehicle Configuration:

- Common Core Booster in Production
- Common Core Booster :
  - Lox RP-1
  - RD-180 engine
  - 933,370 lbf thrust (Vac)
  - I_{SP} 338 sec (Vac)
- Payload: 20.6 mt (45k lbm) to 185 km Circ @ 28.5°
  17.0 mt (37k lbm) to 460 km Circ @ 51.6°
- Payload Fairing: 17.7’ x 76.8’ (5.4m x 23.4m)

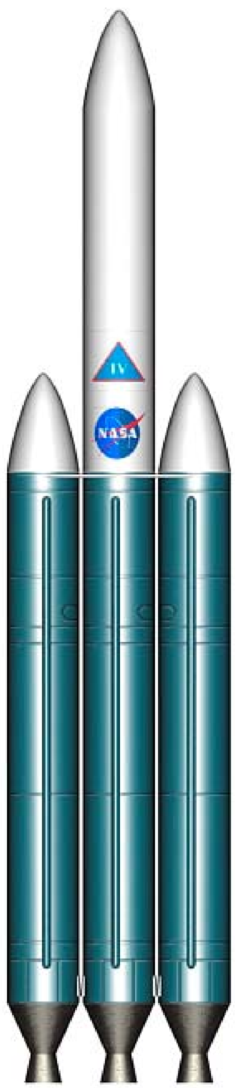
Upperstage:

- Pressure stabilized tanks
- Cryogenic RL-10A-4-2
  - 22,300 lbf thrust (Vac)
  - I_{SP} 450 (Vac)
- .021k mt (45,826 lbm) propellant loading
- Engine restart capability

Performance data limited to 6g’s, minor performance loss for 3g’s

Further analysis is required to better define the influence of various launch vehicle concepts with architectural performance, risk, schedule and cost.

Delta IV Heavy Launch Vehicle Configuration



Delta IV - H

Vehicle Configuration:

- Common Core Booster In Production
- Common Core Booster :
  - LH_2/ Lox
  - RS-68
  - 745,000 lbf thrust (Vac) ea booster
  - ISP 410 sec (Vac)
- Payload: 22.5 mt (50k lbm) to 185 km Circ @ 28.5°
  22.5 mt (50k lbm) to 460 km Circ @ 51.6°
- Payload Fairing:16.4’ x 65.0’ (5.0m x 19.8m)

Upperstage:

- RL-10B-2
  - LH_2/ Lox
  - 24,750 lbf thrust (Vac)
  - ISP 466 sec (Vac)
- .027k mt (60,000 lbm) propellant loading
- Engine restart capability

Performance data limited to 6g’s, minor performance loss for 3g’s

Further analysis is required to better define the influence of various launch vehicle concepts with architectural performance, risk, schedule and cost.

Shuttle-Derived HLLV Configuration

The vehicle shown above was used in this study as representative of the Shuttle-Derived HLLV Class of heavy lift vehicles.

Vehicle Characteristics

Cargo Only

Payload (56 x 278 km @ 28.5°)	93.5 mt (.206 mlbs)
Payload (56 x 460 km @ 51.6°)	85.0 mt 9.187 mlb
Gross Liftoff Mass	2.4k mt (5.4 mlb)
T/W @ Liftoff	1.40
Max Q	646 psf
Max Acceleration	3.8 g
Shroud Mass	N/A
Payload Fairing	25' X 90' (7.62m x 27.43m)

Booster (5-segment):

Propellants	HTPB
Ascent Propellant Mass	1.3k mt (2.9 mlb)
Burnout Mass	.195k mt (.430 mlb)
Separation Conditions	Mach= 4.8, Q= 17.0 psf, alt= 177 kft
Sea Level Thrust	3.33 mlb each
Sea Level Isp	265 sec

External Tank (SLWT w/ 5 ft stretch):

Propellants	LO2/LH2	
Ascent Propellant Mass	.762k mt (1.68 mlb)	
Burnout Mass	.063k mt (104.0 klb)	
Engines	3 SSME Engines (104%)	
Vacuum Thrust	492 klb ea	Vac Isp= 453 sec
Sea Level Thrust	397 klb ea	SL Isp = 365 sec

Further analysis is required to better define the influence of various launch vehicle concepts with architectural performance, risk, schedule and cost.

Exploration Launch Assumptions

- **Launch Vehicle Maximum Payload**
  - Delta IV-H: 22.5 mt (50k lbm) to 185 km Circ @ 28.5°
    22.5 mt (50k lbm) to 460 km Circ @ 51.6°
  - Atlas V 552: 20.6 mt (45k lbm) to 185 km Circ @ 28.5°
    17.0 mt (37k lbm) to 460 km Circ @ 51.6°
  - Shuttle-Derived HLLV: 93.5 mt (206k lbm) to 56 x 278 km Ellip @ 28.5°
    85.0 mt (187k lbm) to 56 x 460 km Ellip @ 51.6°
- **Launch Reliability**
  - EELV-H: 98%
  - Shuttle-Derived HLLV: 99%
- **Launch Cost**
  - EELV-H (Cargo): $140M
  - EELV-H (OSP): $300M
  - Shuttle-Derived HLLV: $800M
- **Other**
  - 70% launch vehicle packaging efficiency
  - One OSP support flight per 3 Cargo flights and one OSP flight per mission for mission crew positioning

Further analysis is required to better define the influence of various launch vehicle concepts with architectural performance, risk, schedule and cost.

Launch Vehicle Capability Trade Study Comparison Matrix

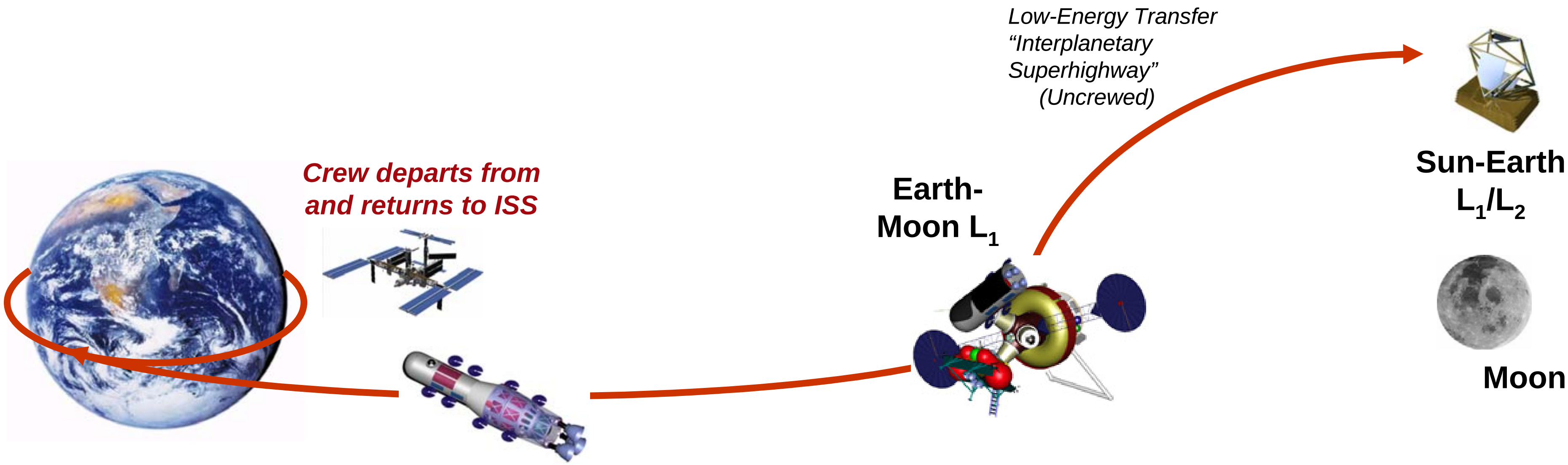
Concept Configuration	Concept Description	Performance (Destination)	Pros	Cons
Shuttle-Derived HLLV 	• 1.5 Stage Vehicle • Sidemount Payload Carrier - 25'x 90' Pld envelope • ET LOX/LH2 Core - 5 ft. stretch LH2 tank • 3 SSME Engines on Carrier • 2 Five-Segment SRBs • Launch Cost $800M	93.5 mt (206k lbm) (56 x 278 km Ellip.. @28.5°) 85.0 mt (187k lbm) (56 x 460 km Ellip.. @51.6°)	• Uses ET Design Heritage/Facilities • Uses Existing Engines • Greater Payload Delivery Capability - Mass - Volume • SRBs Recovered	• Higher Unit Cost • SSME Expended • Ground Processing Concerns with Solids • Higher Dollars per Pound to Orbit • Not an Existing LV, will Require DDT&E • Mods Required to VAB and SRB Facilities • Conflict with Ongoing Shuttle Processing
Delta IV-H 	• 2.5 Stage Vehicle • 5 meter Payload Fairing • RL10B-2 Second Stage Eng. • In-line Payload Fairing • LOX/LH2 Booster Core • 2 Additional Strap-on LRBs • Launch Cost $140M to $170M	22.5 mt (50k lbm)* (185 km Circ.. @28.5°) 22.5 mt (50k lbm) (460 km Circ.. @51.6°)	• Existing Common Core Booster • Uses Existing Facilities • Lower Unit Cost • Has Growth Potential • Lower Dollars per Pound to Orbit • Safer Handling of Boosters	• Less Payload Delivery Capability - Mass - Volume • Several Launches Required for Missions • # of Launches becomes a Design Driver • More Infrastructure for High Launch Rates
Atlas V 552 	• 2.5 Stage Vehicle • 5 meter Payload Fairing • 2-engine Centaur 2nd Stage • In-line Payload Fairing • LOX/RP Booster Core • 5 Strap-on SRBs •Launch Cost $110M	20.6 mt (45k lbm) (185 km Circ.. @28.5°) 17.0 mt (37k lbm) (460 km Circ.. @51.6°)	• Existing Common Core Booster • Uses Existing Facilities • Lower Unit Cost • Has Growth Potential • Lower Dollars per Pound to Orbit	• Less Payload Delivery Capability - Mass - Volume • Several Launches Required for Missions • # of Launches becomes a Design Driver • More Infrastructure for High Launch Rates • Ground Processing Concerns with Solids

* A loft requirement to establish a line-of-sight with the tracking station results in a decrease in performance at lower altitudes.

Further analysis is required to better define the influence of various launch vehicle concepts with architectural performance, risk, schedule and cost.

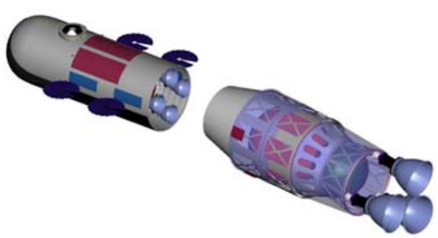
Launch Vehicle Capability Trade Study

Earth's Neighborhood Mission Description



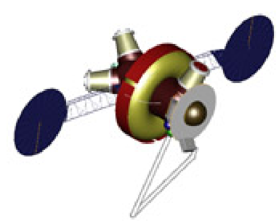
Architecture

Elements



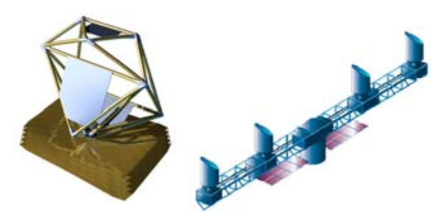
Exploration Transfer Vehicle & High Energy Injection Stage

- Transports crew and cargo between ISS and Lunar L_1
- Nominal return to ISS with contingency direct Earth return



L_1 Gateway Outpost

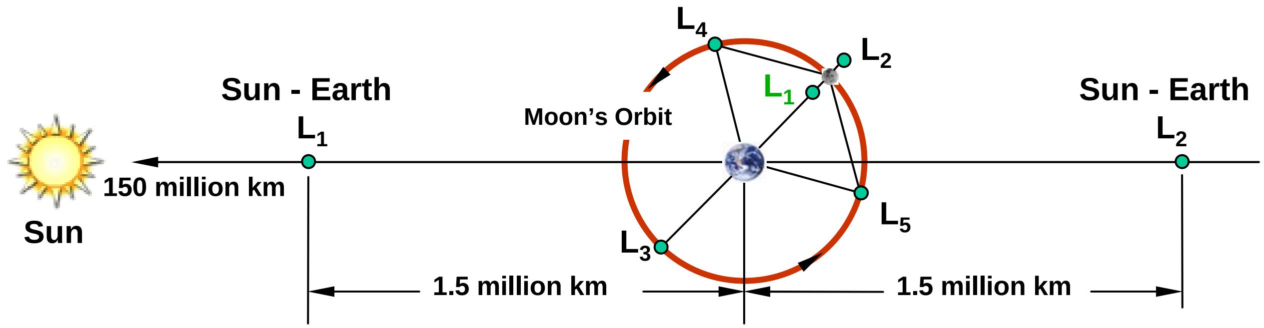
- "Gateway" to the Lunar surface
- Outpost for staging missions to Moon, Mars and telescope construction

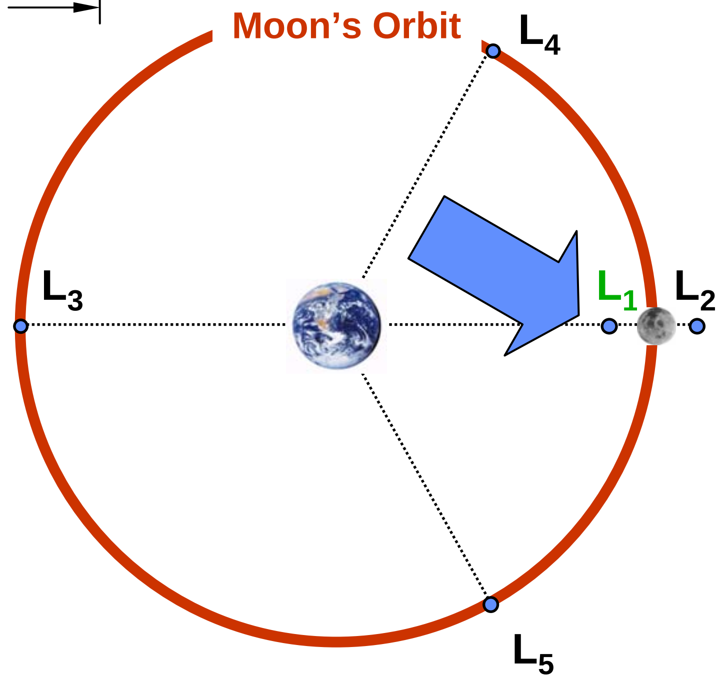


Astronomical Instruments

- Advanced science platforms to be assembled and/or serviced by humans and robots
- Platforms remotely deployed to Sun-Earth L_1/L_2

Earth-Moon L_1 Characteristics





Environment

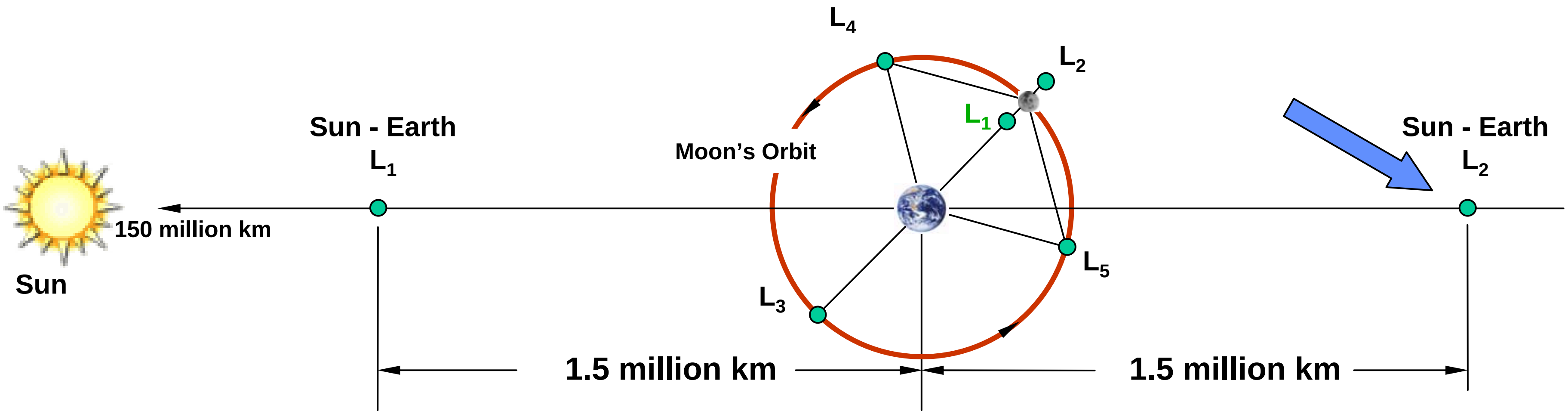
- No orbital debris. Weak instability of L_1 will actively remove artificially created debris.
- Nearly continuous solar energy (>99.91%), no thermal cycling
- Nearly continuous full sky viewing (>99.96%)
- True deep space radiation, thermal environment, zero-g
- Continuous view of Lunar nearside, Earth, terrestrial magnetosphere

Operations

- Excellent transportation node for lunar surface, particularly polar regions
- Four days from Earth, two days from Moon (high thrust)
- Low-energy access to/from Solar Libration Points

	Distance from Earth's Center (km)	Distance from Moon's Center (km)
L_1	326740	57660
L_2	449748	65348
L_3	380556	764956
L_4	384400	384400
L_5	384400	384400

Sun-Earth L2 Characteristics



Environment

- No orbital debris. Weak instability of L_2 will actively remove artificially created debris.
- Continuous solar energy, no thermal cycling
- Continuous full sky viewing
- True deep space radiation, thermal environment, zero-g

Operations

- Identified as advantageous location for advanced astronomical facilities
- Eighteen days from Earth (high thrust)
- Low-energy access to/from Lunar Libration Points

Earth's Neighborhood Mission

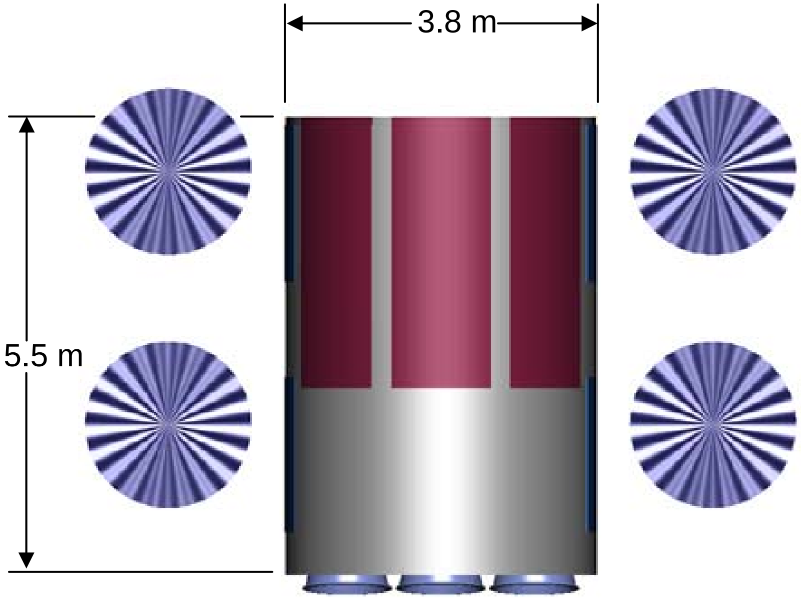
Ground Rules and Assumptions

- Science objectives and precursor requirements will be optimally integrated to meet the overall program science strategy
- Support multiple destinations
  - Sun-Earth L1/L2 (operational location for astronomical instruments)
- Serve as a test bed for future exploration
  - Technologies
  - Operations
  - Systems
- Crew size of 6
- Use ISS as a low-Earth orbit assembly and staging location
- Assemble, checkout, and maintain astronomical observatories in-space

Architecture Elements

Exploration Transfer Vehicle (XTV)

XTV Service Module

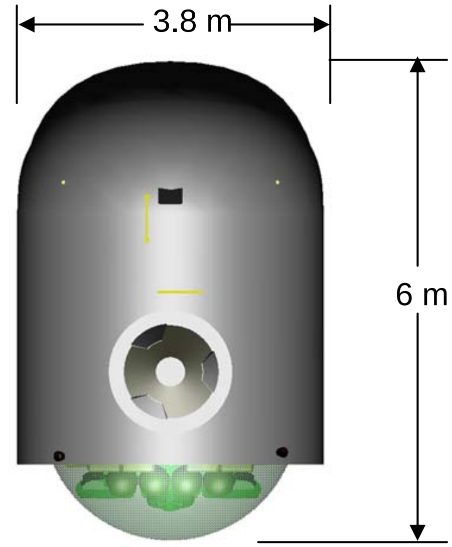


Launch Mass: 2,810 kg (6196 lbm)(dry) / 16,295 kg (35.9k lbm) (wet)
Special Launch Considerations: Contains cryo propellants (O2/CH4)

# of Launches: Once per Mission

Total ΔV 2,405 m/s

XTV Crew Module

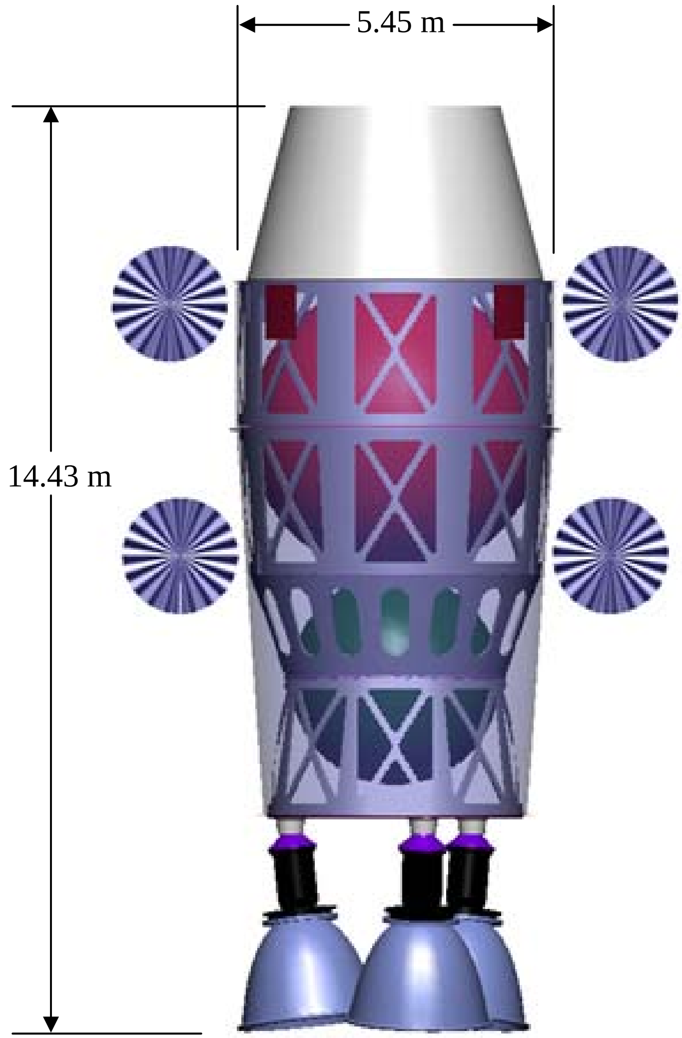


Launch Mass: 10,150 kg (2.3k lbm)

Special Launch Considerations: None

# of Launches: 1 (remains docked to ISS)

Architecture Elements



XTV Injection Stage

Insertion Orbit: ~400 km circ x 51.6°

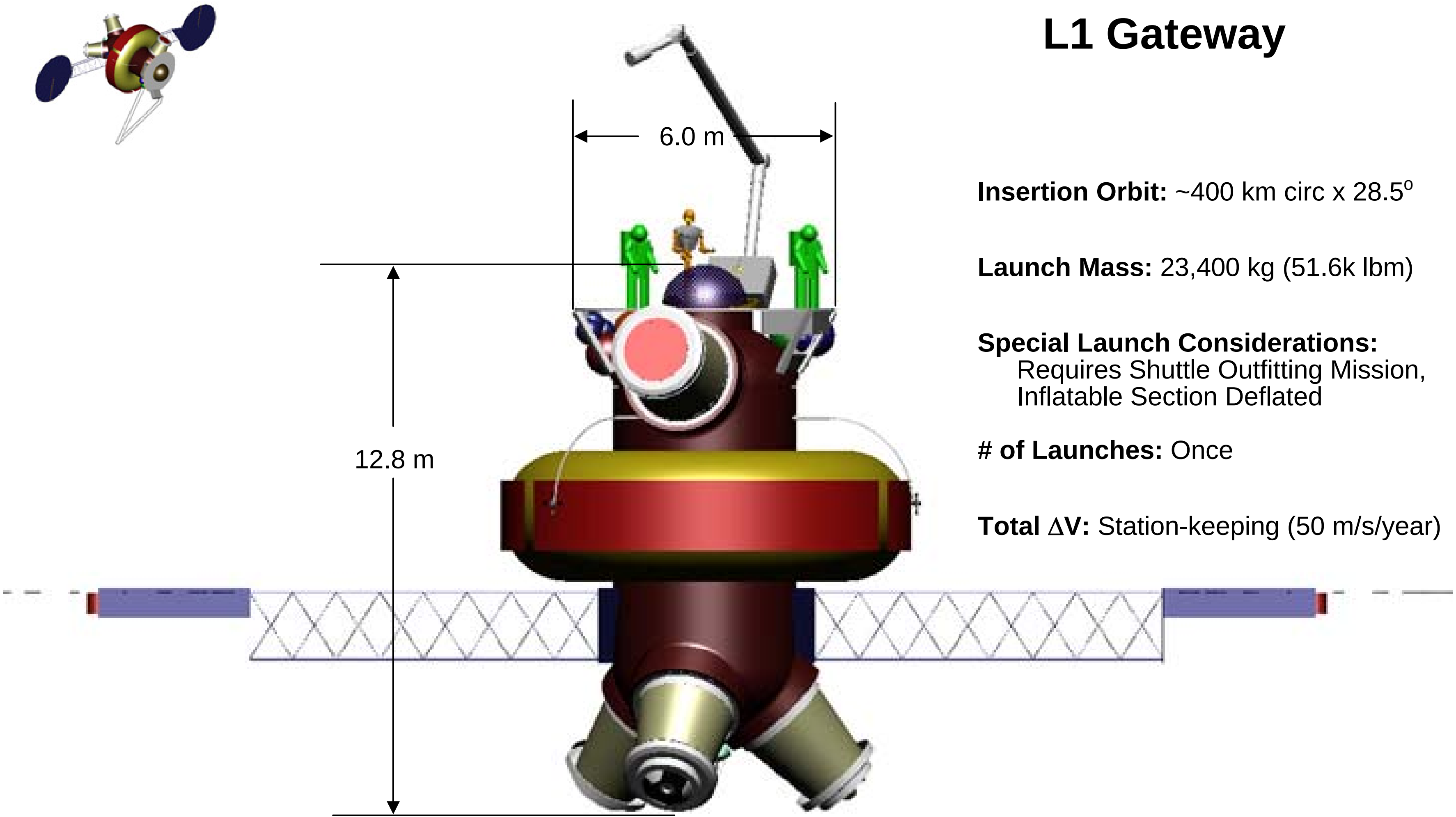
Launch Mass: 6,910 kg (15.2k lbm)(dry) / 44,095 kg (97k lbm) (wet)

Special Launch Considerations: Contains cryo propellants (O2/H2)

# of Launches: Once per Mission

Total ΔV: 3,120 m/s

Architecture Elements



L1 Gateway

Insertion Orbit: ~400 km circ x 28.5^{o}

Launch Mass: 23,400 kg (51.6k lbm)

Special Launch Considerations:
Requires Shuttle Outfitting Mission, Inflatable Section Deflated

# of Launches: Once

Total ΔV: Station-keeping (50 m/s/year)

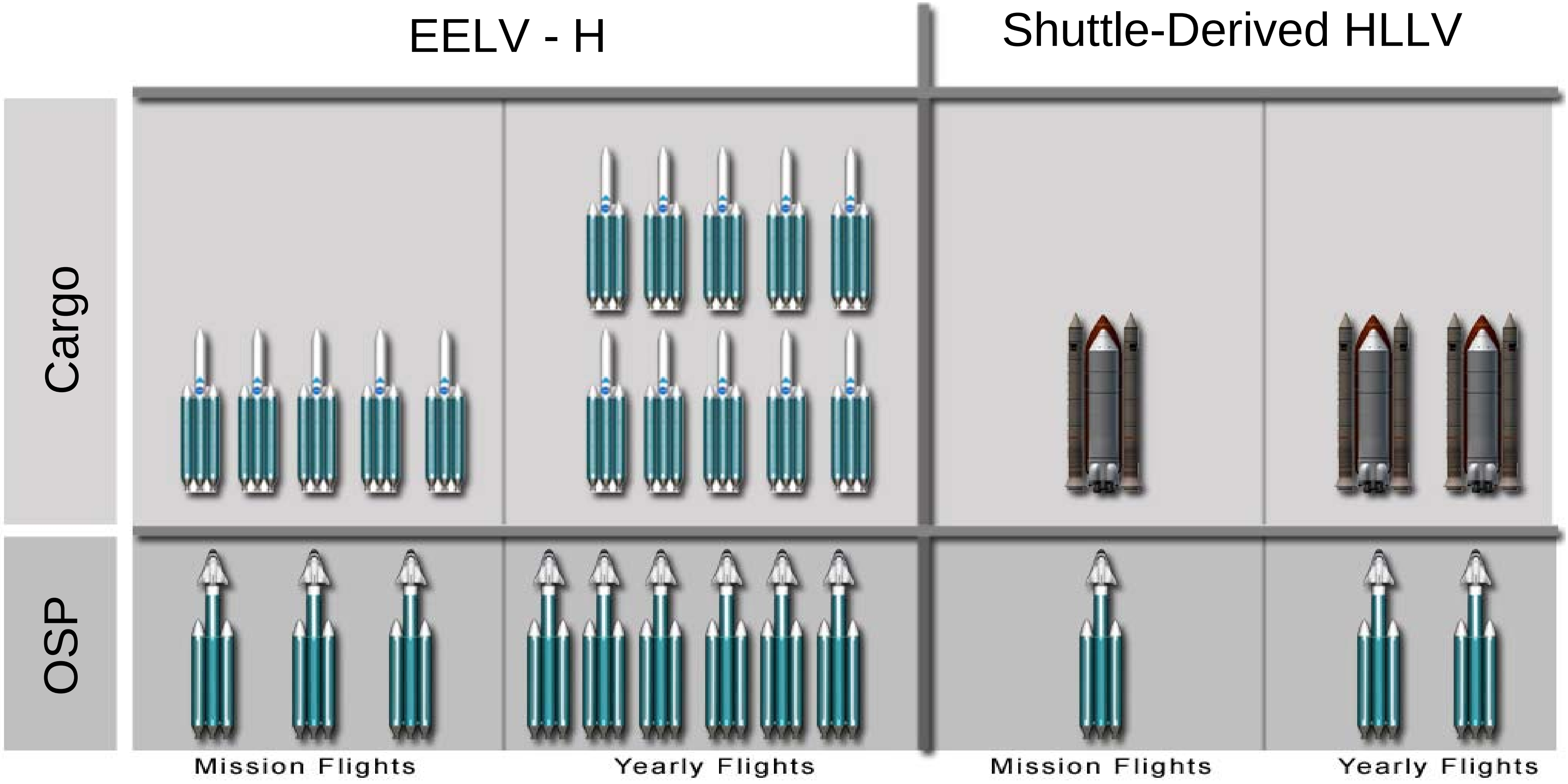
Earth's Neighborhood Mission

Mission Launch Summary	EELV-H	Shuttle-Derived HLLV	EELV-H	Shuttle-Derived HLLV
	Annual		Per Mission	
Launch Vehicle Useful Payload*	15,875 kg (35,004 lbm)	61,670 kg (135,982 lbm)	15,875 kg (35,004 lbm)	61,670 kg (135,982 lbm)
Flight Rate (Cargo/OSP/Total)**	10 / 6 / 16	2 / 2 / 4	5 / 3 / 8	1 / 1 / 2
Probability of Launch Success	72%	94%	85%	97%
Recurring Launch Cost	$3.20B	$2.20B	$1.60B	$1.10B

Notes:

Assumes 2 Earth's Neighborhood missions per year
Support flights assume launch by EELV + OSP
* Includes 70% launch packaging efficiency
** One OSP support flight assumed for every 3 cargo flights plus one OSP flight per mission to position mission crew

Earth's Neighborhood Mission



Summary FOM Assessment

	Perf	Safety	Technology	Schedule	Costs*
EELV Heavy	-	-	-	-	-
Shuttle-Derived HLLV	+	+	+	+	+

*Annual recurring launch costs only. Further assessment of DDT&E, Infrastructure, and Ops costs are required.

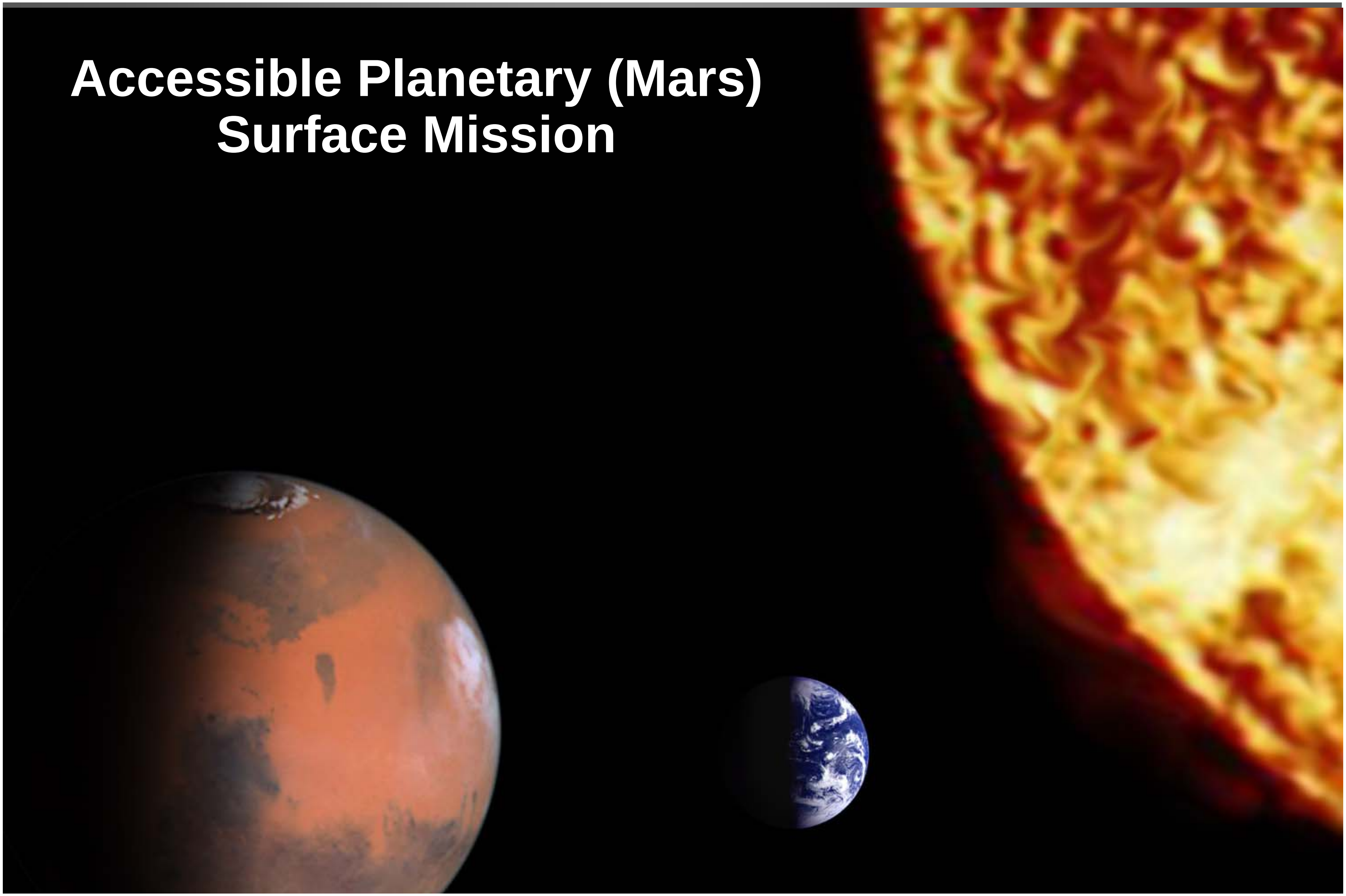
ADVANTAGE		DISADVANTAGE	
+	Minor	-	Minor
++	Moderate	--	Moderate
+++	Significant	---	Significant

Further analysis is required to better define the influence of various launch vehicle concepts with architectural performance, risk, schedule and cost.

Summary FOM Assessment

- **Performance:** Shuttle-Derived HLLV capability eliminates on-orbit assembly, thereby improving probability of mission success.
- **Safety:** Elimination of on-orbit assembly EVA with Shuttle-Derived HLLV reduces crew risk.
- **Technology**: No requirement for advanced technology associated with on-orbit assembly with Shuttle-Derived HLLV.
- **Schedule:** Schedule time associated with assembly is eliminated with Shuttle-Derived HLLV.
- **Costs:** Requirement for more OSP flights to support EELV-H makes it the most costly approach.

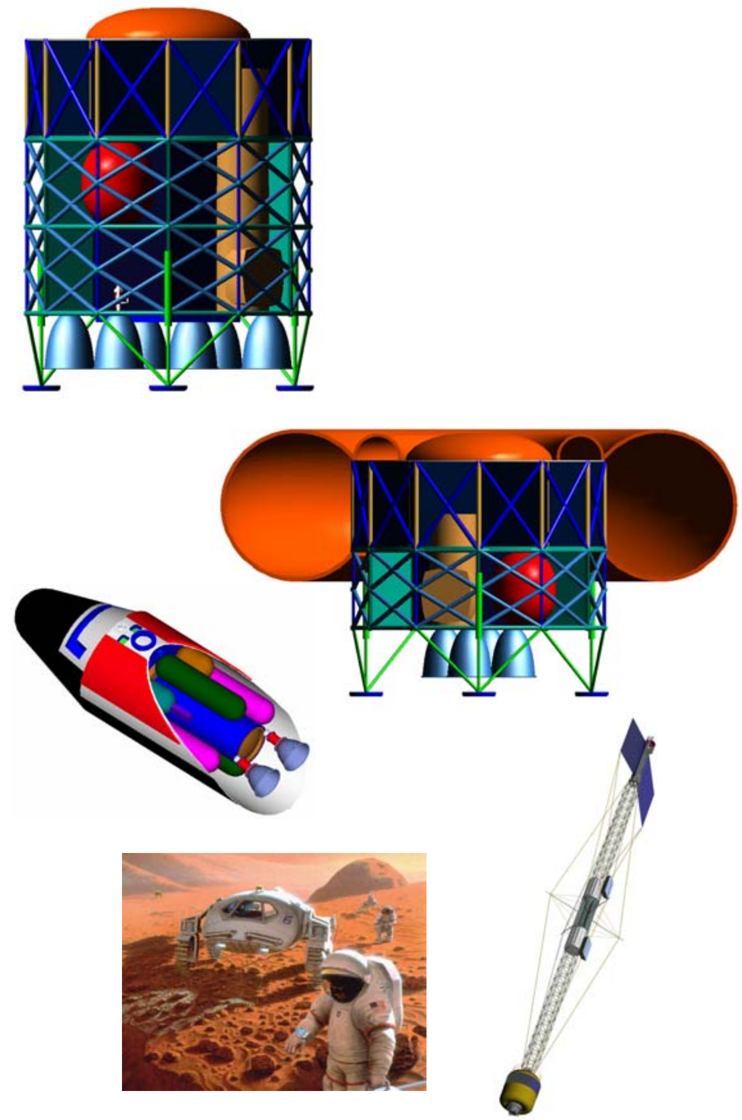
Accessible Planetary (Mars) Surface Mission



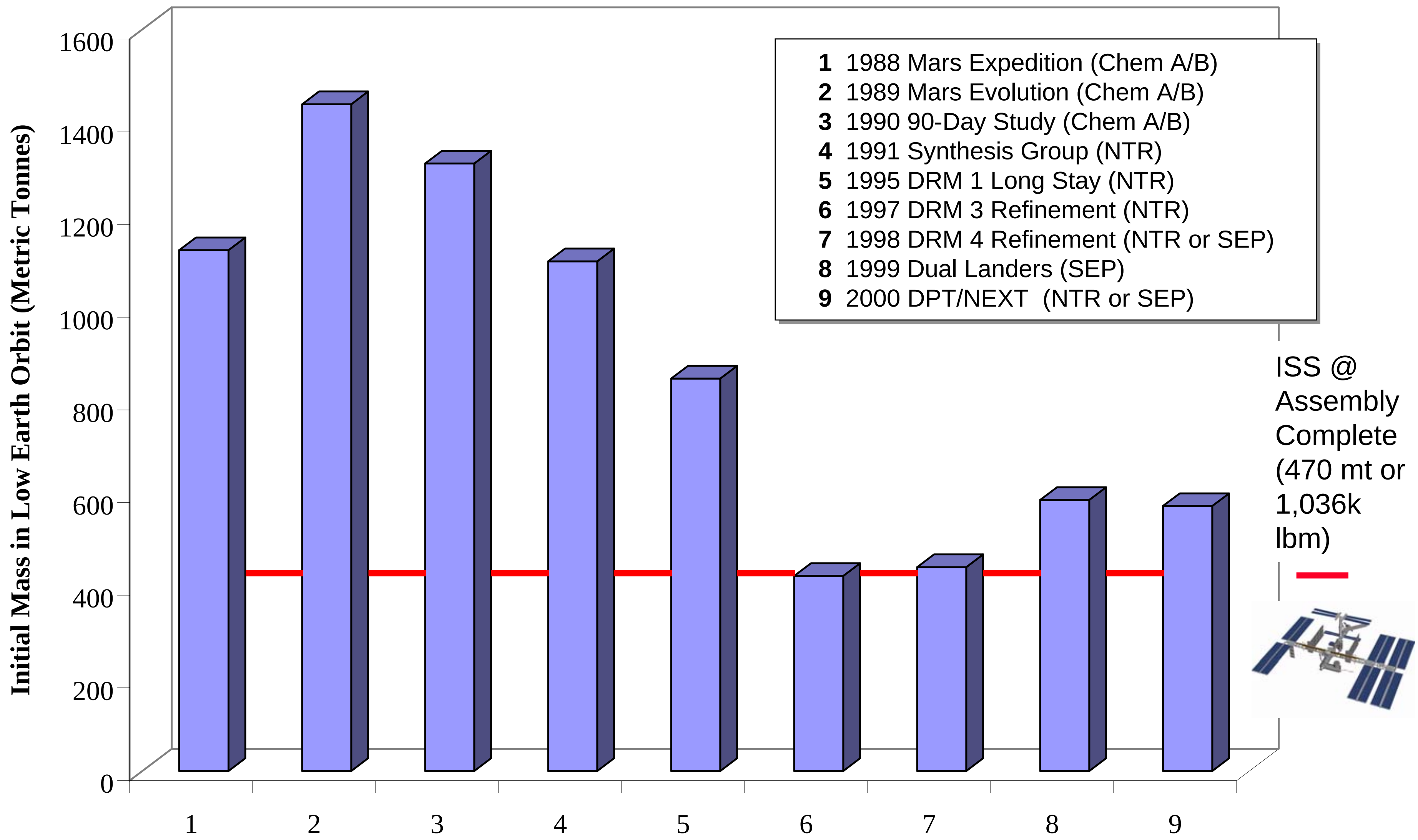
Mars Architecture Key Attributes

- Crew of 6
- Short (30-day) initial visits for focused local science evolving to long (500-day) stays for extensive regional exploration
- Total mission durations range from 365 to 950 days.
- Capability to go to Mars any opportunity
- Maximum use of capabilities developed for Earth's Neighborhood
- Ability to introduce new technologies as they are developed
- Advanced transportation and enhanced launch capacity required to reduce risk and architecture cost

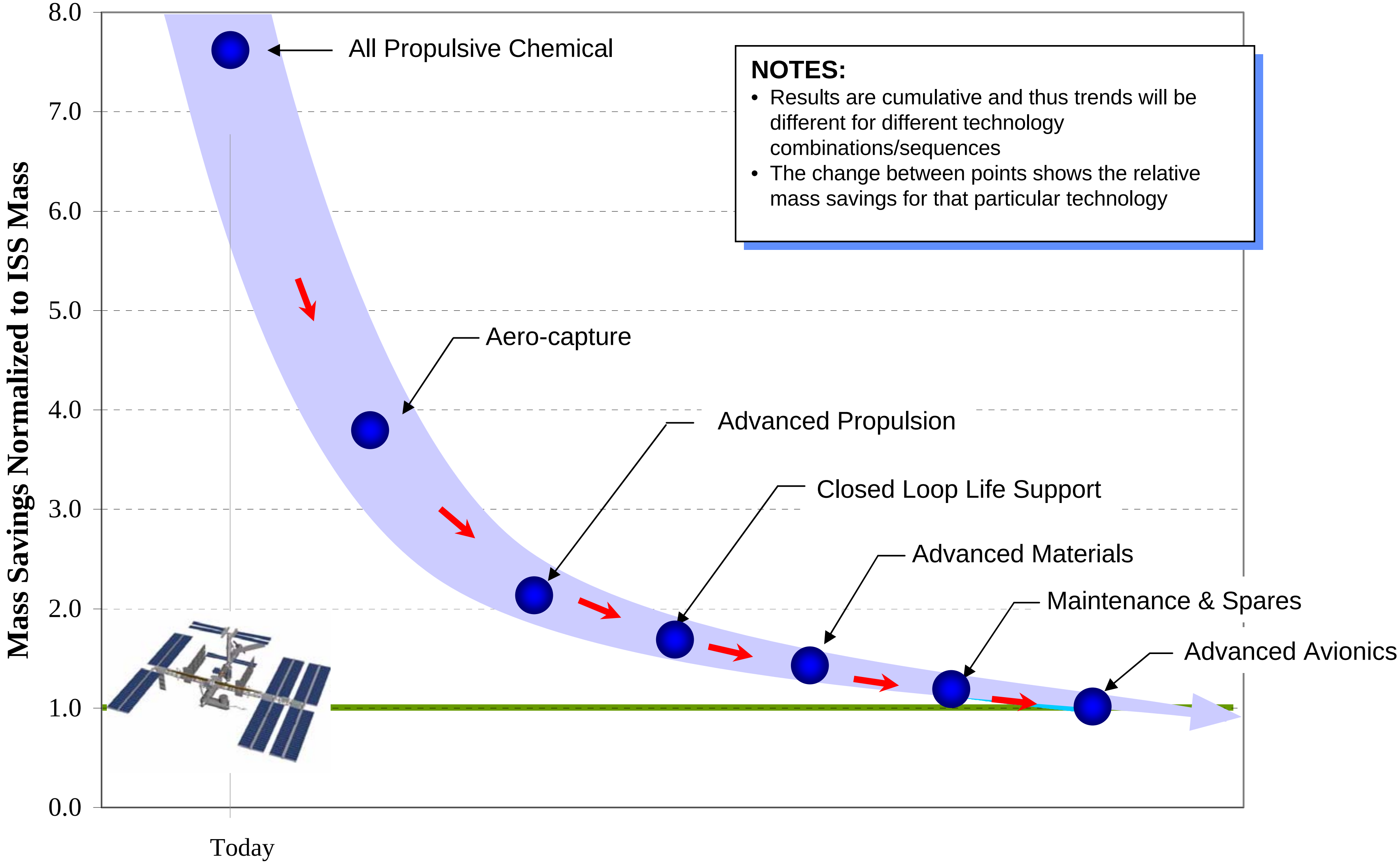
Notional Mission Element Concepts



Mars Architecture Mass History

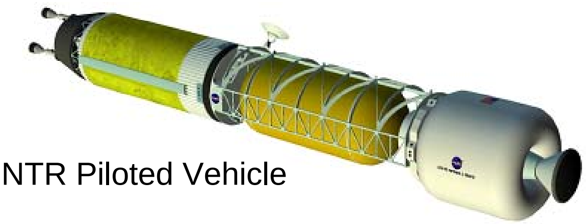


The Value of Technology Investments
Mars Mission Example

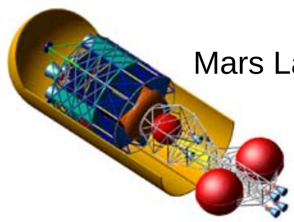


Size Comparison of Notional Mission Elements

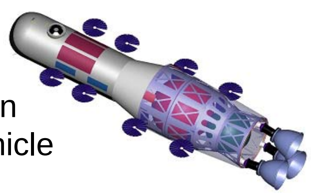
Piloted Vehicles



NTR Piloted Vehicle

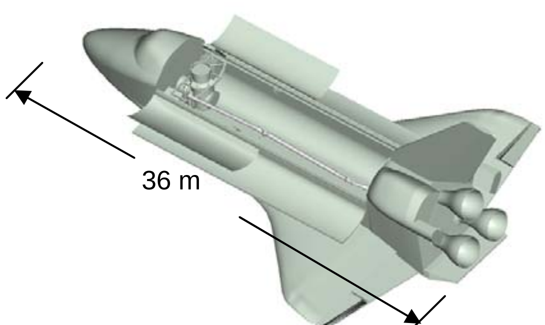


Mars Lander + Aerobrake



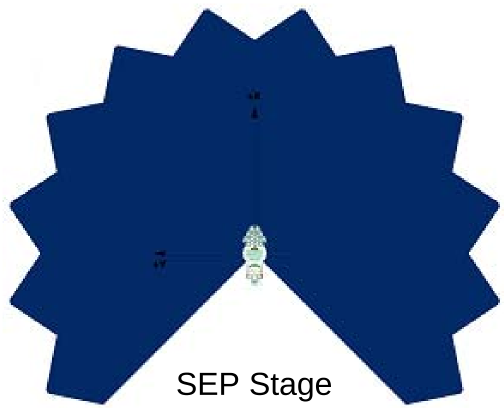
Exploration Transfer Vehicle

Reference Spacecraft (for Scale)



Shuttle Orbiter

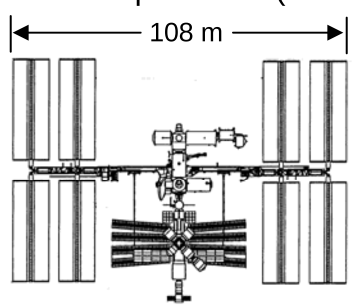
High-Efficiency Transportation



SEP Stage

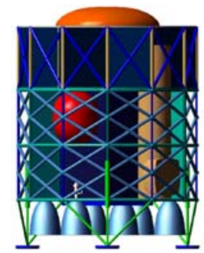
NEP Piloted Vehicle

Reference Spacecraft (for Scale)

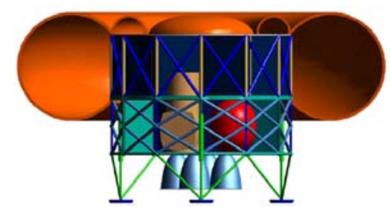


ISS @ Assembly Complete

Landers

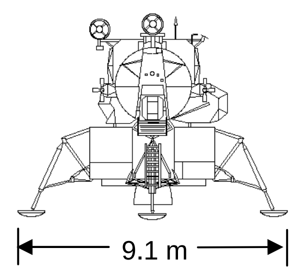


Mars Descent/Ascent Vehicle



Mars Habitat Lander

Reference Spacecraft (for Scale)



Apollo Lunar Module

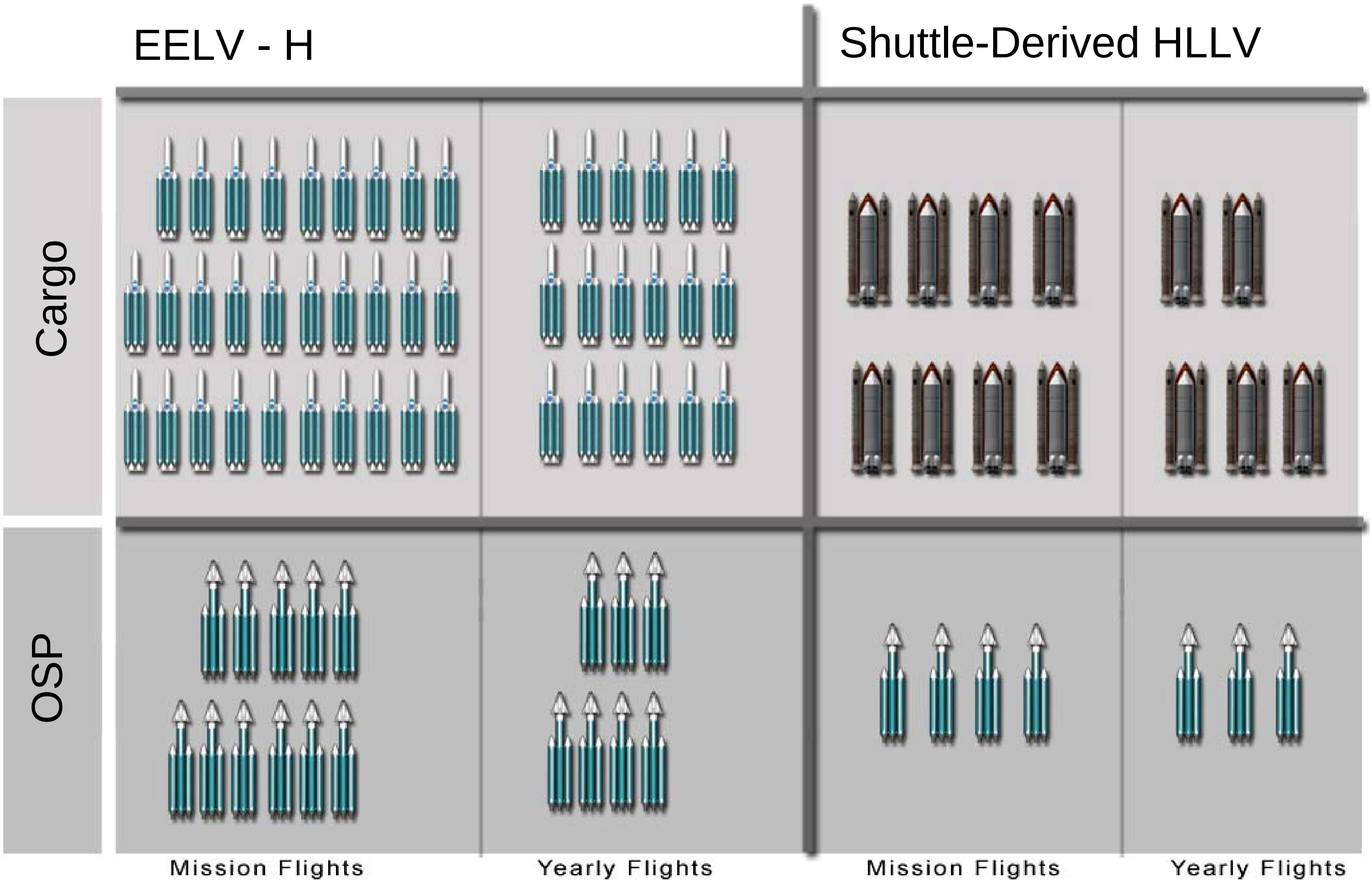
Accessible Planetary (Mars) Surface Mission

Mission Launch Summary	EELV-H	Shuttle-Derived HLLV	EELV-H	Shuttle-Derived HLLV
	Annual		Per Mission	
Launch Vehicle Useful Payload*	**15,875 kg (35,004 lbm)**	**61,670 kg (135,982 lbm)**	**15,875 kg (35,004 lbm)**	**61,670 kg (135,982 lbm)**
Flight Rate (Cargo/OSP/Total)**	**18 / 7 / 25**	**5 / 3 / 8**	**29 / 11 / 40**	**8 / 4 / 12**
Probability of Launch Success	**60%**	**90%**	**45%**	**85%**
Recurring Launch Cost	**$4.62B**	**$4.90B**	**$7.36B**	**$7.60B**

Notes:

Assumes 1 Mars mission every opportunity (26-month frequency)
All hardware launches are completed within a 20-month period
Support flights assume launch by EELV + OSP
* Includes 70% launch packaging efficiency
** One OSP support flight assumed for every 3 cargo flights plus one OSP flight per mission to position mission crew

Accessible Planetary (Mars) Surface Mission



Summary FOM Assessment

	Perf	Safety	Technology	Schedule	Costs*
EELV Heavy	- - -	- -	- -	- - -	+
Shuttle-Derived HLLV	+ + +	+ +	+ +	+ + +	-

*Annual recurring launch costs only. Further assessment of DDT&E, Infrastructure, and Ops costs are required.

ADVANTAGE		DISADVANTAGE	
+	Minor	-	Minor
+ +	Moderate	- -	Moderate
+++	Significant	- - -	Significant

Further analysis is required to better define the influence of various launch vehicle concepts with architectural performance, risk, schedule and cost.

Summary FOM Assessment

- **Performance:** Significantly fewer launches are required with Shuttle-Derived HLLV, thereby improving probability of mission success.
- **Safety:** Reduced number and complexity of assembly flights required with a Shuttle-Derived HLLV significantly enhances crew safety.
- **Technology:** The EELV-H increases the amount and complexity of on-orbit assembly of subassemblies such as the aerobrake, significantly increasing the technology risk.
- **Schedule:** Number of flights required by EELV-H significantly lengthens assembly schedule, increases schedule risks associated with launch windows, and increases the schedule risks associated with launch failures.
- **Costs:** Annual recurring launch costs associated with Shuttle-Derived HLLV is somewhat higher.

Combined Earth's Neighborhood & Accessible Planetary (Mars) Surface Missions

Mission Launch Summary	EELV-H	Shuttle-Derived HLLV	EELV-H	Shuttle-Derived HLLV
	Annual		Combined Per Mission	
Launch Vehicle Useful Payload*	15,875 kg (35,004 lbm)	61,670 kg (135,982 lbm)	15,875 kg (35,004 lbm)	61,670 kg (135,982 lbm)
Flight Rate (Cargo/OSP/Total)**	28 / 13 / 41	7 / 5 / 12	34 / 14 / 48	9 / 5 / 14
Probability of Launch Success	44%	84%	38%	83%
Recurring Launch Cost	$7.82B	$7.10B	$8.96B	$8.70B

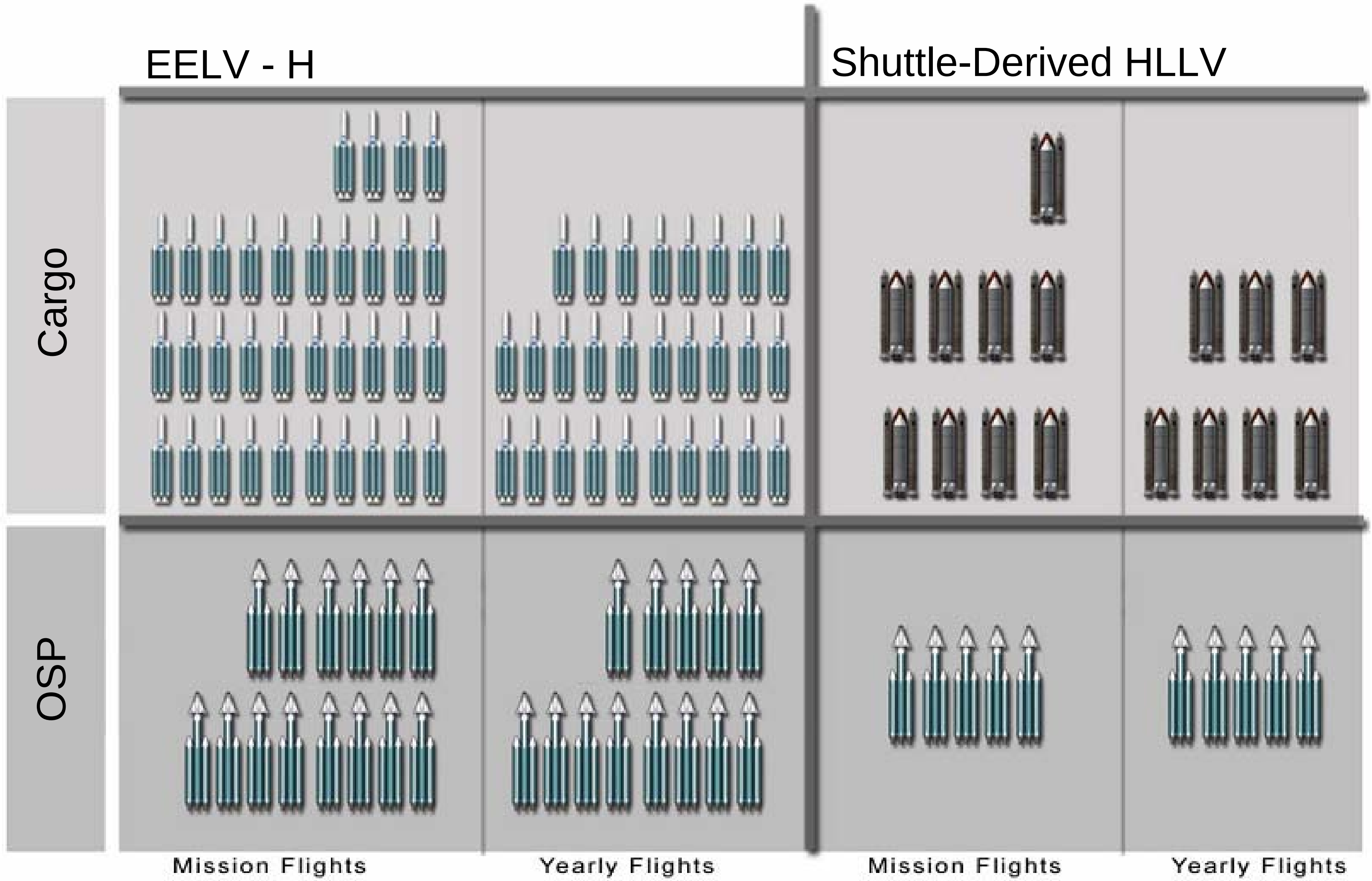
Notes:

Assumes 2 Earth's Neighborhood missions per year and 1 Mars mission every opportunity (26 month frequency)
All Mars hardware launches are completed within a 20-month period
Support flights assume launch by EELV + OSP

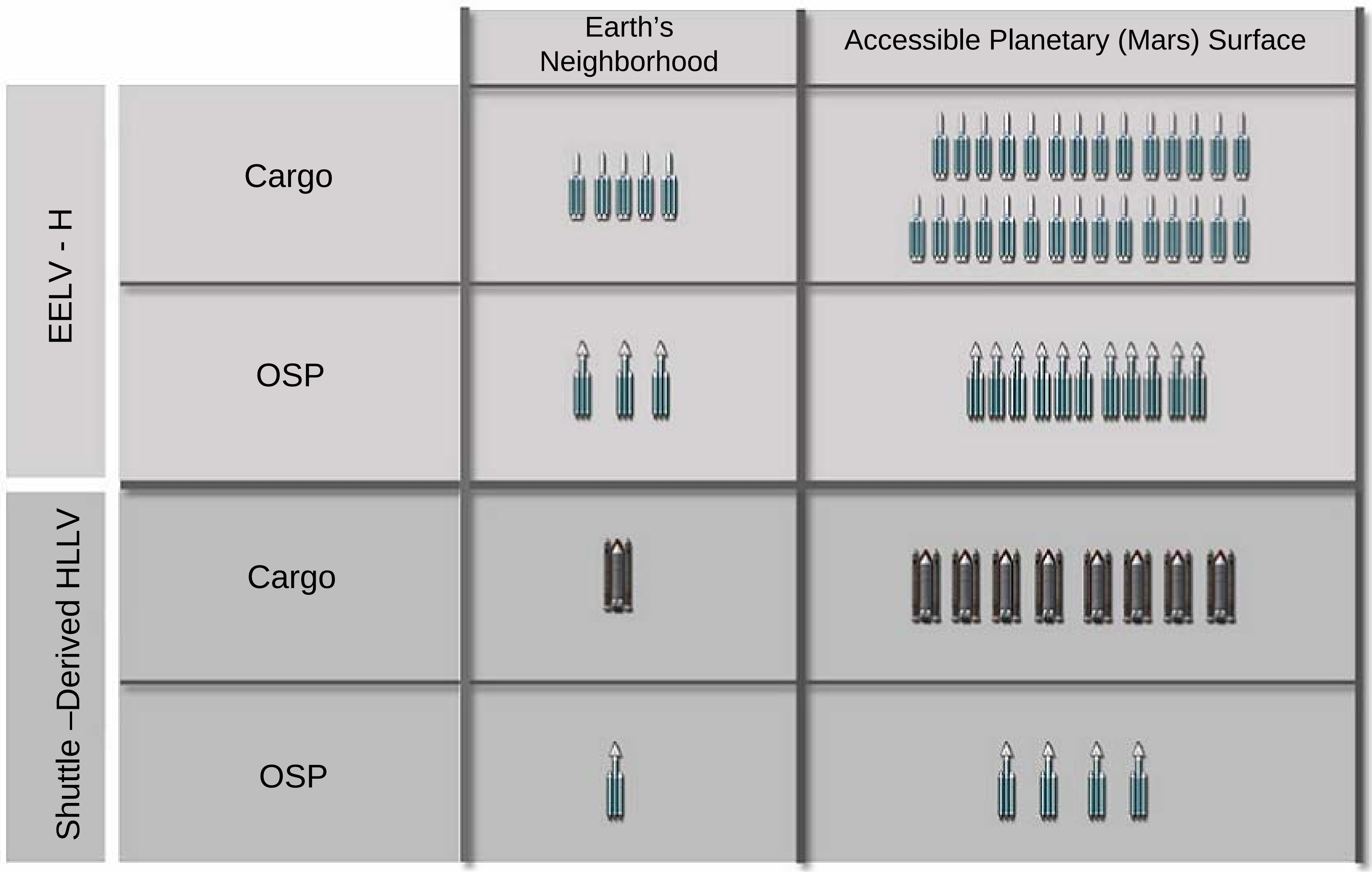
* Includes 70% launch packaging efficiency

** One OSP support flight assumed for every 3 cargo flights plus one OSP flight per mission to position mission crew

Combined Earth's Neighborhood & Accessible Planetary (Mars) Surface Missions



Comparison of Mission Class Flight Requirements



Combined Earth's Neighborhood and Accessible Planetary (Mars) Surface Missions

Summary FOM Assessment

	Perf	Safety	Technology	Schedule	Costs*
EELV Heavy	- - -	- -	- -	- - -	-
Shuttle-Derived HLLV	+ + +	+ +	+ +	+ + +	+

*Annual recurring launch costs only. Further assessment of DDT&E, Infrastructure, and Ops costs are required.

ADVANTAGE		DISADVANTAGE	
+	Minor	-	Minor
++	Moderate	--	Moderate
+++	Significant	---	Significant

Further analysis is required to better define the influence of various launch vehicle concepts with architectural performance, risk, schedule and cost.

Summary FOM Assessment

- **Performance:** Significantly fewer launches required with HLLV.

- **Safety:** Reduced amount and complexity of on-orbit assembly flights required with an HLLV significantly enhances probability of mission success and crew safety**.**

- **Technology:** Use of the EELV increases the amount and complexity of on-orbit assembly of subassemblies such as the aerobrake, significantly increasing the technology risk.

- **Schedule:** Number of flights required by EELV significantly lengthens assembly schedule, increases schedule risks associated with launch windows, and increases the schedule risks associated with launch failures.

- **Cost:** Annual recurring launch costs associated with HLLV somewhat less than that of the EELV.

Observations and Findings

Earth’s Neighborhood Mission

- A heavy lift launch capability is favored by all Figures of Merit and is highly enhancing for this class of mission.
- Assessment of investment in on-orbit assembly vs heavy lift capability is needed.
- Number of launches of EELV-H to support Earth’s Neighborhood is about the same as number of Heavy Lift launches needed to support the Accessible Planetary (Mars) Surface Mission.
- Investment costs of EELV-H borne by other mission applications.

Accessible Planetary (Mars) Surface Mission

- A heavy lift launch capability is enabling for this class of mission.
- Feasibility of using Station to support magnitude of on-orbit assembly highly uncertain.
- Feasibility of successfully assembling subassemblies into major elements such as aerobrakes, NEP, and habitats is highly uncertain.
- Risks and costs associated with unreliability is significant for launch rates associated with EELV-H vehicle class.

General

- Life cycle cost assessment incomplete for both mission classes and vehicle options.
- A vehicle trade study is needed to assess a range of vehicle and propulsion concepts to identify the preferred approach for a HLLV capability.

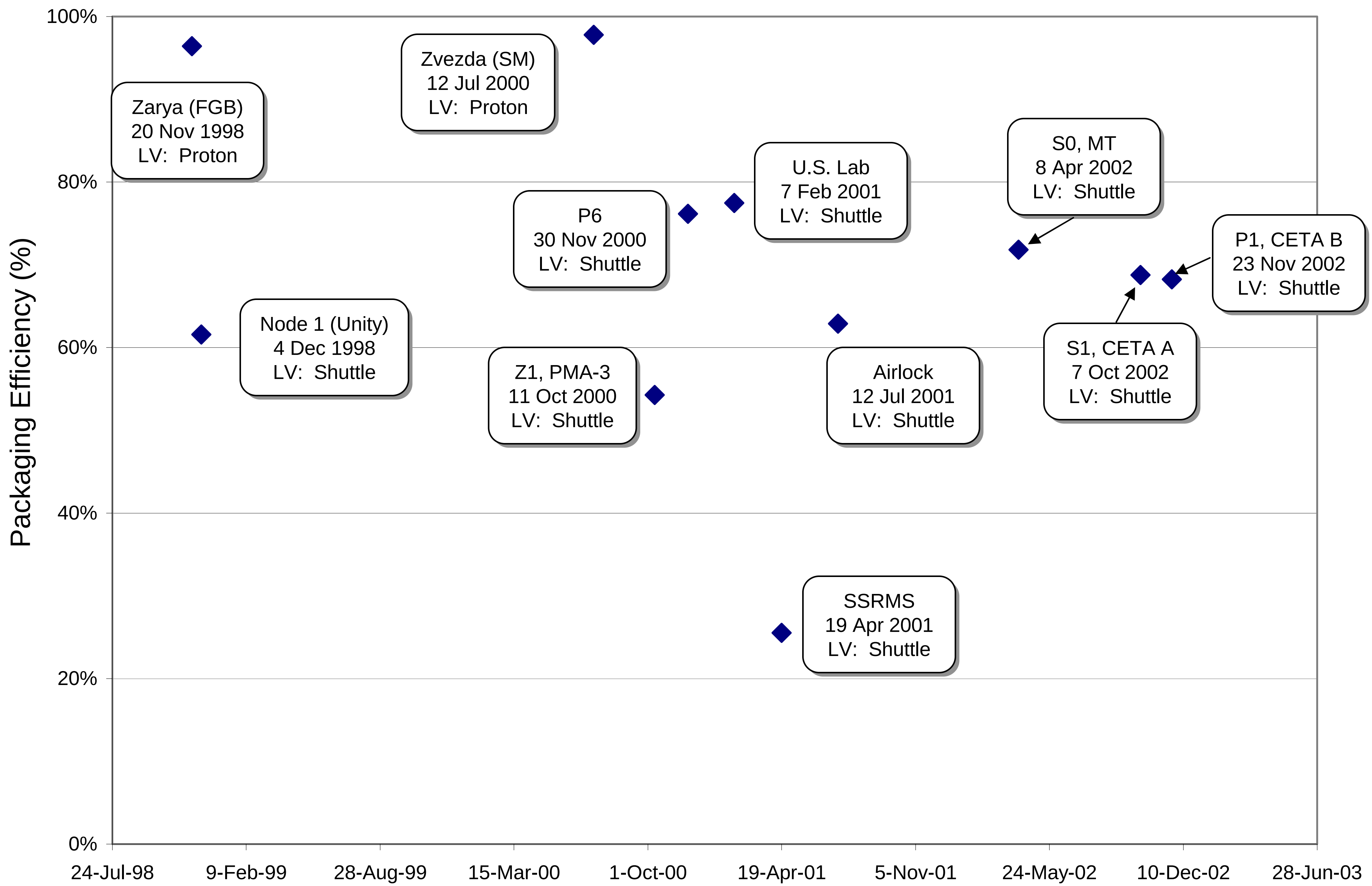
Follow-on Studies *Draft*

Conduct a Heavy Lift Launch Vehicle trade study to assess alternative vehicle and propulsion concepts in a space exploration architectural setting

- Study should address a range of vehicle concepts
  - Shuttle-evolved and shuttle-derived
  - NGLT-based
  - Clean Sheet “big dumb boosters”
  - Concepts should include expendable, reusable and partially reusable systems
  - Vehicle performance should address a range of payload delivery capabilities to LEO from 40 to 100 tonnes for each concept
- Perform manifesting analyses for each concept across a spread of payload volumetric envelopes (length, diameter)
- Establish requirements and concepts for on-orbit assembly
- For each concept develop life-cycle cost definition to include
  - DDT&E
  - Ground infrastructure for production, processing, and launch
  - Infrastructure and operations of on-orbit assembly
  - Loss of mission assets during assembly phase of mission

Backup

ISS Historical Packaging Efficiency



Space Station Evolution - 1989 Assessment

Augmentation Estimates (Which Mars Mission)

- Habitation	23 mt
- Servicing laboratory	35 mt
- Servicing facility	12 mt
- Resource nodes	31 mt
- Truss and utility bays	17 mt
- Power augmentation	28 mt
- Thermal radiators	6 mt
- Attached payload accommodations	1 mt
- Docking systems	1 mt
	154 mt

Initial Mars Short-Stay NTR Case Study Findings

Non-Venus Swing-by Option

It is the consensus of the architecture team that the only way to perform the short-stay, non-Venus swing-by missions in the harder opportunities is to <u>pre-deploy both the lander and return propellant</u>

- Lowers mission mass by approximately 36% (return propellant pre-deployed on minimum energy transfers)
- Increases risk: Rendezvous in Mars orbit must be performed for crew survival (return)
- Increases operating time of crew systems by 114% (as compared to non pre-deploy missions)

Number of launches required poses a significant challenge

- # of EELV-H launches = 54 (1 launch every 2 weeks)
- # of 80 mt Shuttle Compatible launches = 22 (1 launch every 4 weeks)
- Neither of these launch rates can be sustained
    - No margin for launch failure
    - No margin for launch delay
    - Current production/launch rate for Delta-IV is 14 per year (x 4 current capacity)
- Probability of mission success significantly decreases with increased launch rate

"Go Anywhere / Go Anytime" + Small Launch Vehicle

Launch Vehicle Size / Number of Launches	Launch Vehicle Reliability	Probability of Successful Launches
EELV-H / 54	**94%**	**4%**
EELV-H/ 54	99%	58%
"Shuttle Comp." / 22	94%	26%
"Shuttle Comp." / 22	99%	80%

Current Industry Launch Success Rate 94%

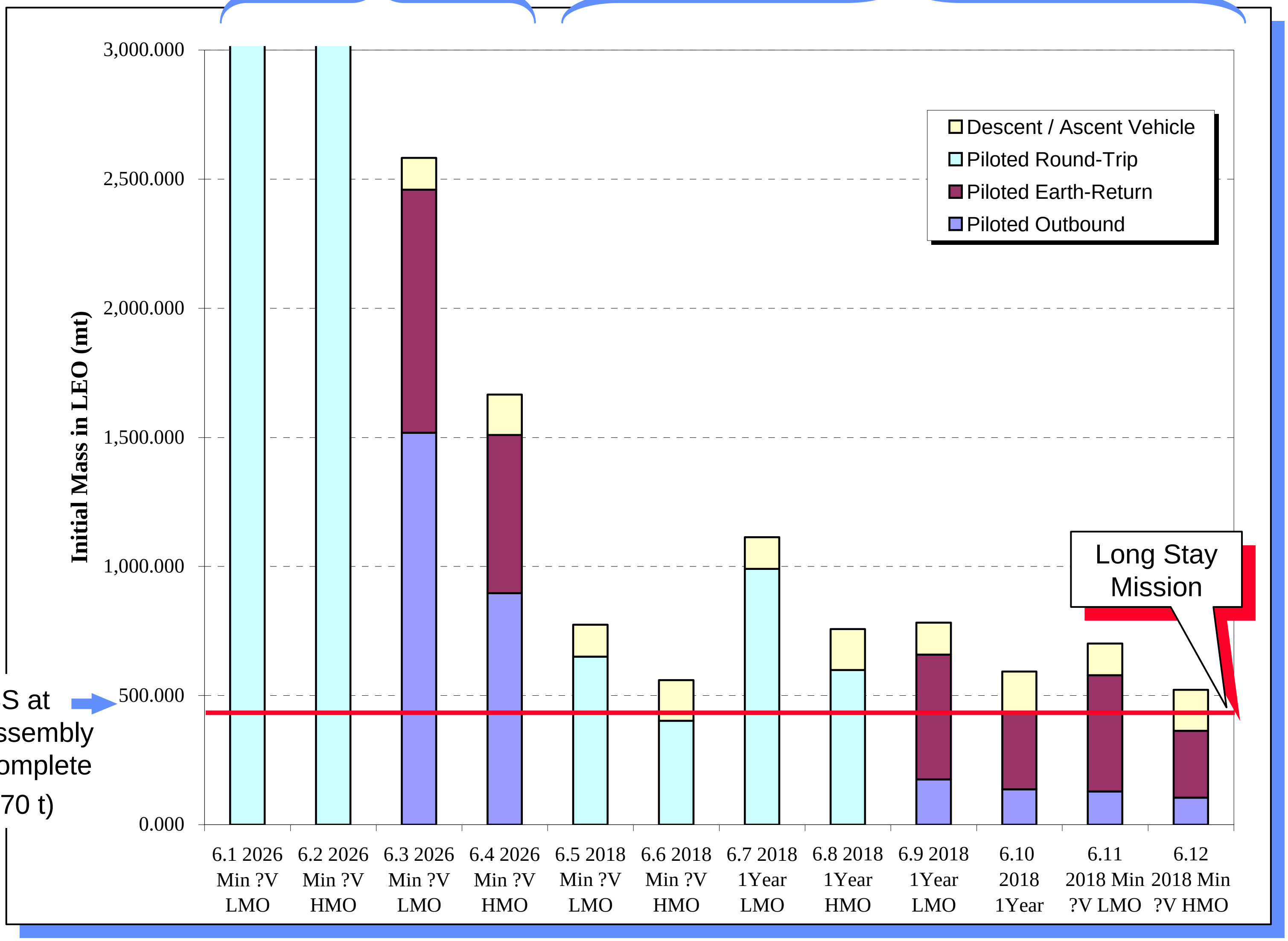
Mars Short-Stay Mission

Initial NTR Case Study Results

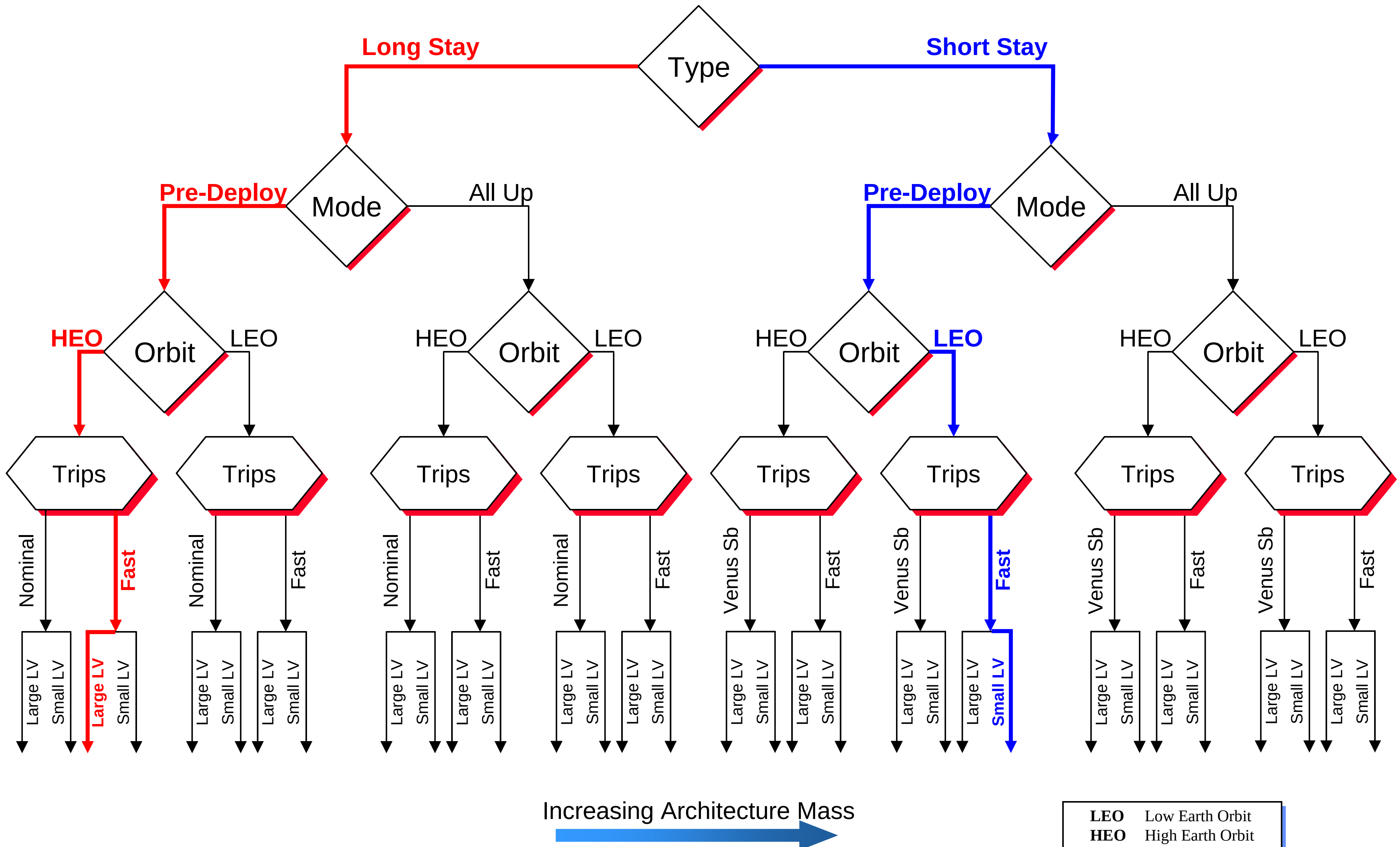
Worst Opportunity (2026 No Swing-by)

Best Opportunity (2018)

ISS at Assembly Complete (470 t)

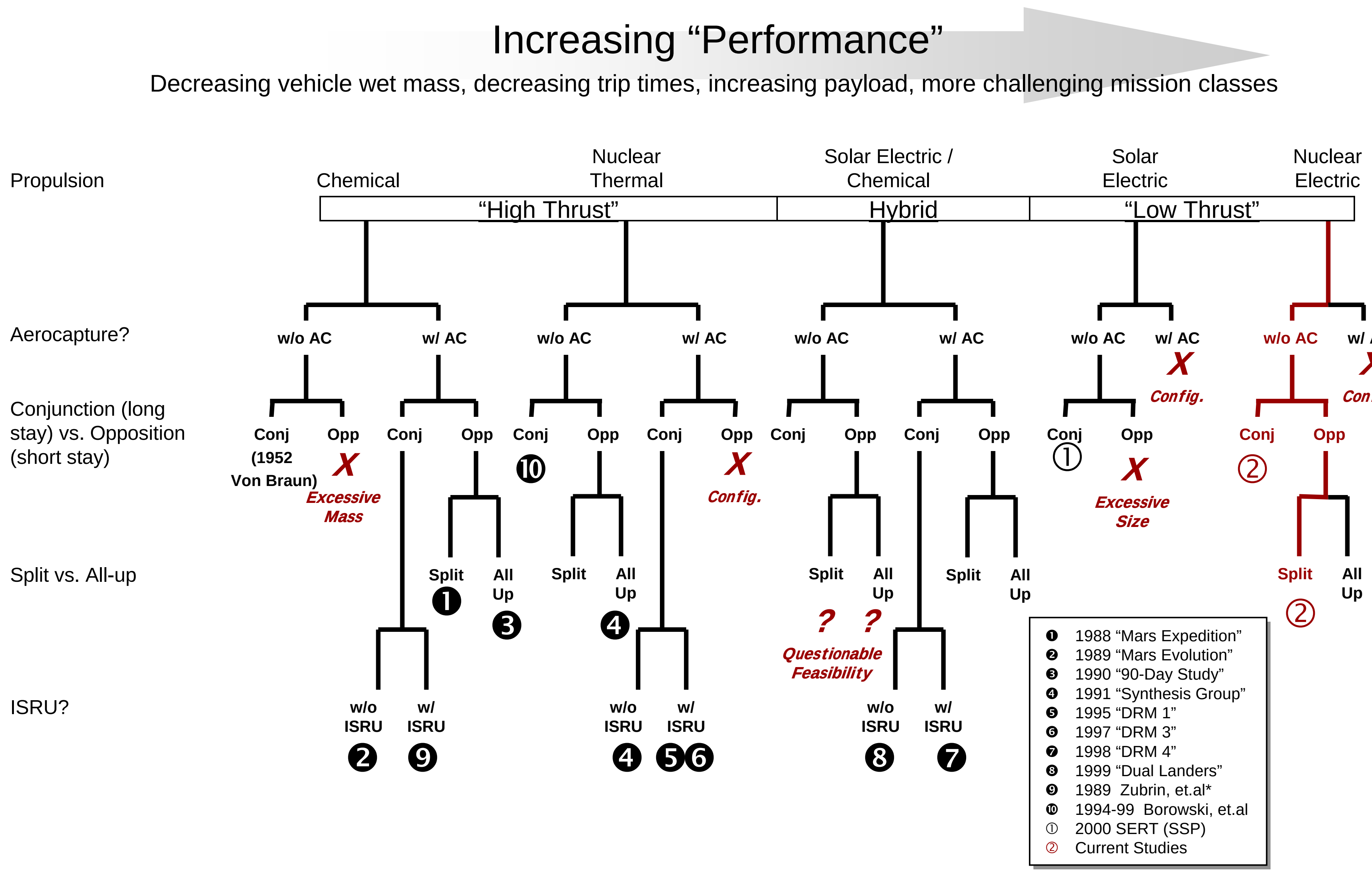


Example Human Mars Mission Decision Tree



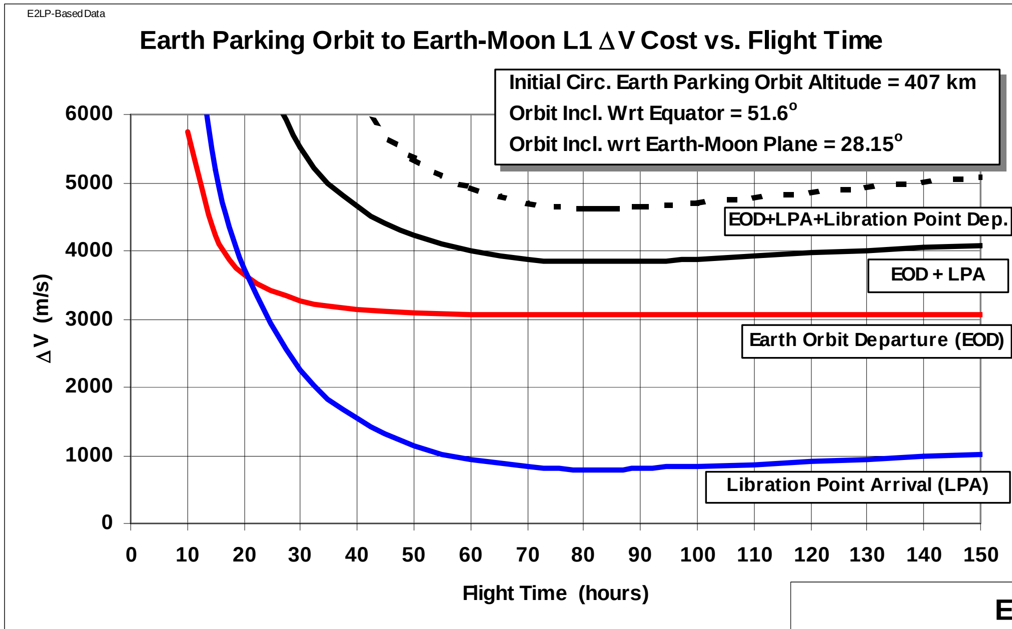
LEO	Low Earth Orbit
HEO	High Earth Orbit
LV	Launch Vehicle
Sb	Swing-by

Mars Mission Trade Space

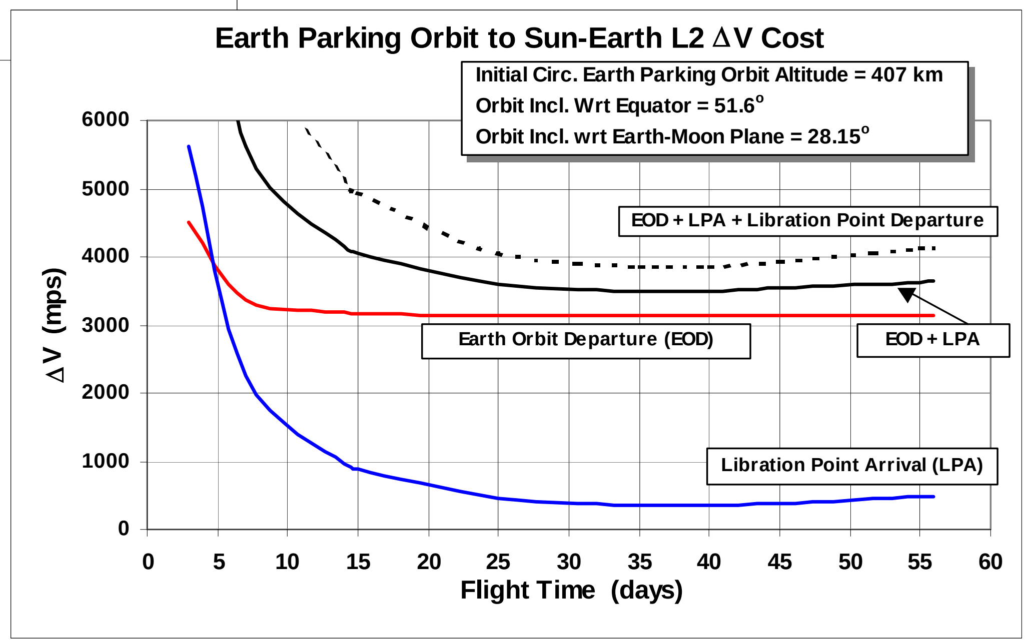


*Assumptions not necessarily consistent

Performance Comparison – Transfer DV for Earth Parking Orbit to: Earth-Moon L1, Sun-Earth L2

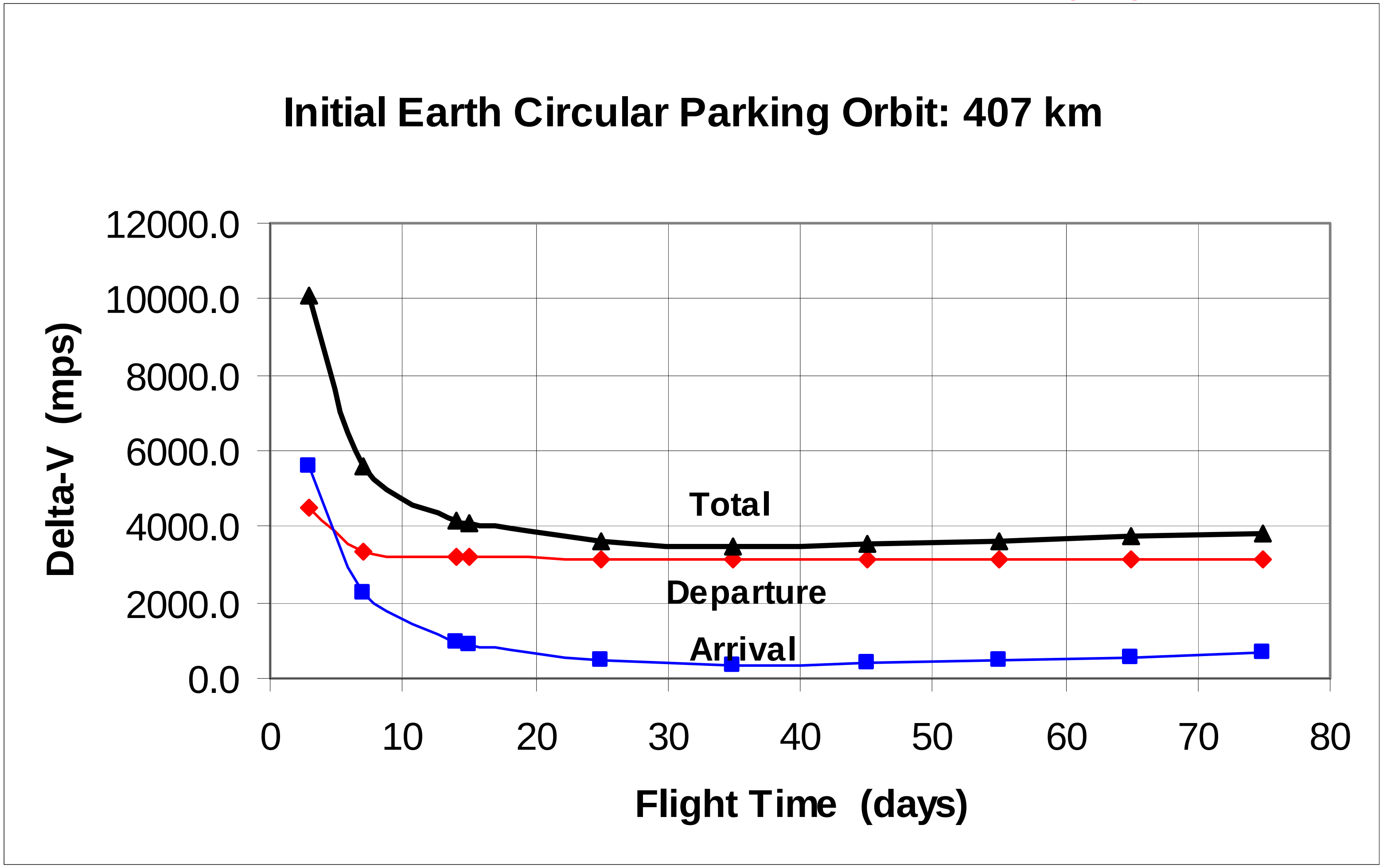


What is purpose of this chart?

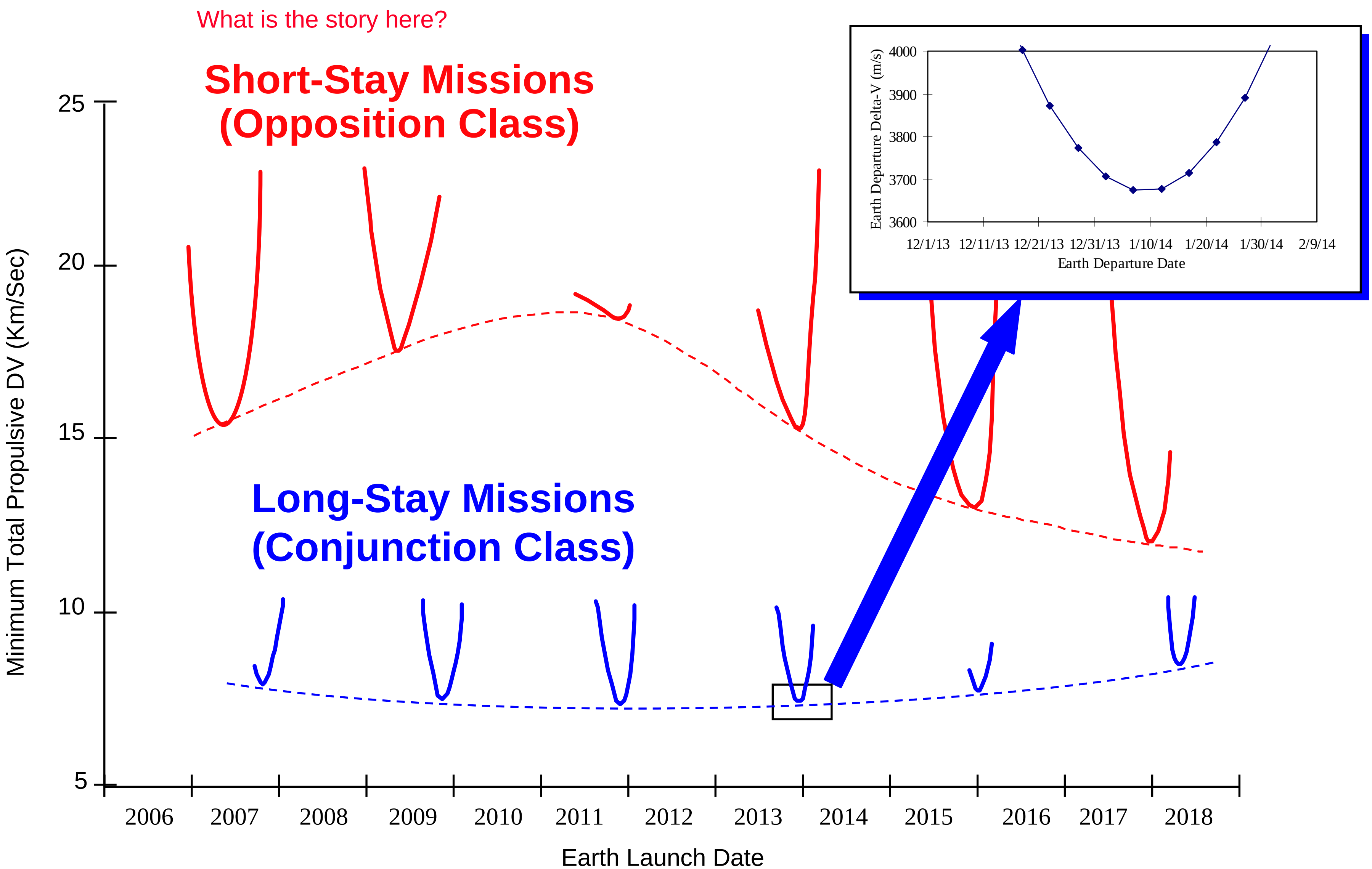


L1 Earth Sun: Arrival DV vs. Flight Time from LEO

What is purpose of this chart?



Delta-V Variations



Common Core Crew Vehicle Requirements

12-12-2002

Common Core Crew Vehicle Requirements

- **Objective:**
  - Establish the requirements for a common core crew vehicle which can satisfy multiple, Agency-wide, needs.
- **Approach:**
  - Initiate an analysis process for coordinating the functions and requirements for the range of future crew vehicles to establish a common set of requirements
  - Crew vehicle requirements should include needs for:
    - ISS Crew Return Vehicle (return from low-Earth orbit) Priority 1
    - Crew Transfer Vehicle (to and from low-Earth orbit) Priority 2
    - Exploration Transfer Vehicles (beyond low-Earth orbit and return) Priority 3

Recommendation for Common Requirements

- Initial assessment of common core crew vehicle requirements include the following:
  - Configurable pressurized volume for 4-7 deconditioned crew
  - One day mission duration independent from a service module
  - Enable autonomous / manual operations
  - Provides propulsive orbital maneuvering capability
  - Return the crew safely to Earth

Key Points to Consider

- **An CRV is simplest function.**
  - Including CTV function is hardest step
  - Including XTV is less of a step
- **Winged Vehicle is more complex than simple entry shape**
  - Additional systems (ie actuators/control surfaces)
  - Complex aero/flight control interactions through Mach regimes
  - Complex structural loads during ascent (mass/CG/structure)
  - Potentially results in longer schedule and higher cost
  - Increased operations and crew training for more complex entry/descent and landing
- **Wings preclude Earth's Neighborhood entry velocities (11 Km/sec)**
  - Wings are impractical above low Earth orbit (mass/heating)
- **What Evolvable means:**
  - <u>Not</u> open ended requirements
  - Replace TPS in critical heating areas when higher velocities are encountered.
  - Crew of up to 6-7
  - Possible later upgrades of some systems-modular systems components also enables better serviceability

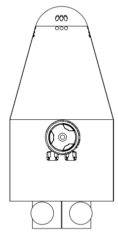
Key Design Discriminators

There is a greater degree of commonality between the Crew Return Vehicle (CRV) design and the core of the Exploration Transfer Vehicle (XTV) than the Crew Transfer Vehicle (CTV).

	CRV	XTV	CTV
Crew Size	4-7 Crew	4-6 Crew	5 Crew
Duration	< 1 Day	< 1 Day [1]	**10-12 Days**
Propulsive Maneuver	< 150 m/s	< 300 m/s	**450+ m/s**
Volume [2]	1 day	**4 days**	**3 days**
Entry Speed	7.5 km/s	**11.0 km/s**	7.5 km/s
Landing Mode/locale	Near Hospital	Any	**Runway 10,000 ft**
Launch Vehicle	STS	STS Derived	**EELV & RLV**
Crew Escape System	No	If crew during launched	**Yes**
Key Interfaces	STS & ISS	LV and Service Module	EELV (2), RLV, ISS

1 Additional resources provided by external service module.
2 Total volume driven by maximum length of time inhabited.

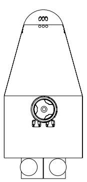
Common Crew Vehicle Design Capture



Core Crew Vehicle

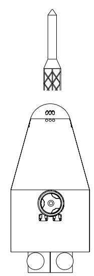
- Common crew element satisfying multiple mission capabilities
- Key Design Requirements :
  - Configurable for 4-7 crew
  - Independent one day mission duration
  - Autonomous / manual operations
  - Propulsive orbital maneuvering
  - Return the crew safely to Earth

ISS Crew Return



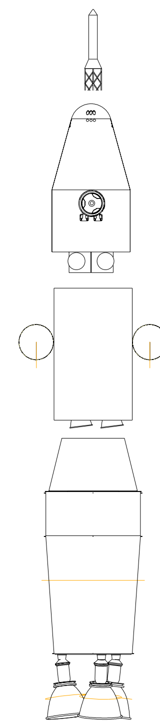
- Provides safe and expeditious recovery of astronauts from low-Earth orbit
- Core Vehicle Configuration Changes:
  - Configured for 4 deconditioned crew
  - Medical emergency provisions
  - Emergency undock capability
  - ISS interfaces and six-month to two-year on-orbit stay
- Key Issues:
  - EELV launch compatibility including automated delivery to ISS
  - Degree of vehicle reusability

LEO Crew Transfer



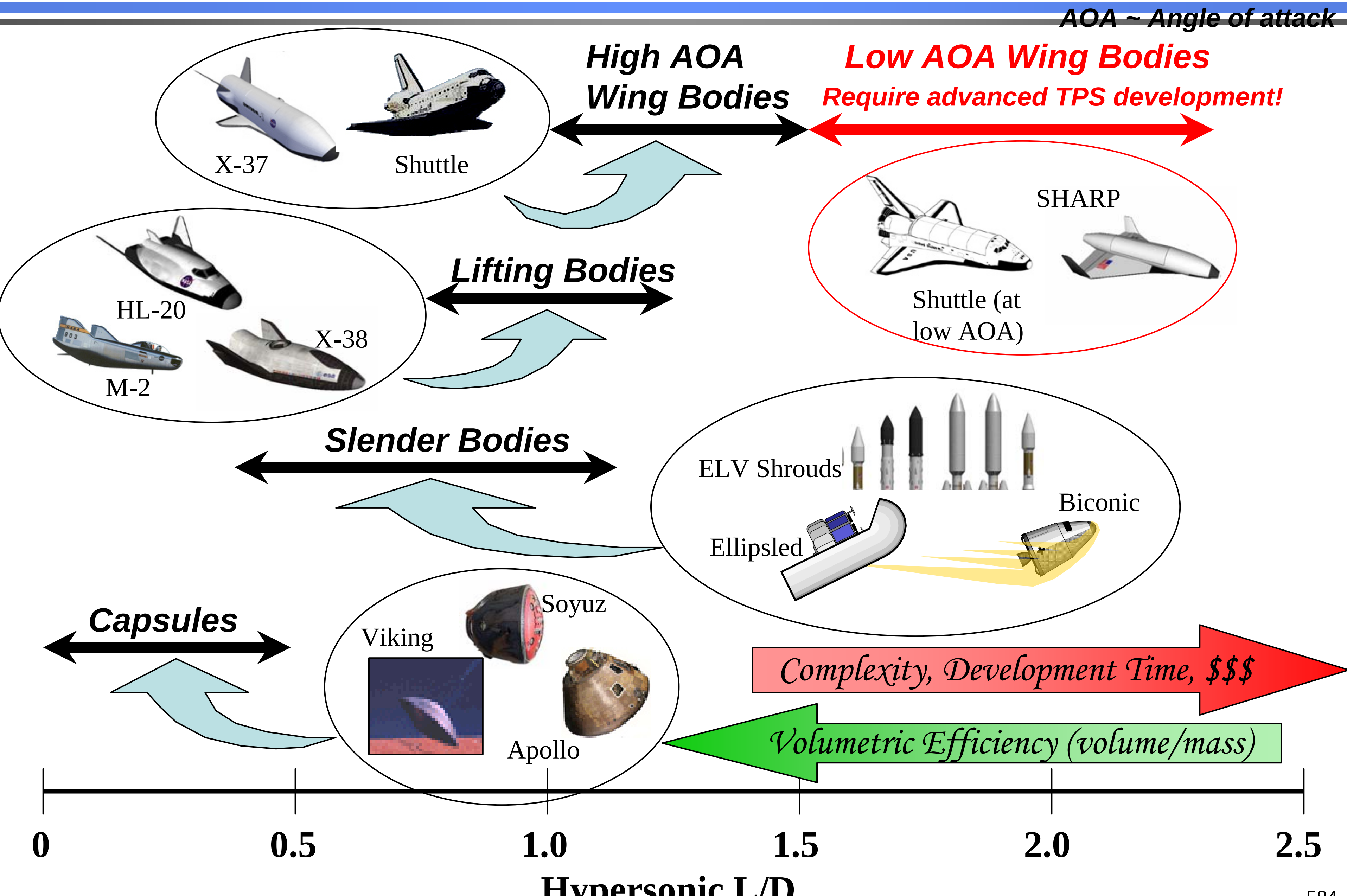
- Crew transfer to low-Earth orbit and return
- Core Vehicle Configuration Changes:
  - Crew escape for aborts
  - Configured for 5 crew (3 ISS transfer)
  - 12 day mission duration for ISS support
  - Resources for extended mission duration (propellant, power, thermal control, life support consumables)
- Additional Systems:
  - EVA systems for on-orbit satellite servicing and repair
- Key Issues:
  - EELV launch compatibility and human rating
  - Degree of vehicle reusability

Near-Earth Transfer



- Transport crew to lunar vicinity and return to Earth
- Core Vehicle Configuration Changes:
  - Configured for 4-6 crew (mission dependent)
  - Crew escape for aborts
  - 12 (active) + 8 (dormant) day mission
  - Deep-space environmental protection
  - Resources for extended mission duration (propellant, power, thermal control, life support consumables)
- Additional Systems:
  - EVA systems for servicing and repair as required
  - Injection stage for trans-lunar injection
- Key Issues:
  - Lunar return velocities
  - Large launch vehicle
  - Degree of vehicle reusability

Vehicle Shapes' Lift-to-Drag (L/D) Characteristics



Bottom Line

Entry G-load Limit

No return | Lunar/L1 return: reclined LEO return: upright & sick/injured reclined | Any return sitting upright & sick/injured reclined

LEO Return TPS

Current reusable TPS | Advanced Reusable Ceramics | Ablators (TRL5) and Flight-limited UHTC (TRL3)

Landing Sites Req'd for CRV

> 4 Landing Sites Req'd | 3 - 4 Landing Sites Req'd | 1 or 2 Landing Sites Required

Impact on ELV Control

Similar to current ELV launch shrouds ? Within current ELV launch capability ? Requires change to ELV control or OSP lift spoilers

Ascent Abort Capability

Exceeds crew load limit on hi-altitude aborts | Requires land and water landing ascent abort capability

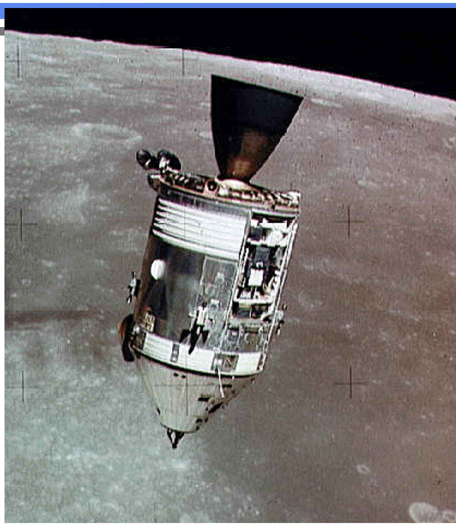
Desirable Range

0 0.5 1.0 1.5 2.0 2.5

L/D

Common Core Vehicle Existence Proof

- **NASA Prior History with combined CRV/CTV/XTV Functions**
- **A concept for landing wingless spacecraft**

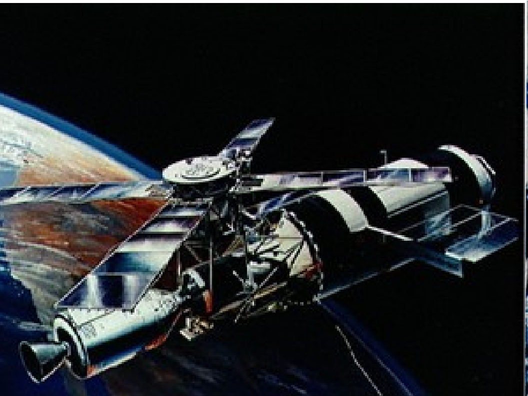


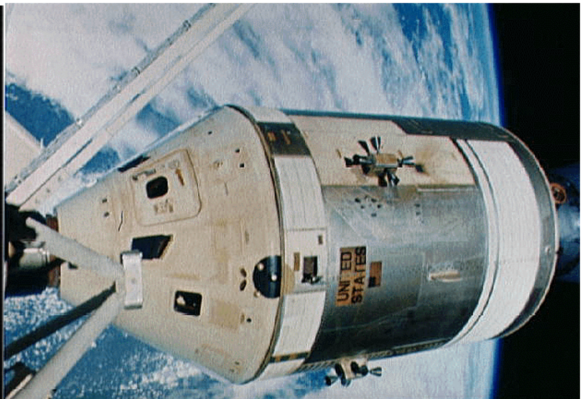
Lunar Return Function

CTV Function

Skid Landing

CTV/CRV Function





Vehicle Shape Issues

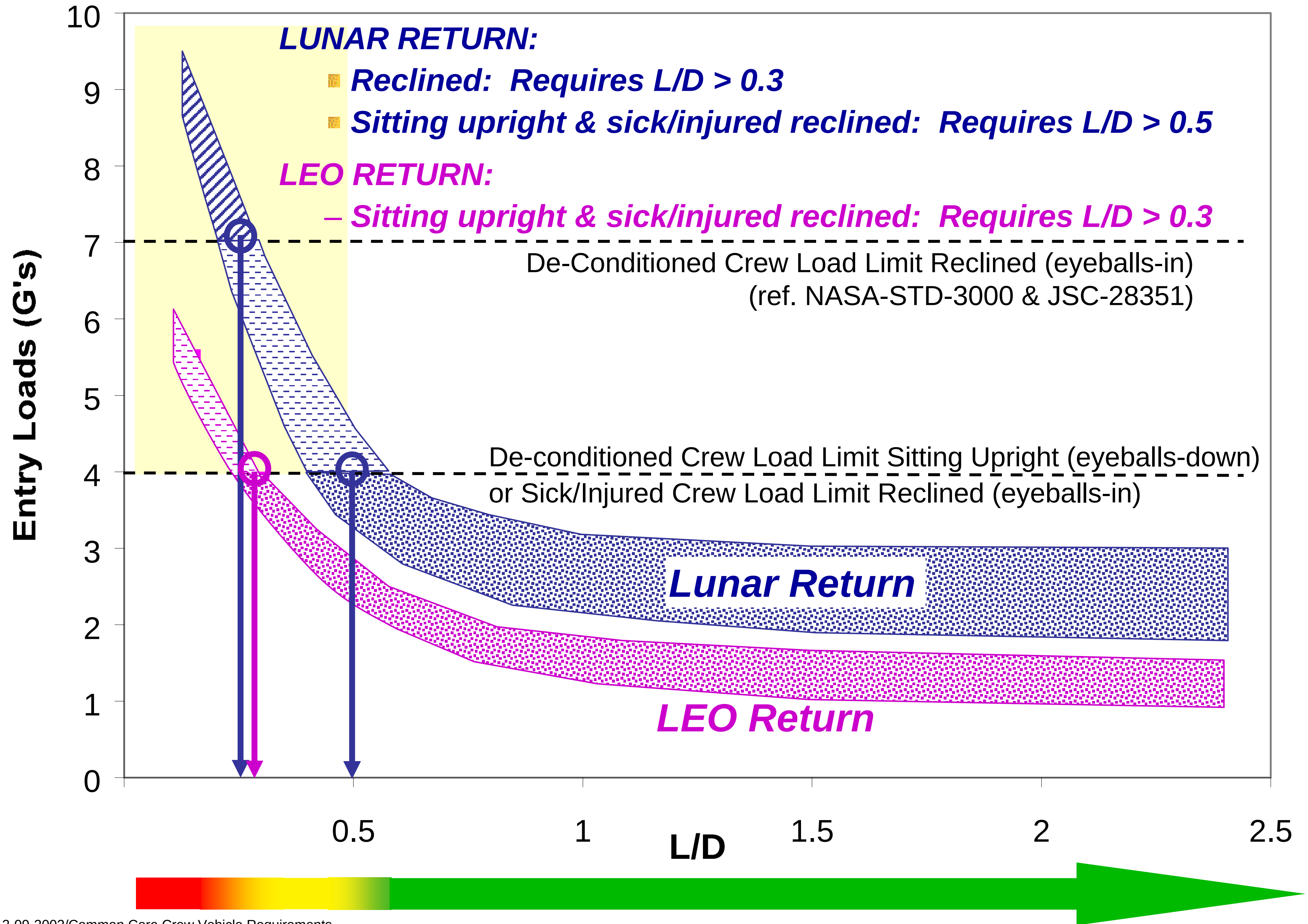
- **Are wings and wheels required?**
  - Many of the mission modes (CRV and CTV) derive a requirement for soft runway landings, which implies wings and wheels, in order to satisfy multiple higher-level requirements including:
    - Cross range as one approach to meeting loss of crew requirements
    - Landing accelerations for medical and system certification purposes
    - Quick turnaround between flights
  - Wings are incompatible for missions beyond low-Earth orbit
    - Peak heating limits nose and wing radius of curvature – thus eliminating wings from consideration
  - Maintaining pressure in wheels for long periods in space may be an issue
  - Wings may be incompatible for launch modes where the vehicle is exposed to the free air stream.
- **If wings are considered a strong Level I requirement, then an additional requirement should be added:**
  - The system shall be capable of accommodating outer mold lines of multiple vehicles
    - With this approach, the common core vehicle requirements would be contained within a common crew cabin or reduced to common system components

Summary

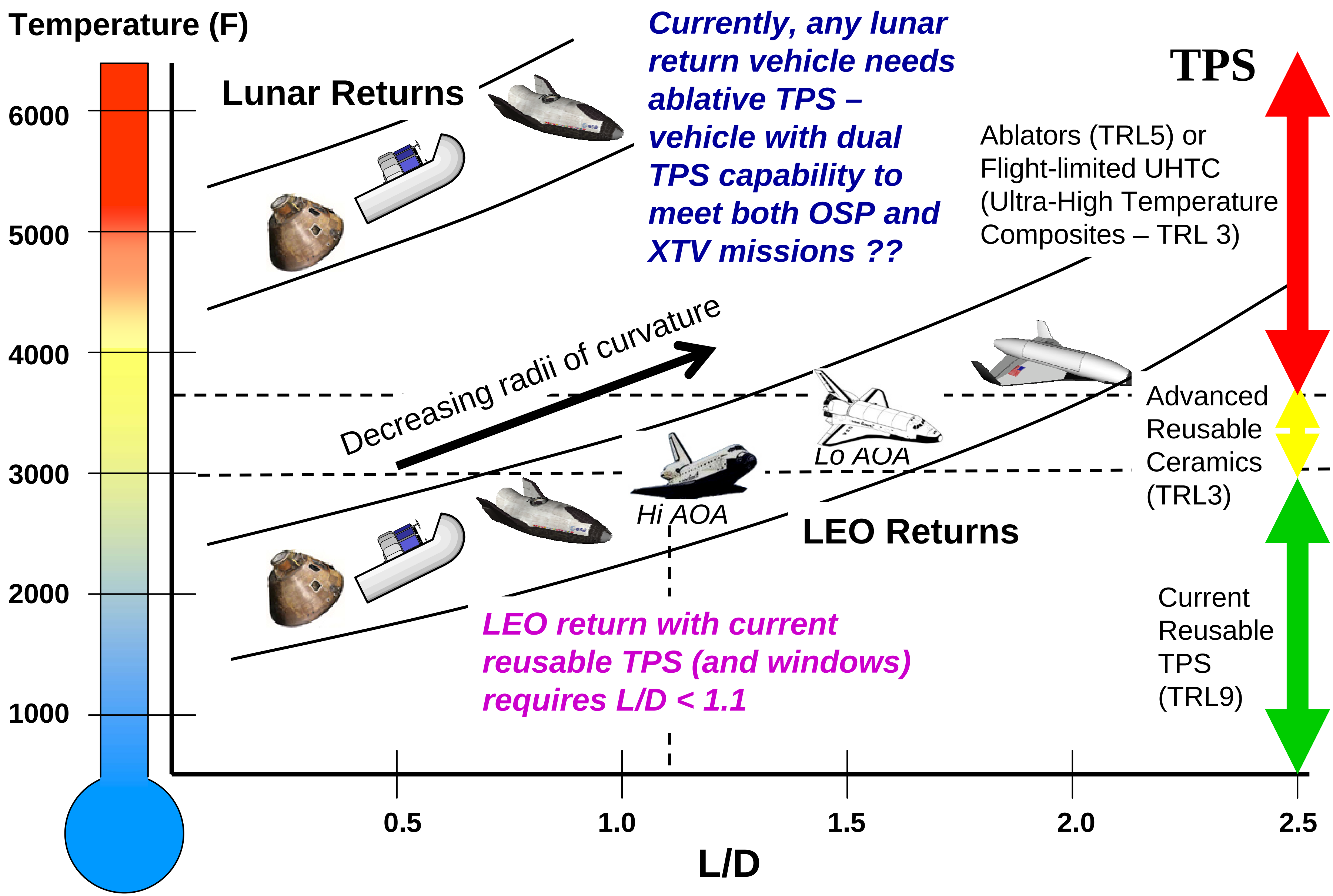
- **Defining the requirements on a multipurpose vehicle requires consideration of all potential mission modes.**
- **Strategies exist that can satisfy the top-level requirements which are common between mission modes.**
- **Further analysis of the impacts of the mission modes on the multipurpose vehicle is required in order to finalize core requirements**
- **Exploration driving requirements- If concepts considering these are included in trade space, Exploration could be enabled**
  - Crew of 6
  - Entry shapes with larger radii of curvature (ie no wings) to preclude heating outside thermal constraints

Backup 1

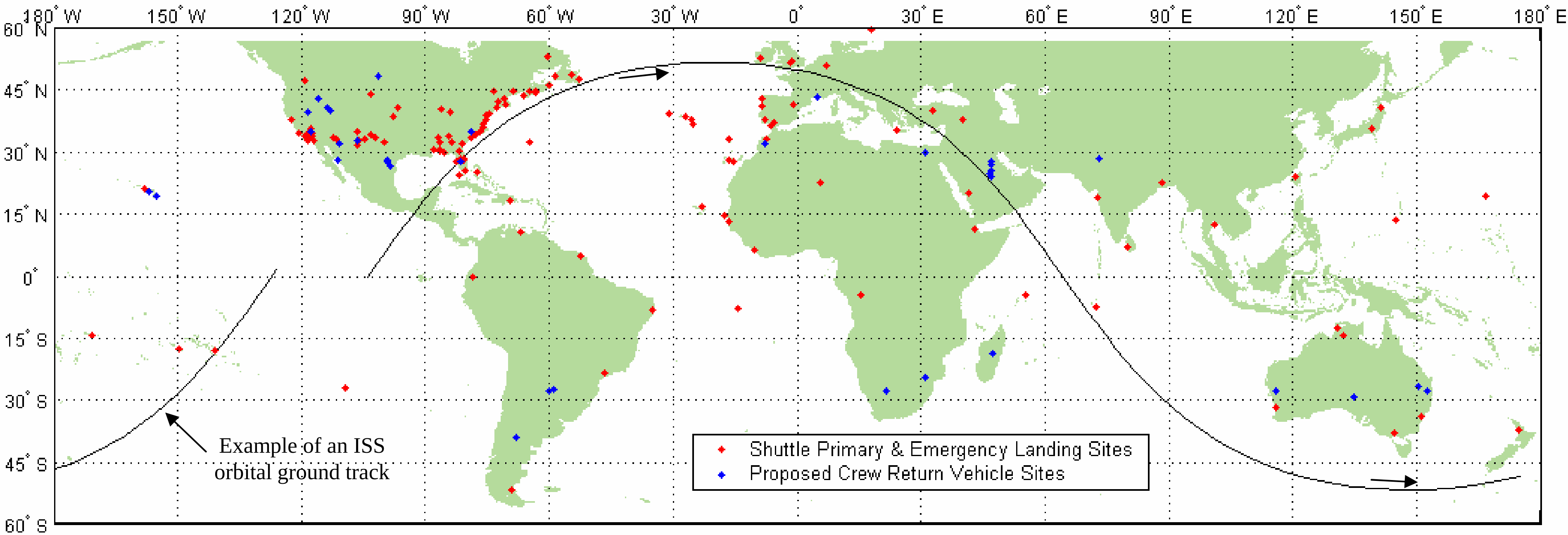
Entry G-Loads



Entry Heating (vehicles sized for 5-7 crew)



Landing Sites



- **Map shows sites used for shuttle & considered for previous crew return vehicles**
- **Multiple sites are desired because**
  - Primary site closure due to poor conditions
  - Emergency crew or vehicle return when opportunity to primary site will not be soon enough
  - Reduce the maximum time between de-orbit opportunities

OSP Landing Site Opportunities

- **For a given set of emergency return requirements, there exists an minimum number of landing sites needed for a particular vehicle L/D**
  - Dependent on vehicle landing system design & suitable site locations

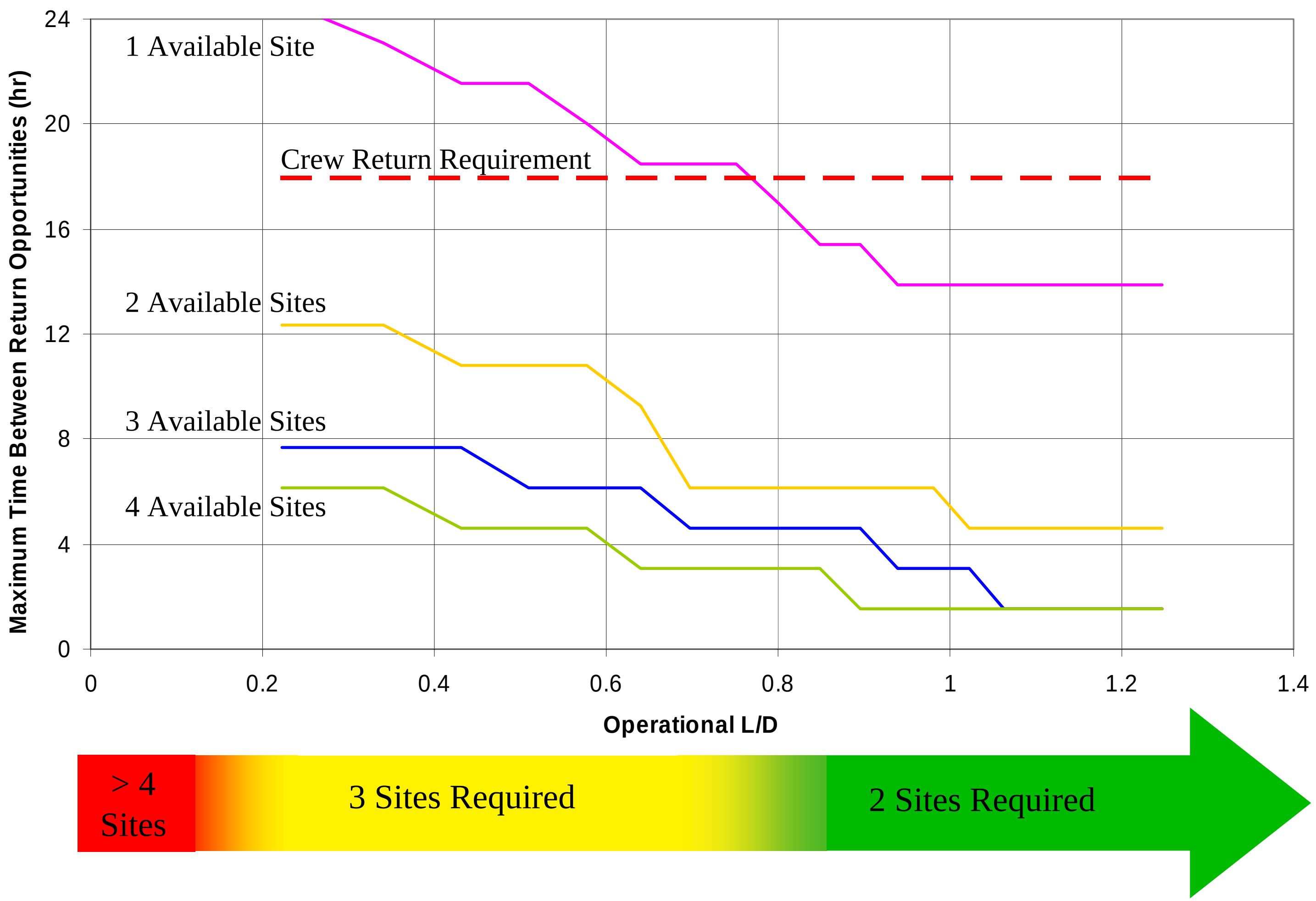
Return from ISS 51.6° inclination orbit.

Crew return to Earth required to be less than 24 hours to reach medical facilities in time.

Site locations optimized to minimize time between opportunities.

Real site locations may increase the maximum time by an orbit or two, or 1.5 to 3 hours. More study required to assess suitable real sites.

At least 1 additional site is always desired in case of poor conditions at one.

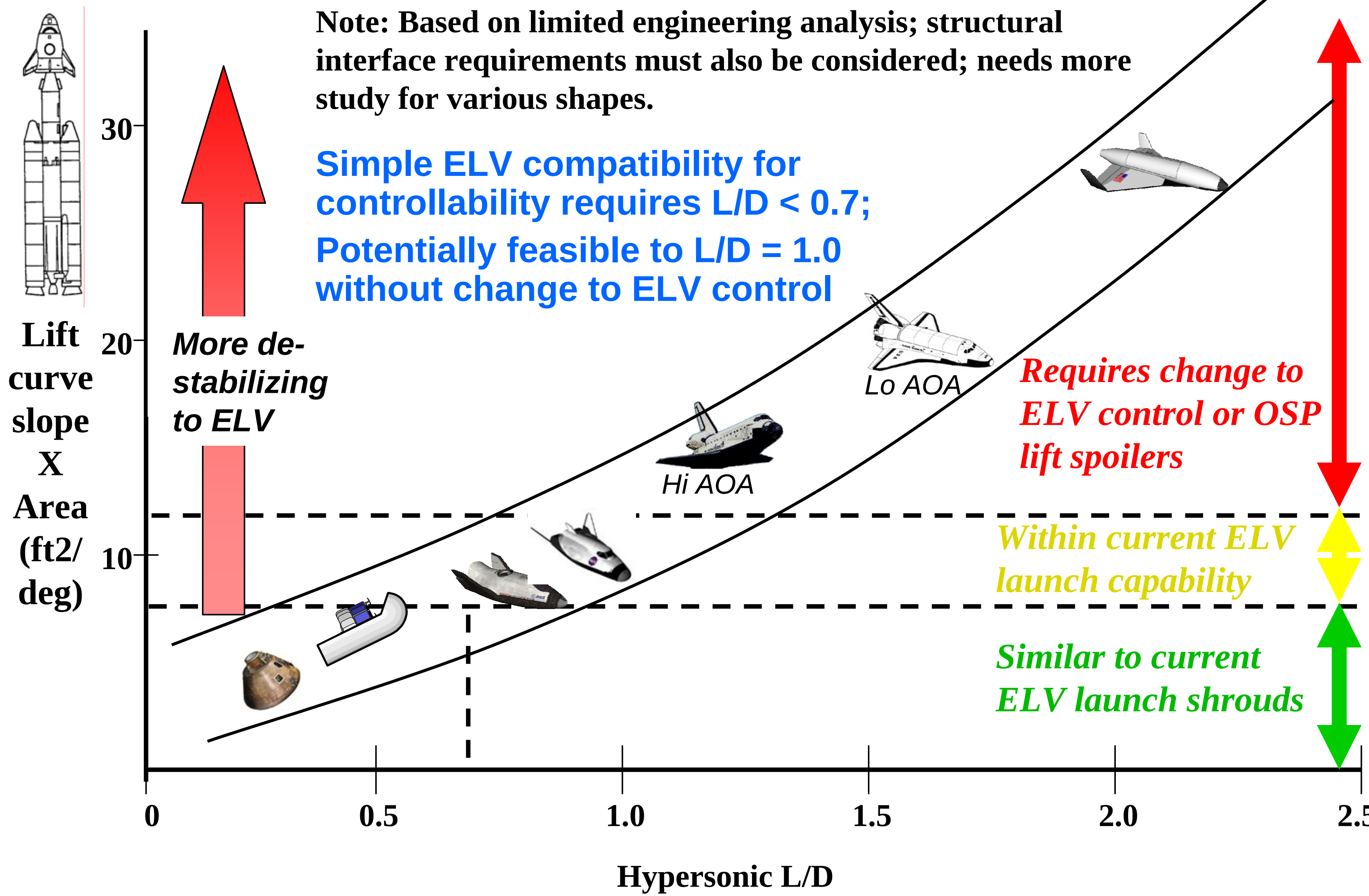


ELV Launch Controllability (OSP sized for 5-7 crew)

Note: Based on limited engineering analysis; structural interface requirements must also be considered; needs more study for various shapes.

Simple ELV compatibility for controllability requires L/D < 0.7;

Potentially feasible to L/D = 1.0 without change to ELV control

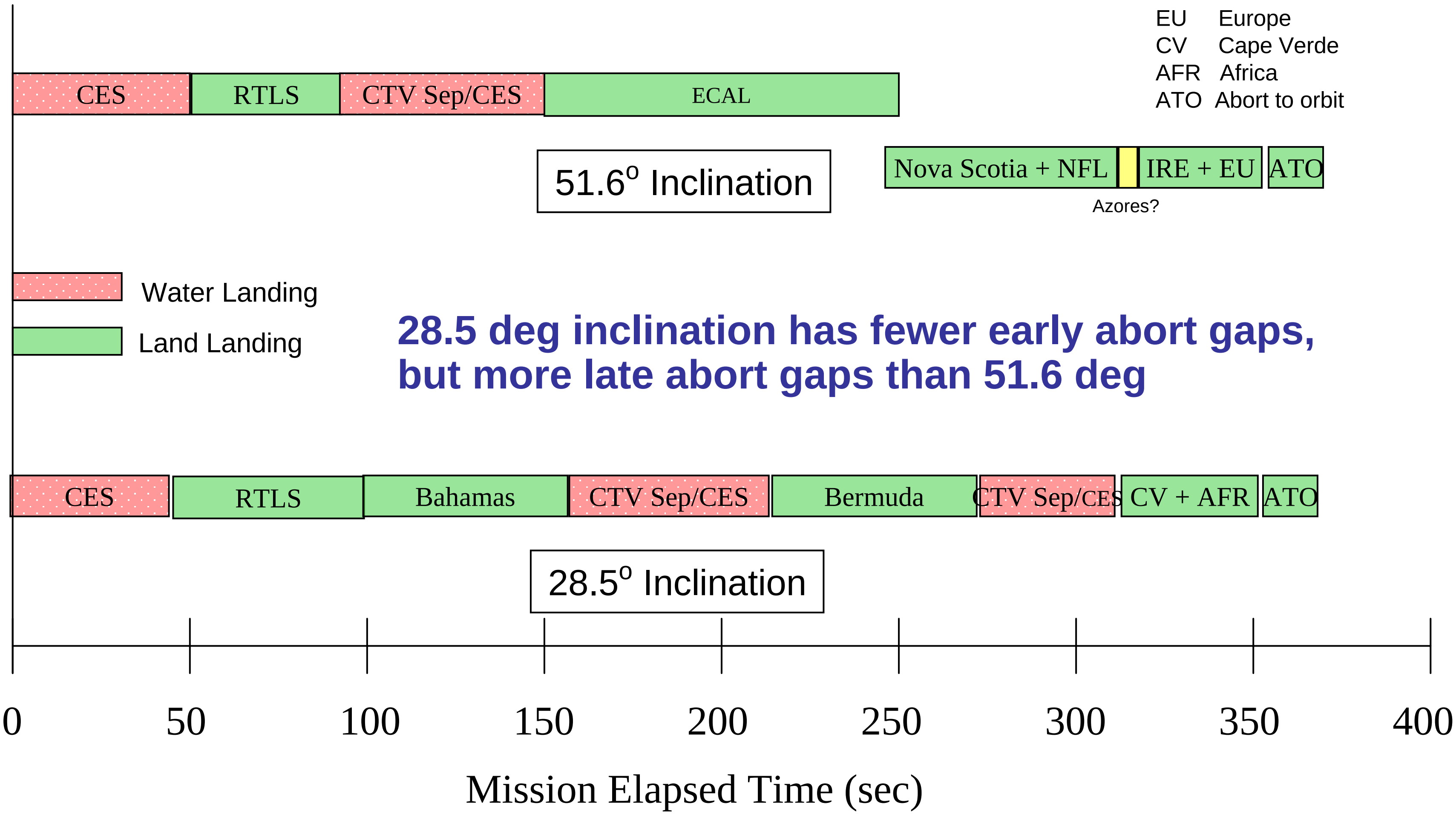


Ascent Abort Gaps (inability to reach land)

Aborts follow total loss of booster thrust.

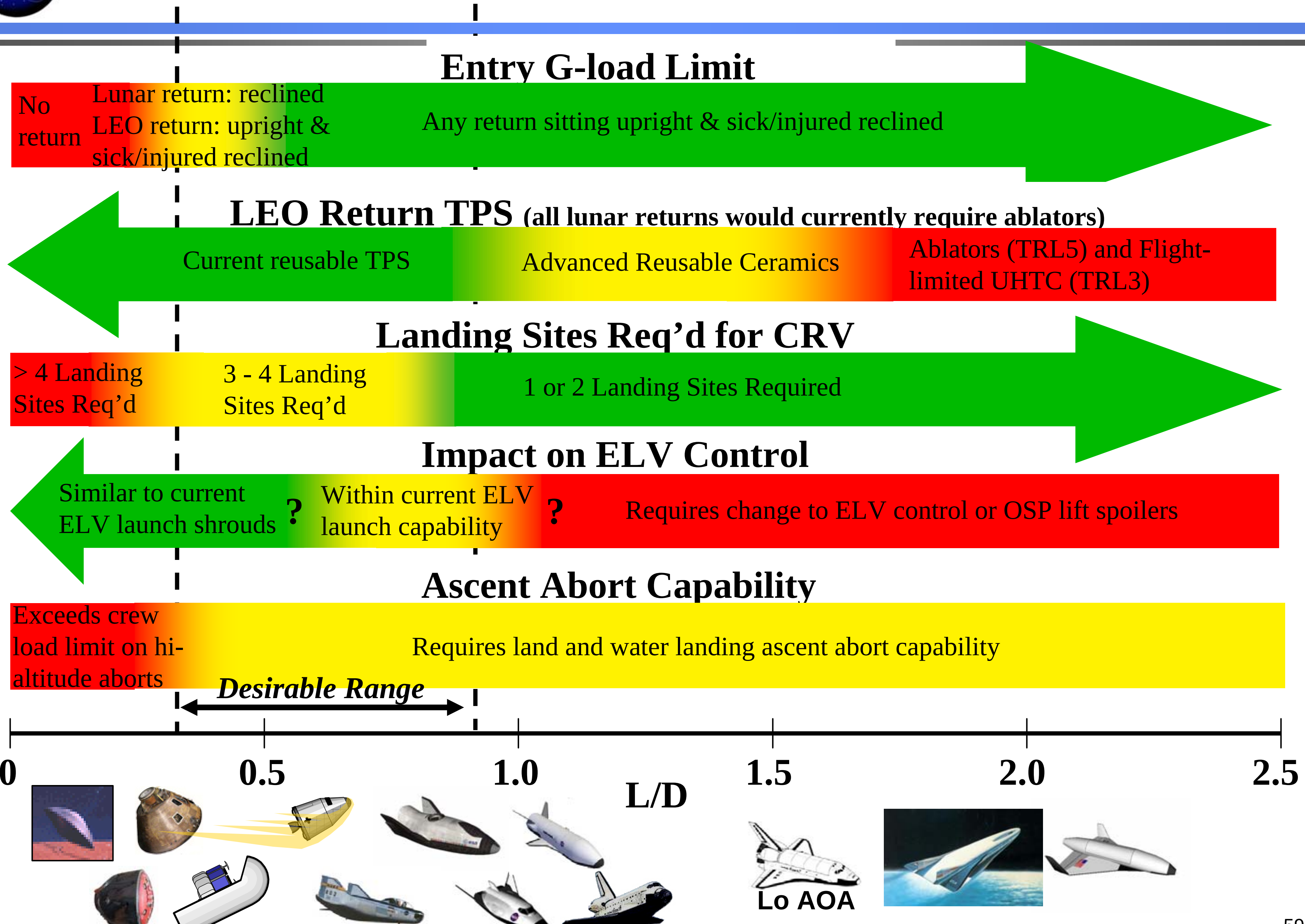
Hypersonic $L/D_{MAX} = 1.85$

ECAL East Coast
NFL Newfoundland
IRE Ireland
EU Europe
CV Cape Verde
AFR Africa
ATO Abort to orbit



28.5 deg inclination has fewer early abort gaps, but more late abort gaps than 51.6 deg

Bottom Line


Entry G-load Limit
No return
Lunar return: reclined
LEO return: upright & sick/injured reclined
Any return sitting upright & sick/injured reclined
LEO Return TPS (all lunar returns would currently require ablators)
Current reusable TPS
Advanced Reusable Ceramics
Ablators (TRL5) and Flight-limited UHTC (TRL3)
Landing Sites Req'd for CRV
> 4 Landing Sites Req'd
3 - 4 Landing Sites Req'd
1 or 2 Landing Sites Required
Impact on ELV Control
Similar to current ELV launch shrouds
?
Within current ELV launch capability
?
Requires change to ELV control or OSP lift spoilers
Ascent Abort Capability
Exceeds crew load limit on hi-altitude aborts
Requires land and water landing ascent abort capability
Desirable Range
0
0.5
1.0
L/D
1.5
2.0
2.5
Lo AOA

Other Considerations

- **Volumetric efficiency**
  - Weight is exceedingly critical for EELV launch and missions beyond LEO
- **System complexity and cost**
  - Tends to increase with L/D
- **New TPS materials real applicability**
  - Weight
  - Fabrication
  - Attachment
  - Low emissivity (heat flux) - need for coating
- **Probability of Loss of Crew or Vehicle rather than strictly abort gaps**
- **Landing and recovery techniques and systems**
  - Refurbishment and operations
  - Impact loads
- **Crew seating and loads directions**
- **Structural I/F requirements with ELV**
  - Bending moments
  - Attach points
- **Additional actual landing site locations effects on CRV mission time**
- **Potential shape "add-ons" for different missions**

What Next?

- **Complete general trade studies of shape (L/D) impacts**
  - Launch on ELV
    - Controllability
    - Structural interface requirements
  - Probability of Loss of Crew or Vehicle
    - Launch abort survival in cold water requirements
    - SAR time for various crossrange
    - Vehicle loss impact to overall cost
  - Actual potential landing sites and crossrange requirement to meet CRV mission timeline at 51.6 deg inclination
  - Refurbishment and operations costs of various landing systems

- **More detailed trade studies of candidate vehicles in L/D range dictated by requirements**
  - Perhaps three designs to investigate across desired L/D range
  - System volume and weight
  - TPS requirements and weight
  - Launch and entry abort system requirements
  - Landing systems applicability
  - ELV launch requirements
  - Development and operations costs

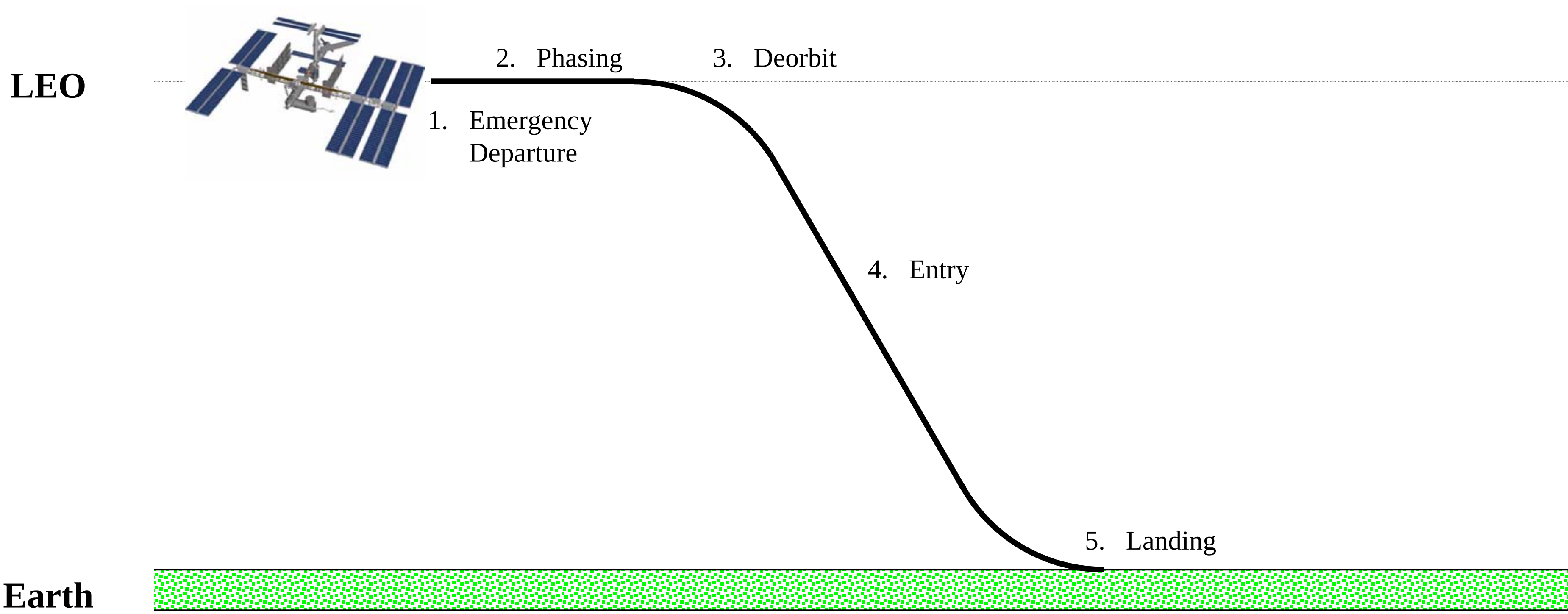
Backup 2

ISS Crew Return Vehicle

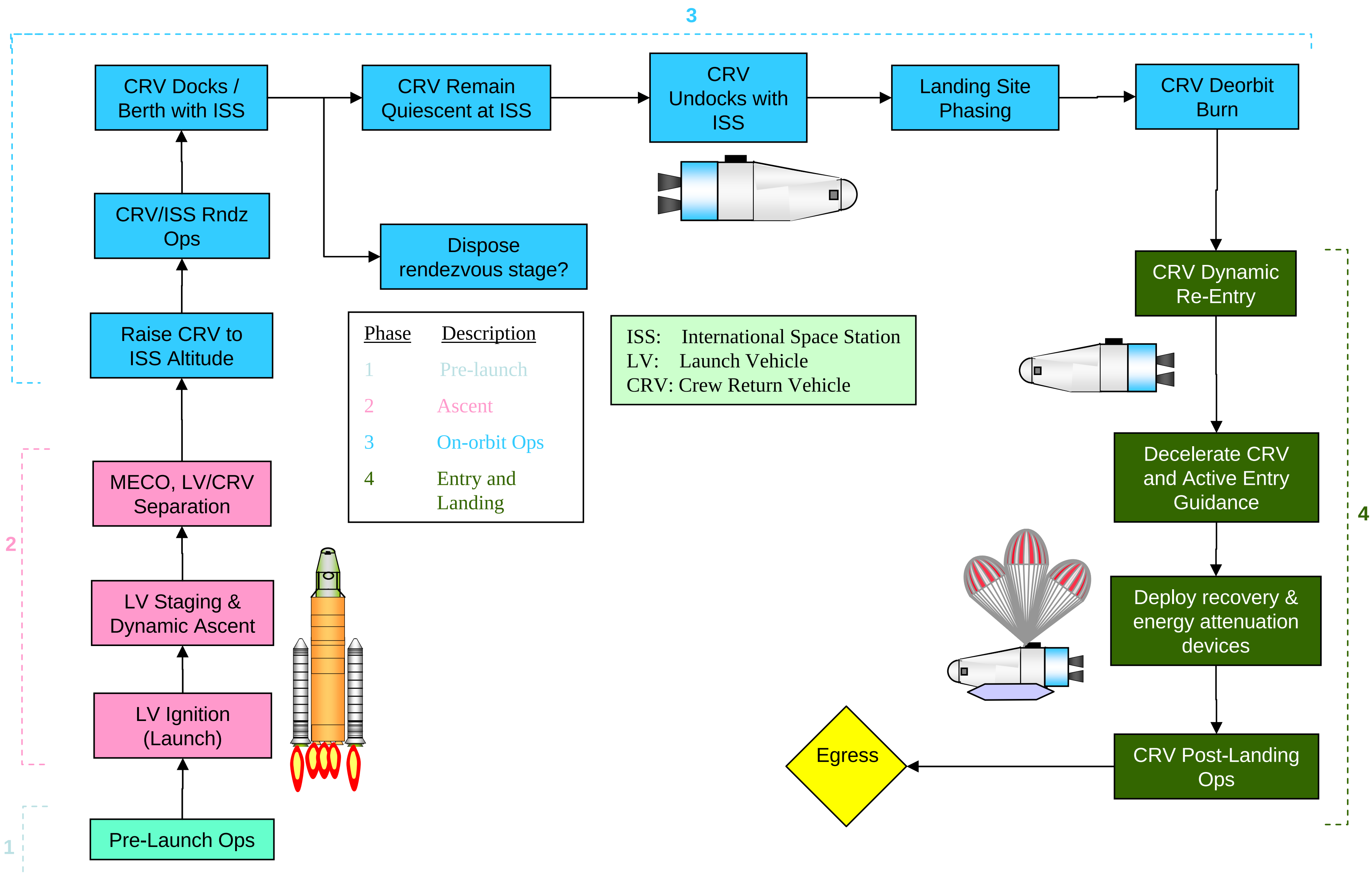
- **Primary CRV function is the expeditious return of crew from ISS due to:**
  - Crew medical emergencies
  - ISS emergency situations
  - Grounded Shuttle fleet

- **Key functional needs which drive the CRV design:**
  - Capability to return 4 crew (7 desired)
  - Capability for a quick departure from an uncontrolled ISS
  - Capability to return a sick or injured crewmember
  - Total mission duration less than one day
  - Capability to be stored for a long duration (2-years) (TBD) at ISS
  - The desire for the system to be reusable

Notional Mission Profile
ISS Crew Return



CRV Ops Flow

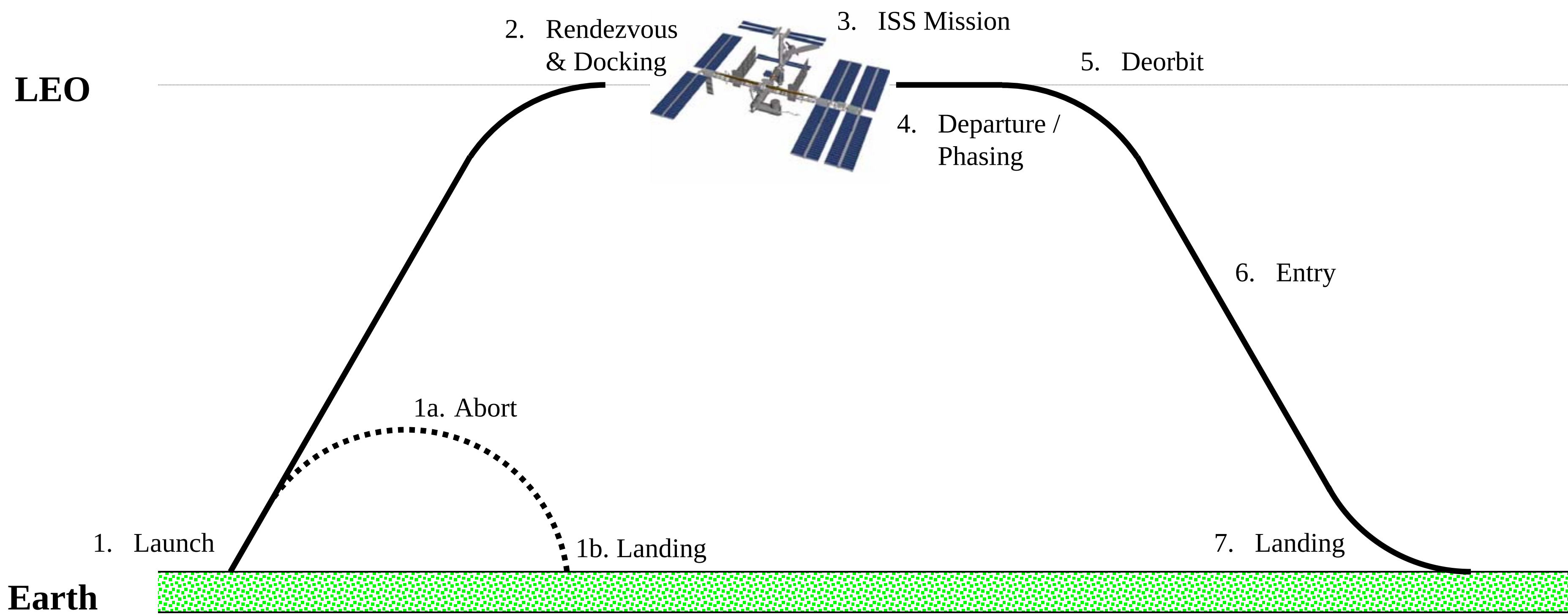

3
CRV Docks / Berth with ISS
CRV Remain Quiescent at ISS
CRV Undocks with ISS
Landing Site Phasing
CRV Deorbit Burn
CRV/ISS Rndz Ops
Dispose rendezvous stage?
Raise CRV to ISS Altitude
Phase Description
1 Pre-launch
2 Ascent
3 On-orbit Ops
4 Entry and Landing
ISS: International Space Station
LV: Launch Vehicle
CRV: Crew Return Vehicle
CRV Dynamic Re-Entry
Decelerate CRV and Active Entry Guidance
4
2
MECO, LV/CRV Separation
LV Staging & Dynamic Ascent
LV Ignition (Launch)
Deploy recovery & energy attenuation devices
Egress
CRV Post-Landing Ops
1
Pre-Launch Ops

Crew Transfer Vehicle

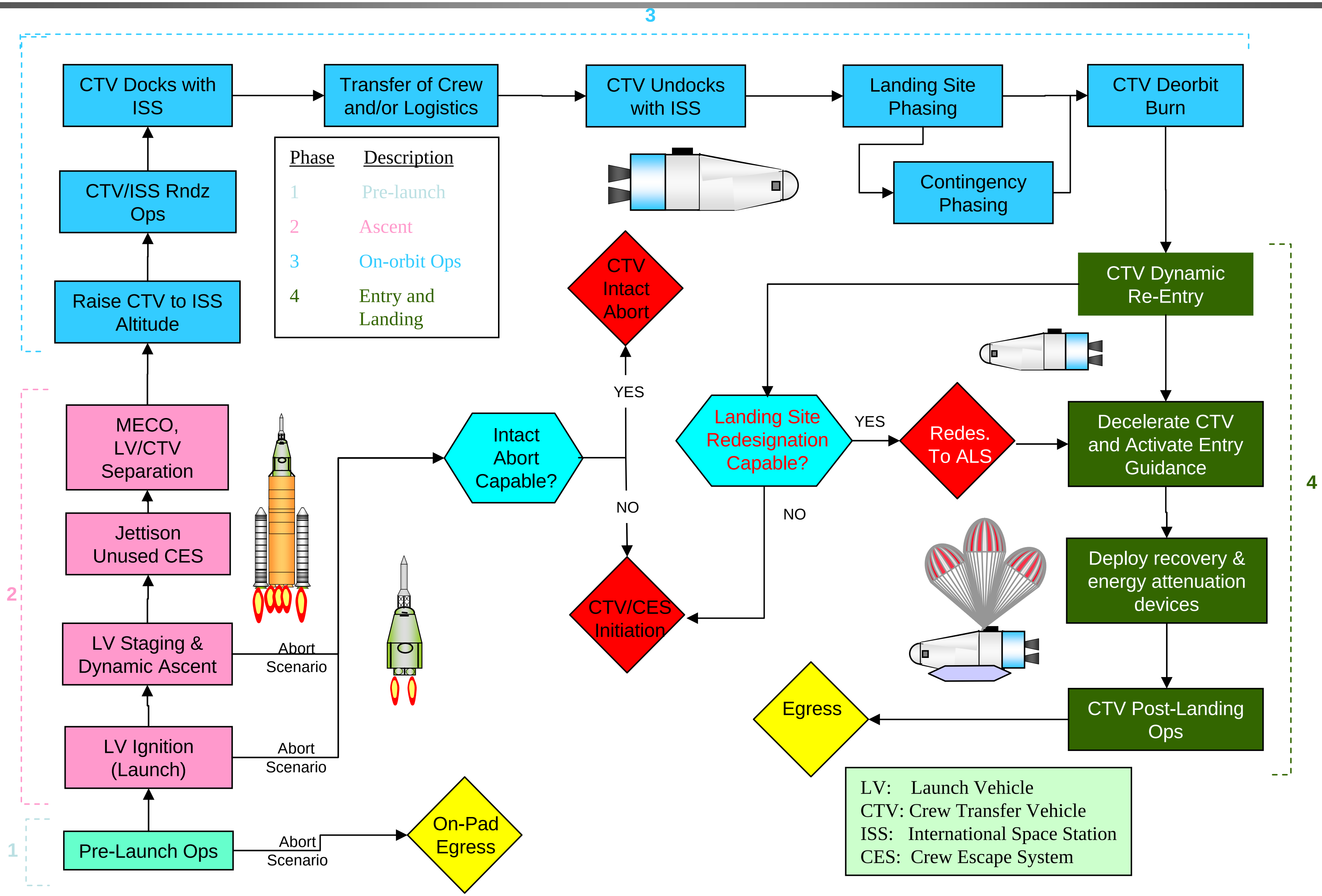
- **The Crew Transfer Vehicle (CTV) provides an alternate crew delivery and return capability to and from low-Earth orbit:**

- **Key functional needs which drive the CTV design:**
  - Capability to exchange 3 ISS crew (implies a total crew complement of 4-5 depending on operational requirements)
  - Capability to be launched on US EELV-H launch vehicles
  - Capability to be launched on future US launch vehicles (reusable launch vehicle)
  - Provide adequate crew escape methods during ascent
  - Total mission duration of 12 days for ISS crew exchange missions
  - System should be reusable and able perform a soft runway landing (wings and wheels)
  - The CTV shall be capable of performing other missions, such as satellite servicing, when combined with other (additional) mission elements.

Notional Mission Profile
Crew Transfer Vehicle



CTV ISS Ops Flow



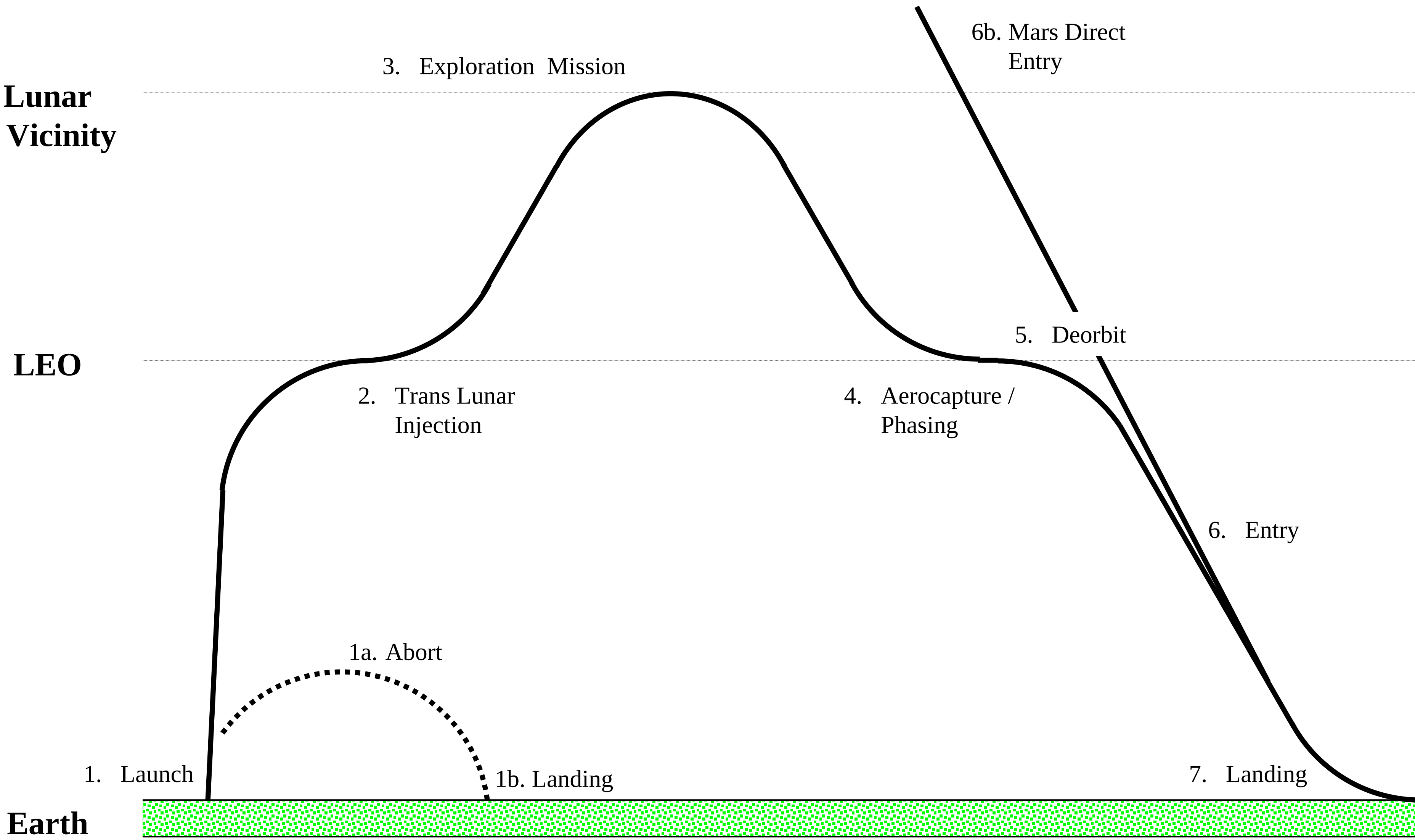
Exploration Transfer Vehicle

- **Provides the capability to transfer mission crew from Earth, to the lunar vicinity, and return back to Earth:**
- **Includes capability for transfers to high earth orbit for potential Mars mission concepts**
- **Key functional needs which drive the XTV design:**
  - Capability to support up to 6 exploration mission crew
  - Total mission duration of 12 days active plus 8 days dormant
  - The desire for the system to be reusable
  - Capability to accommodate lunar return velocities

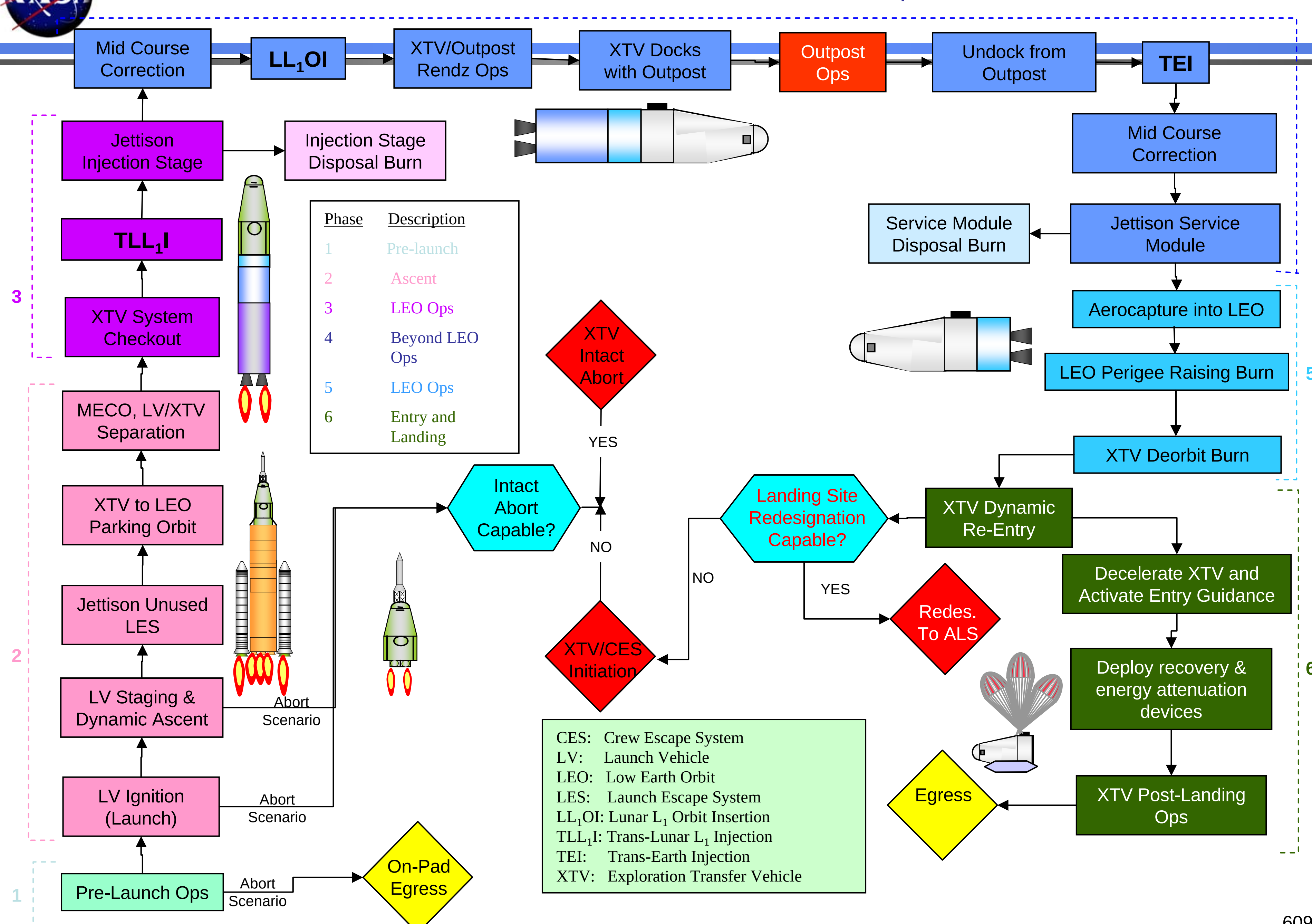
- **Provides the capability to return exploration mission crews from Mars return trajectories to the surface of the Earth:**

- **Key functional needs which drive the Mars Earth Return Vehicle design:**
  - Capability to support up to 6 exploration mission crew
  - Capable of being stored in a dormant state during the Mars mission
  - Total active mission duration of one day
  - Capability to accommodate Mars return velocities

Notional Mission Profile
Exploration Mission



XTV Ops Flow



Phase	Description
1	Pre-launch
2	Ascent
3	LEO Ops
4	Beyond LEO Ops
5	LEO Ops
6	Entry and Landing

CES: Crew Escape System
LV: Launch Vehicle
LEO: Low Earth Orbit
LES: Launch Escape System
LL_1OI: Lunar L_1 Orbit Insertion
TLL_1I: Trans-Lunar L_1 Injection
TEI: Trans-Earth Injection
XTV: Exploration Transfer Vehicle