JSC-63725

NASA's Decadal Planning Team

Mars Mission Analysis Summary

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FOREWORD

In June 1999 the NASA Administrator chartered an internal NASA task force, termed the Decadal Planning Team, to create new integrated vision and strategy for space exploration. The efforts of the Decadal Planning Team evolved into the Agency-wide team known as the NASA Exploration Team (NEXT). This team was also instructed to identify technology roadmaps to enable the science-driven exploration vision, established a cross-Enterprise, cross-Center systems engineering team with emphasis focused on revolutionary not evolutionary approaches. The strategy of the DPT and NEXT teams was to "Go Anywhere, Anytime" by conquering key exploration hurdles of space transportation, crew health and safety, human/robotic partnerships, affordable abundant power, and advanced space systems performance. Early emphasis was placed on revolutionary exploration concepts such as rail gun and electromagnetic launchers, propellant depots, retrograde trajectories, nano structures, and gas core nuclear rockets to name a few. Many of these revolutionary concepts turned out to be either not feasible for human exploration missions or well beyond expected technology readiness for near-term implementation. During the DPT and NEXT study cycles, several architectures were analyzed including missions to the Earth-Sun Libration Point (L2), the Earth-Moon Gateway and L1, the lunar surface, Mars (both short and long stays), one-year round trip Mars, and near-Earth asteroids. Common emphasis of these studies included utilization of the Earth-Moon Libration Point (L1) as a staging point for exploration activities, current (Shuttle) and near-term launch capabilities (EELV), advanced propulsion, and robust space power. Although there was much emphasis placed on utilization of existing launch capabilities, the team concluded that missions in near-Earth space are only marginally feasible and human missions to Mars were not feasible without a heavy lift launch capability. In addition, the team concluded that missions in Earth's neighborhood, such as to the Moon, can serve as stepping-stones toward further deep-space missions in terms of proving systems, technologies, and operational concepts.

The material contained in this presentation was compiled to capture the work performed by the Mars Sub-Team of the DPT NEXT efforts in the late 1999-2001 timeframe.

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DPT Mars Short-Stay Mission

Architecture Status

Mid-Term (2018) Nuclear Thermal Propulsion System Option

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July 11, 2000

Outline

- Ground Rules and Assumptions
- Trajectory Options
- Mission Case Studies
- Systems Overview
  - Transit Habitat
  - Descent / Ascent Vehicle
  - Interplanetary Transportation
- Technology Needs
- Architecture Summary

Guiding Principles

- Go Anywhere - Go Anytime
- Avoid political obstacles - No HLLV
- Limit the total mission duration (goal of one-year)
- Push advanced technologies
  - Advanced space transportation - NTR
  - Advanced materials (factor of 9)

Mars Short-Stay Ground Rules and Assumptions

- Detailed GR&A provided in the “Mars ‘Short-Mission’ Scenario/Architecture GR&A” document dated 4-10-2000

- Primary DPT GR&A which drive this architecture include:
  - “Go Anywhere – Go Anytime” Philosophy
  - Short stay on Mars
  - Short total mission duration – goal of one year round-trip
  - First cargo mission 2016, First human mission 2018
  - Four crew
  - Zero-g transits
  - Technology freeze to TRL 6 by 2011
  - Factor of nine improvement for primary and secondary structures
  - Transportation Assumptions
    - EELV-H for cargo delivery to Earth orbit
    - Bi-Modal Nuclear Thermal Propulsion for interplanetary transits
    - Long-term cryogenic fluids storage

Purpose of Architecture Analysis

- Development of architectures serve as an "Existence Proof" of the various technology options and mission approaches under consideration
  - Feasibility check
  - Plausibility

- Architecture analysis includes detailed end-to-end analysis of
  - Mission goals and objectives
  - Mission sequence
  - Approaches to minimizing risks and maximizing crew safety
  - Vehicles and systems
  - Technology applicability and benefits
  - System drivers
  - Operations concepts
  - Schedules

From Earth – to the destination – back to Earth

Architecture Study Team

Architecture Integration (JSC)

- *DPT Transportation* (MSFC)
- *Cost Analysis* (LaRC)
- *Science/Scenario* (HQ, ?)

Trajectory / Mission Analysis (JSC, MSFC, GRC)

NTR Analysis (GRC)

Crew Systems (JSC)

Power System (GRC)

Operations (JSC)

Aeroassist (LaRC, JSC)

Risk Analysis (JSC)

Ground Processing (KSC)

Study Process

Initial Payload Definition
(JSC)

- Transit Habitat
- Descent/Ascent Vehicle

Transportation Studies
(MSFC)

- Abundant Chemical, Tethers, EP, NTR, VASIMR, Pulsed Detonation, M2P2, Beamed MPD, etc.

Payload / Mission Refinement
(JSC)

- Trajectory Options
- Advanced Materials
- Trip-time sensitivities
- Vehicle configurations

NTR as an example

NTR Concept Initialized
(Architecture Team)

- Initialization Package
- Case Studies Defined
- System Concepts Refined

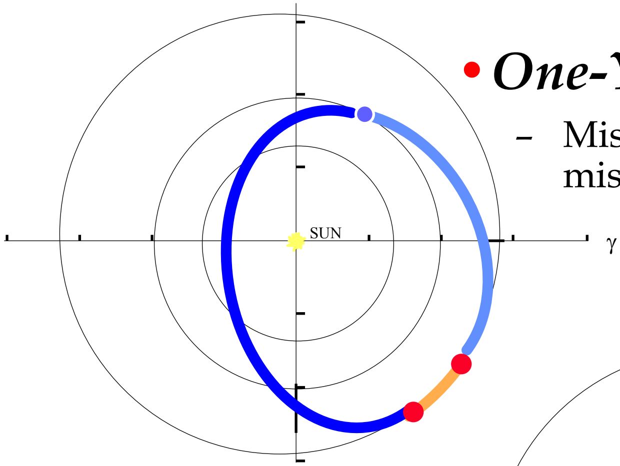
NTR Case Study Analysis
(GRC)

- Feasibility
- Initial Mass in LEO
- Number of Launches

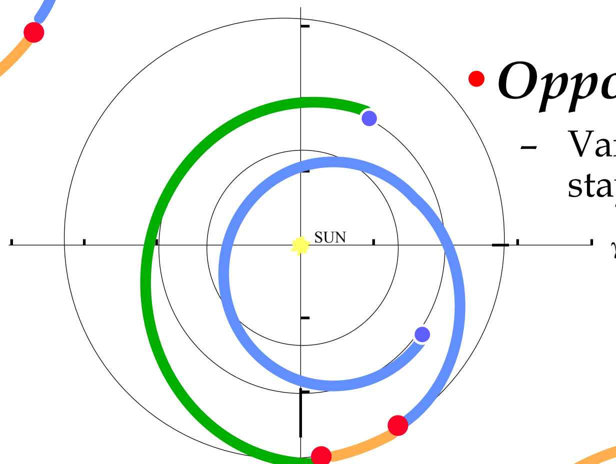
Results and Issues
(Architecture Team)

Architecture Refinement

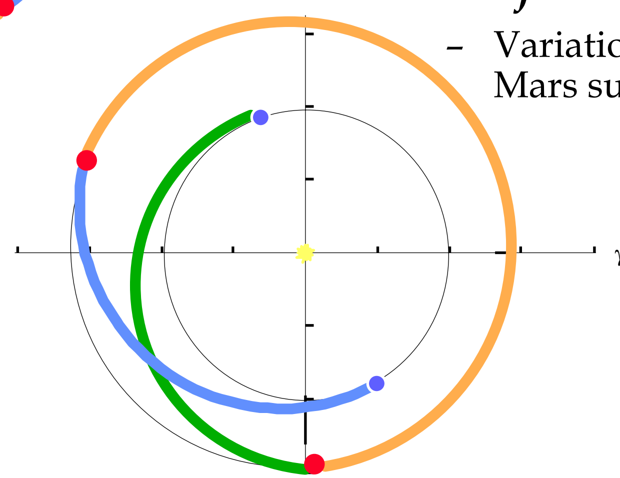
Trajectory Options Under Consideration



- ***One-Year Mission***
  - Missions with short Mars surface stays with total mission duration of one year or less



- ***Opposition Class Mission***
  - Variations of missions with short Mars surface stays and may include Venus swing-by



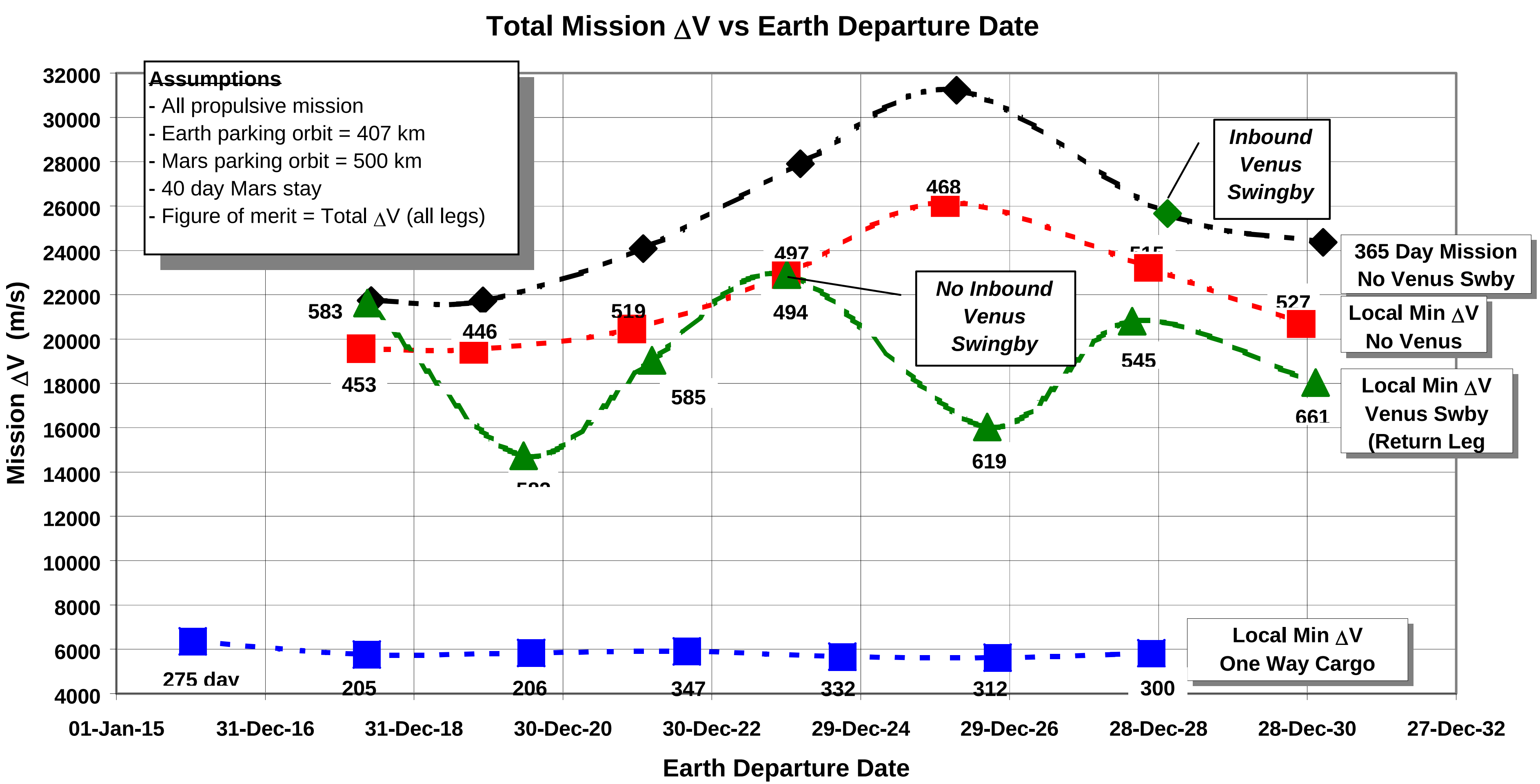
- ***Conjunction Class Mission***
  - Variations of missions with long Mars surface stays.

Outbound
Surface Stay
Inbound

Total Mission ΔV vs Earth Departure Date

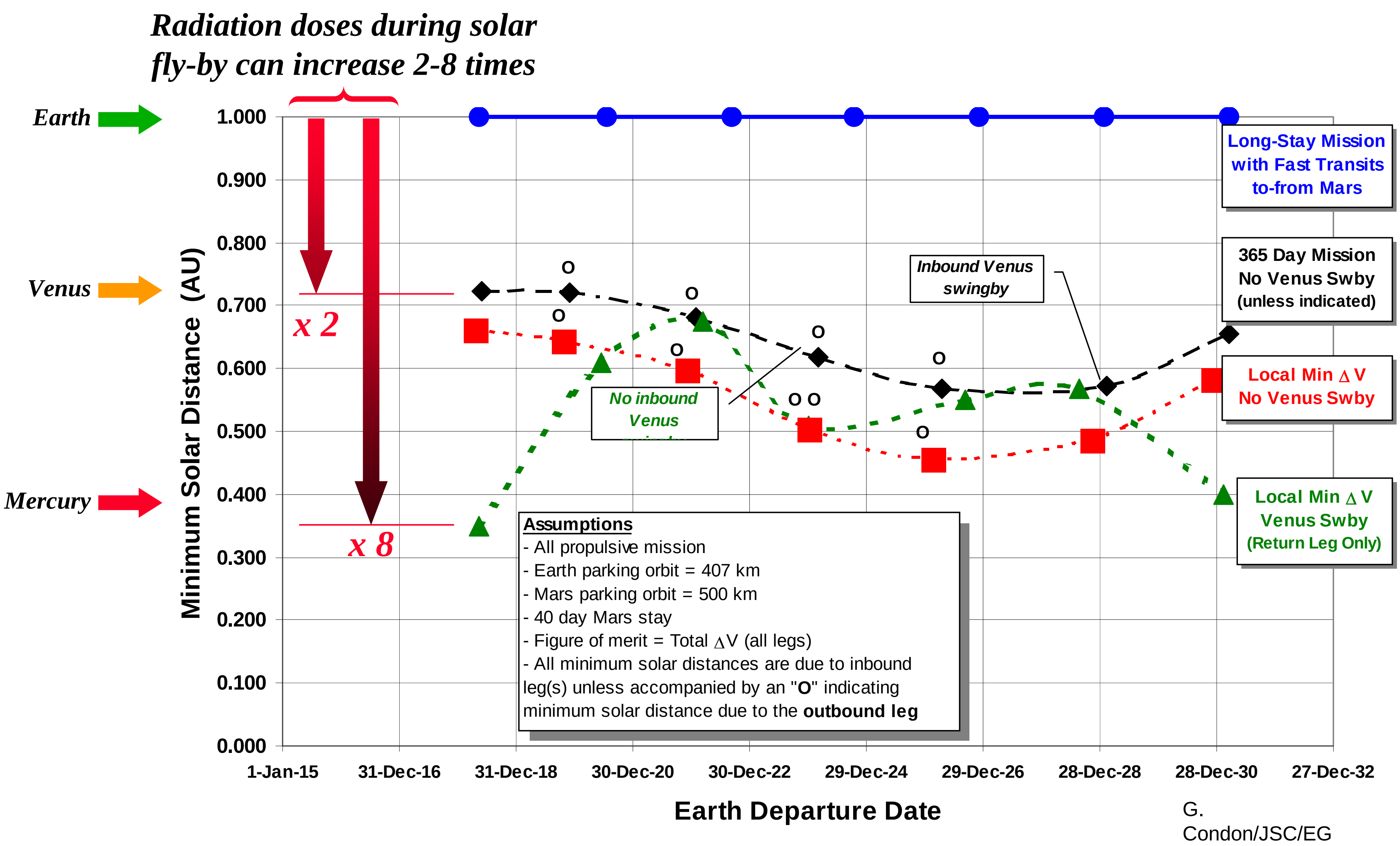
Short-Stay Mars Missions

Exploration Office



Minimum Solar Distance vs. Mission Opportunity

Short-Stay Mars Missions



Mars Short-Stay Initial Case Studies

- Prior to performing detailed architectural analysis a series of focused case studies were conducted

- Primary case study variables included
  - **WORST** versus **BEST** mission opportunity
  - **HIGH** versus **LOW** Mars parking orbit
  - Pre-deploy **LANDER** versus pre-deploy **LANDER & RETURN VEHICLE**

- The results were used to determine the relative benefits and technology needs for the various mission approaches under consideration

Mars Short-Stay Initial Case Studies

	Opportunity	Energy Level	Trip Time	Mars Orbit	Pre-Deploy
6.1	Worst (2026)	Minimize ΔV	< 650 days	500 x 500 km	Lander
6.2	Worst (2026)	Minimize ΔV	< 650 days	250 x 33,793 km	Lander
6.3	Worst (2026)	Minimize ΔV	< 650 days	500 x 500 km	Lander & Return Vehicle
6.4*	Worst (2026)	Minimize ΔV	< 650 days	250 x 33,793 km	Lander & Return Vehicle
6.5	Best (2018)	Minimize ΔV	< 650 days	500 x 500 km	Lander
6.6*	Best (2018)	Minimize ΔV	< 650 days	250 x 33,793 km	Lander
6.7	Best (2018)	One-Year	< 365 days	500 x 500 km	Lander
6.8	Best (2018)	One-Year	< 365 days	250 x 33,793 km	Lander
6.9	Best (2018)	One-Year	< 365 days	500 x 500 km	Lander & Return Vehicle
6.10	Best (2018)	One-Year	< 365 days	250 x 33,793 km	Lander & Return Vehicle
6.11	Best (2018)	Minimize ΔV	< 650 days	500 x 500 km	Lander & Return Vehicle
6.12	Best (2018)	Minimize DV	< 650 days	250 x 33,793 km	Lander & Return Vehicle

Mars Mission Overview
(NTR Option)

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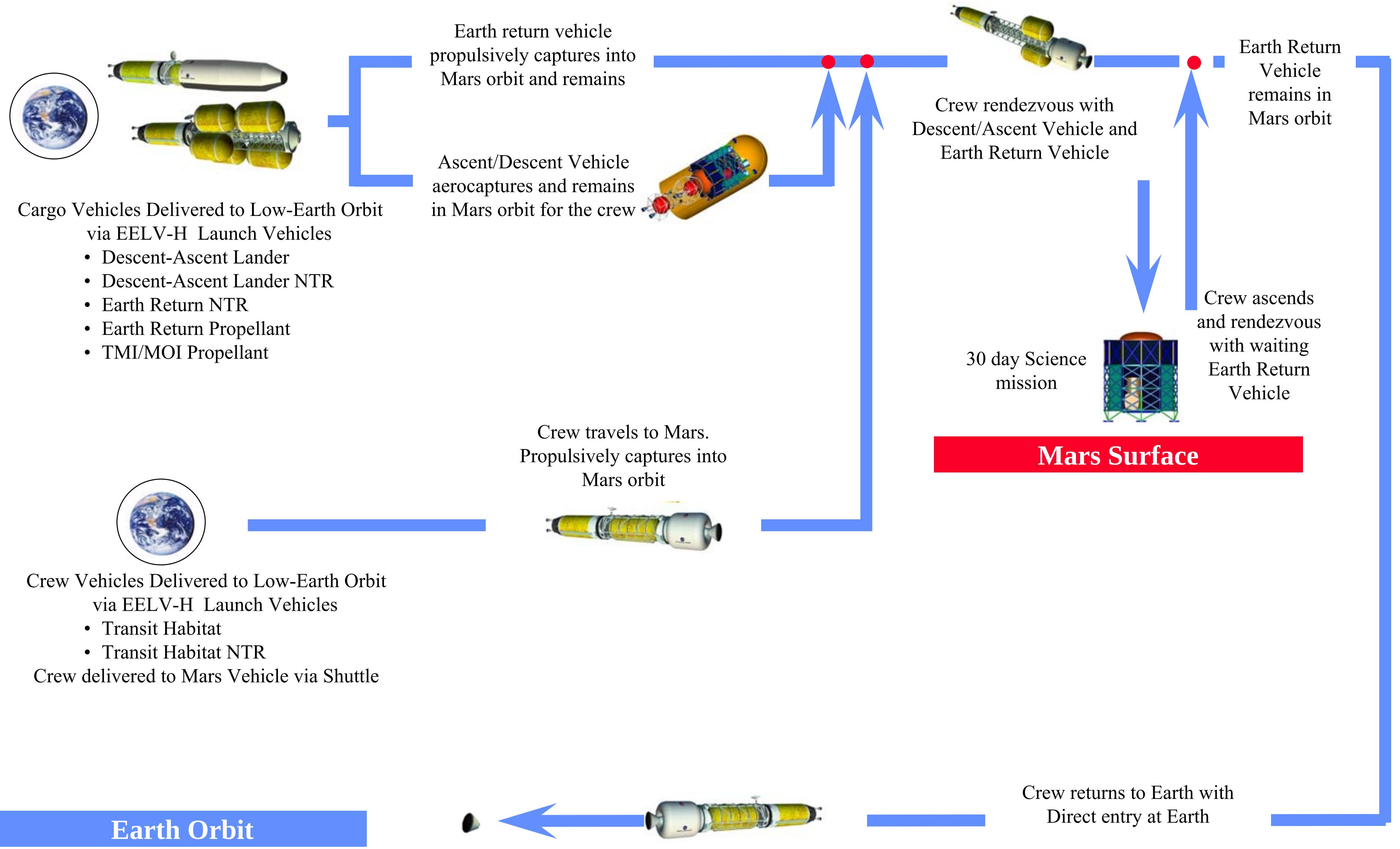
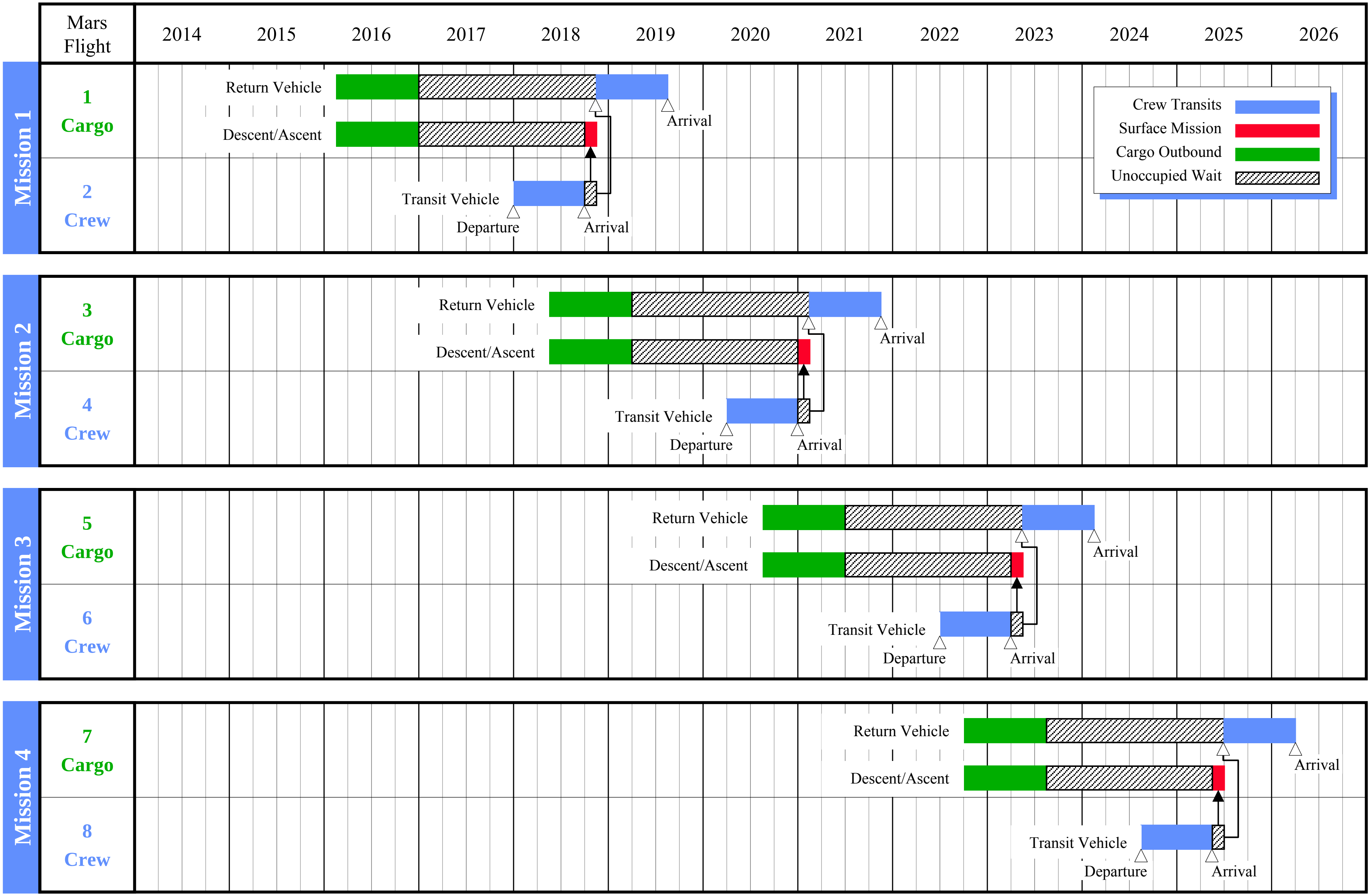


Short-Stay Mission Sequence



Mars Short-Stay Mission
Initial NTR Case Study Results

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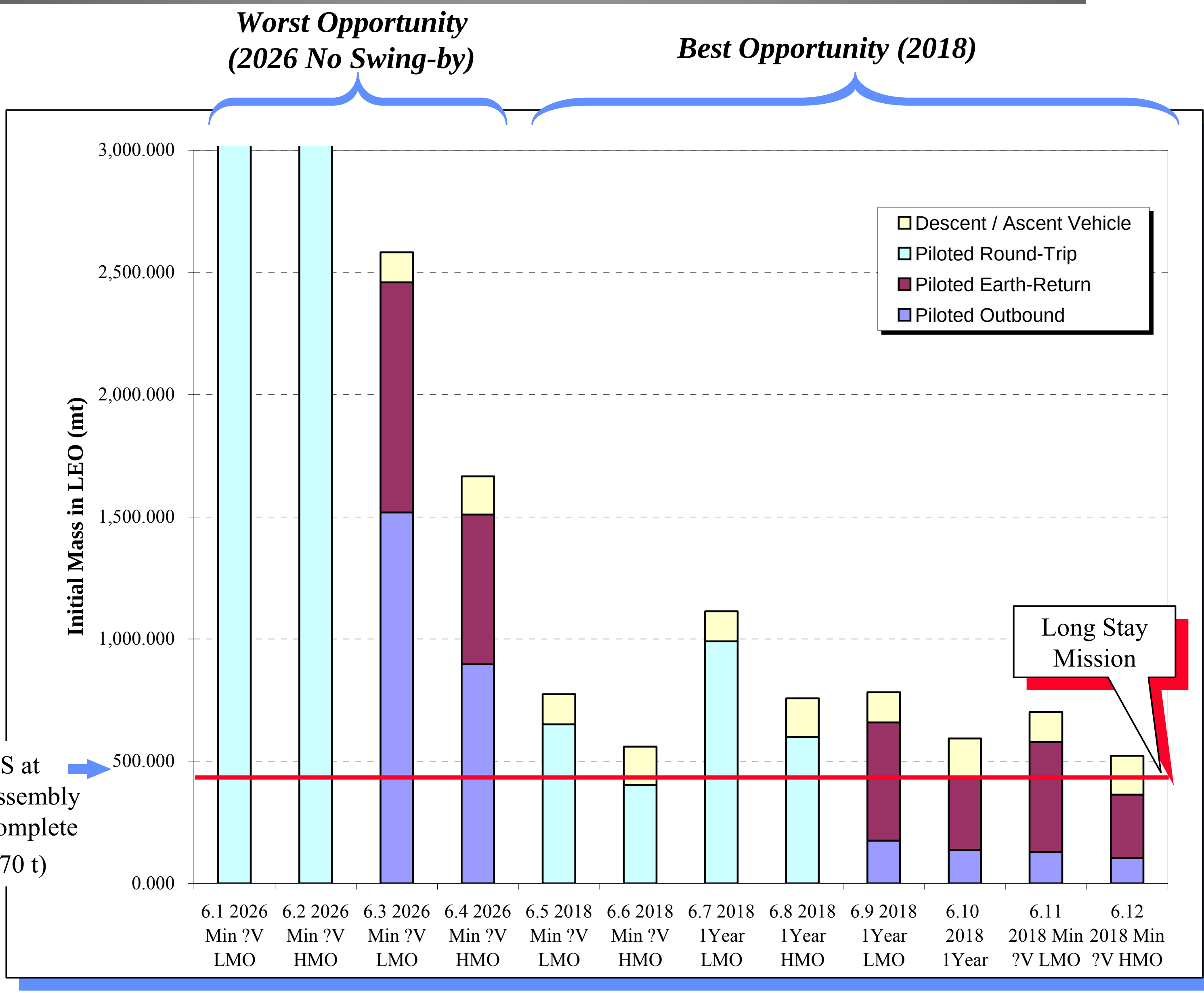

ISS at Assembly Complete (470 t)

Ref. Glenn Research Center

EELV-H Launch/Assembly Scenario

Best Case (2018) Mission Opportunity

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LANDER AND RETURN PROPELLANT

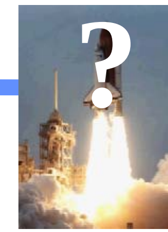
7 — **4 Vehicle**, **3 Propellant Tanks**

9 — **2 Vehicle**, **7 Propellant Tanks**

<u>Cargo Launches</u>
Lander Ascent, Descent Aerobrake assembled in LEO

<u>STS</u>
Crew involvement TBD

<u>Cargo Launches</u>
NTR cargo vehicle & crew return vehicle launched & assembled



<u>STS</u>
Crew involvement TBD

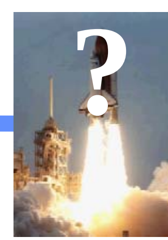
Placeholder for NTR Graphic

PILOTED VEHICLE

4 — **2 Vehicle**, **2 Propellant Tanks**

<u>STS</u>
Transit Habitat, Earth Return Capsule

<u>Cargo Launches</u>
NTR piloted vehicle launched & assembled



<u>STS</u>
Crew involvement TBD

<u>STS</u>
Crew Delivery

Placeholder for NTR Graphic

Mars Short-Stay Launch Strategy
EELV-H Option (Best Opportunity Example)

Best Opportunity (2018) Pre-Deploy Lander and Return Vehicle

Assumptions:

- Evolved commercial EELV, heavy lift option, with exploration unique upper stage
- Large shroud assumed (8 x 30 m)
- 35 mt lift capacity due east (assumed performance - no data yet)
- Only mission hardware considered (need for on-orbit infrastructure not yet determined)
- Crew support for on-orbit assembly, outfitting, and checkout not yet addressed
- Launch rate shown does not support continuous exploration (cargo launches must be supported in the 2018 launch opportunity)
- Detailed analysis not yet complete

	Launch #	Descent / Ascent Vehicle	Vehicle Type
2016 Cargo	1	Ascent Stage	Delta IV-H
	2	Aerobrake / Deorbit Descent Stage	Delta IV-H
	3	Propellants	Delta IV-H
	4	NTR Core Stage	Delta IV-H
	5	NTR Structure Assembly	Delta IV-H
	6	NTR Propellant Tank	Delta IV-H
	7	NTR Propellant Tank	Delta IV-M
		Earth Return Vehicle	
	8	NTR Core Stage	Delta IV-H
	9	NTR Structure Assembly	Delta IV-H
	10	NTR Propellant Tank	Delta IV-H
	11	NTR Propellant Tank	Delta IV-H
	12	NTR Propellant Tank	Delta IV-H
	13	NTR Propellant Tank	Delta IV-M
	14	NTR Propellant Tank	Delta IV-H
	15	NTR Propellant Tank	Delta IV-H
	16	NTR Propellant Tank	Delta IV-M
2018 Crew		**Transit Habitat**	
	17	Transit Habitat	Delta IV-H
	18	Habitat Consumables / ERC / Shadow Shield	Shuttle
	19	NTR Core Stage	Delta IV-H
	20	NTR Structure Assembly	Delta IV-H
	21	NTR Tank Set 2	Delta IV-H
	22	NTR Tank Set 3	Delta IV-H
	23	Checkout Crew	Shuttle
	24	Flight Crew	Shuttle

Cargo launches for next mission

"Shuttle Compatible" Launch/Assembly Scenario

Best Case (2018) Mission Opportunity

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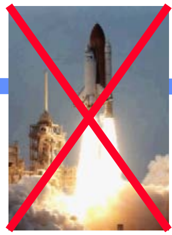
LANDER AND RETURN PROPELLANT

2

6

2 Vehicle
4 Propellant Tanks

Cargo Launches
Descent/ Ascent Vehicle



STS
No Crew involvement

Cargo Launches
NTR cargo vehicle & crew return vehicle launched & assembled

STS
Crew involvement TBD

Placeholder for NTR Graphic

PILOTED VEHICLE

1

1 Vehicle

STS
Transit Habitat, Earth Return Capsule

Cargo Launches
NTR piloted vehicle launched

STS
Crew Delivery

Placeholder for NTR Graphic

EELV-H Launch/Assembly Scenario

Worst Case (2026) Mission Opportunity

Exploration Office

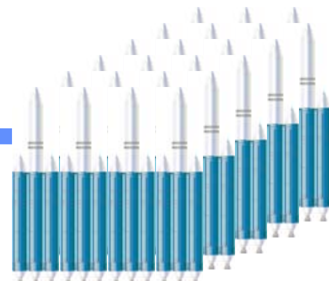
LANDER AND RETURN PROPELLANT

5

Cargo Launches
Assembly platform
Lander, Aerobrake
assembled in LEO

STS
Crew
involvement
TBD

23 **4 Vehicle**
19 Propellant Tanks



Cargo Launches
NTR cargo vehicle &
crew return vehicle
launched & assembled

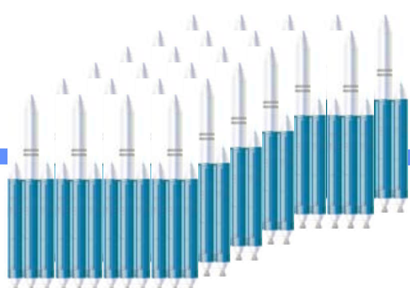
STS
Crew involvement
TBD

Placeholder for NTR Graphic

PILOTED VEHICLE

STS
Transit Habitat, Earth
Return Capsule

26 **2 Vehicle**
24 Propellant Tanks



Cargo Launches
NTR piloted vehicle
launched & assembled

STS
Crew involvement
TBD

STS
Crew Delivery

Placeholder for NTR Graphic

"Shuttle Compatible" Launch/Assembly Scenario

Worst Case (2026) Mission Opportunity

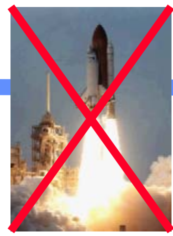
Exploration Office

LANDER AND RETURN PROPELLANT

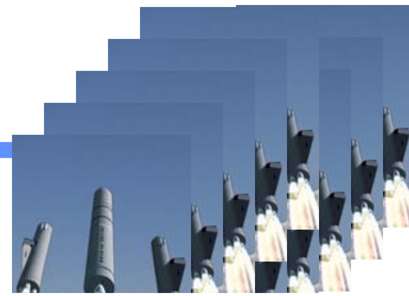
10 — **3 Vehicle**, **7 Propellant Tanks**

1

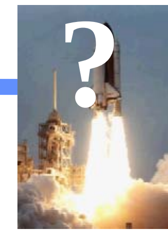
Cargo Launches
Descent/ Ascent Vehicle



STS
No Crew involvement



Cargo Launches
NTR cargo vehicle & crew return vehicle launched & assembled



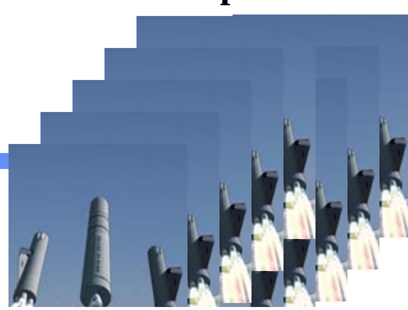
STS
Crew involvement TBD

Placeholder for NTR Graphic

PILOTED VEHICLE

11 — **2 Vehicle**, **9 Propellant Tanks**

STS
Transit Habitat, Earth Return Capsule



Cargo Launches
NTR piloted vehicle launched & assembled

STS
Crew involvement TBD

STS
Crew Delivery

Placeholder for NTR Graphic

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 pre-deploy both the lander and return propellant
  - 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

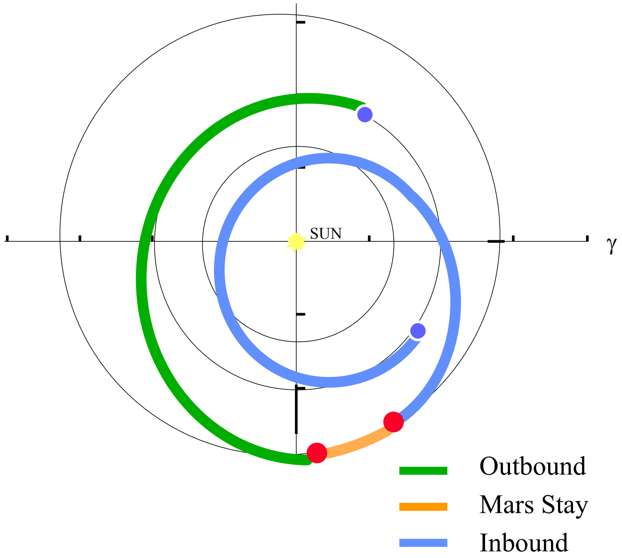
"Go Anywhere / Go Anytime" + Small Launch Vehicle

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%

Utility of Venus Swing-by Trajectories

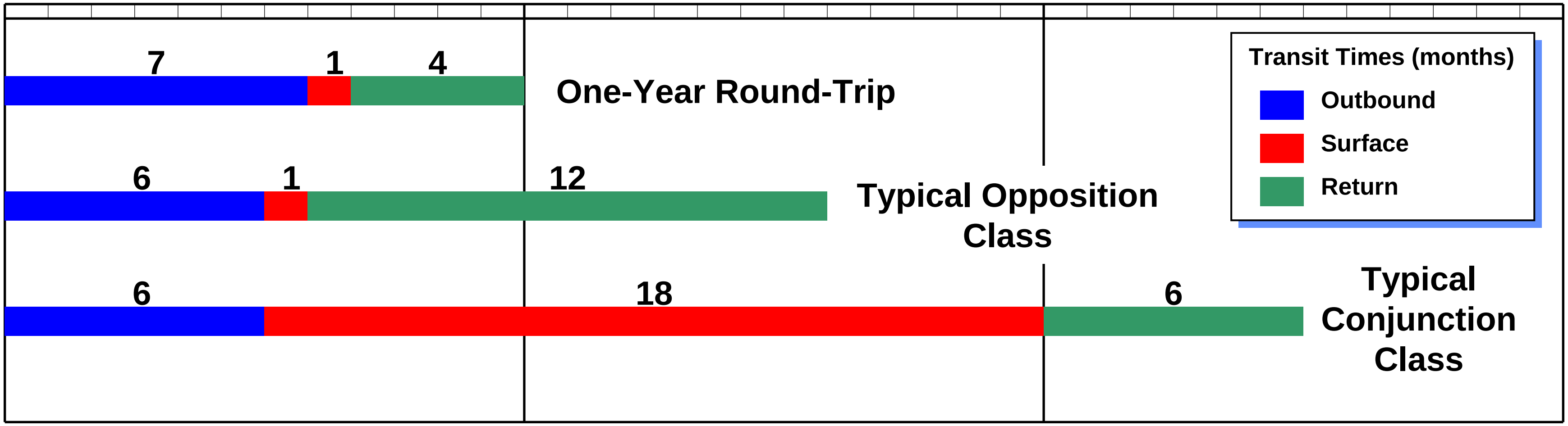
- Venus swing-by trajectories can significantly decrease mission mass
- Characterized by one short leg combined with a long Venus swing-by leg
- Swing-by occurs on either outbound or inbound leg
- Desired to constrain the swing-by to the inbound leg
  - Short outbound leg maximizes crew health at Mars
  - Crew will have Earth support at end of mission
  - Can save up to 39% delta-V
- Allowing the Venus swing-by on either leg
  - Outbound legs can be up to 310 days long
  - Can save up to 42% delta-V
- Issues of solar distance during swing-by need to be addressed
  - Radiation dose to the crew
  - Thermal environment



Trajectory Characteristics Comparison

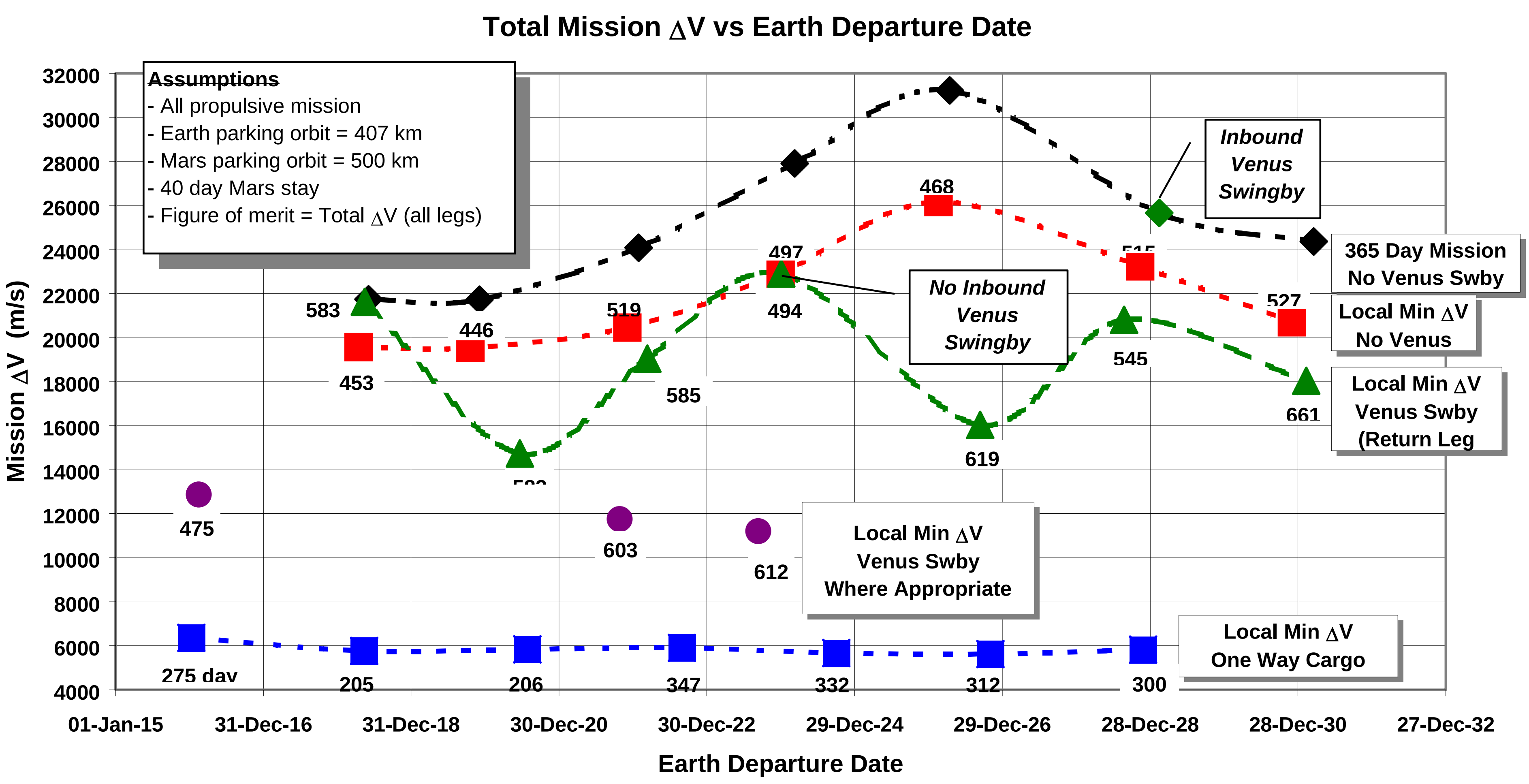
Exploration Office

Parameter	1-Year	Opposition	Conjunction
Interplanetary Delta-V (m/s)	21,700-**31,200**	14,800-**25,800**	5,600-**6,700**
Normalized Mass Ratio (for NTR)	**5.9 – 16.8**	2.7 – **9.3**	1.0 – **1.1**
Mission Duration (months)	**12**	15-**22**	30-**32**
Surface Stay	**1**	**1**	16-**21**
One-Way Transits	4-**9**	6-**13**	6-**7**
Total Transit Time	**11**	14-**21**	8-**13**
Health Concerns			
Sun Closest Approach (AU)	**0.57**-0.72	**0.35** -0.72	**1.0**
% Time in Zero-g Space	92%	93-96%	38-44%
% Time on Mars Surface	8%	7-4%	56-62%

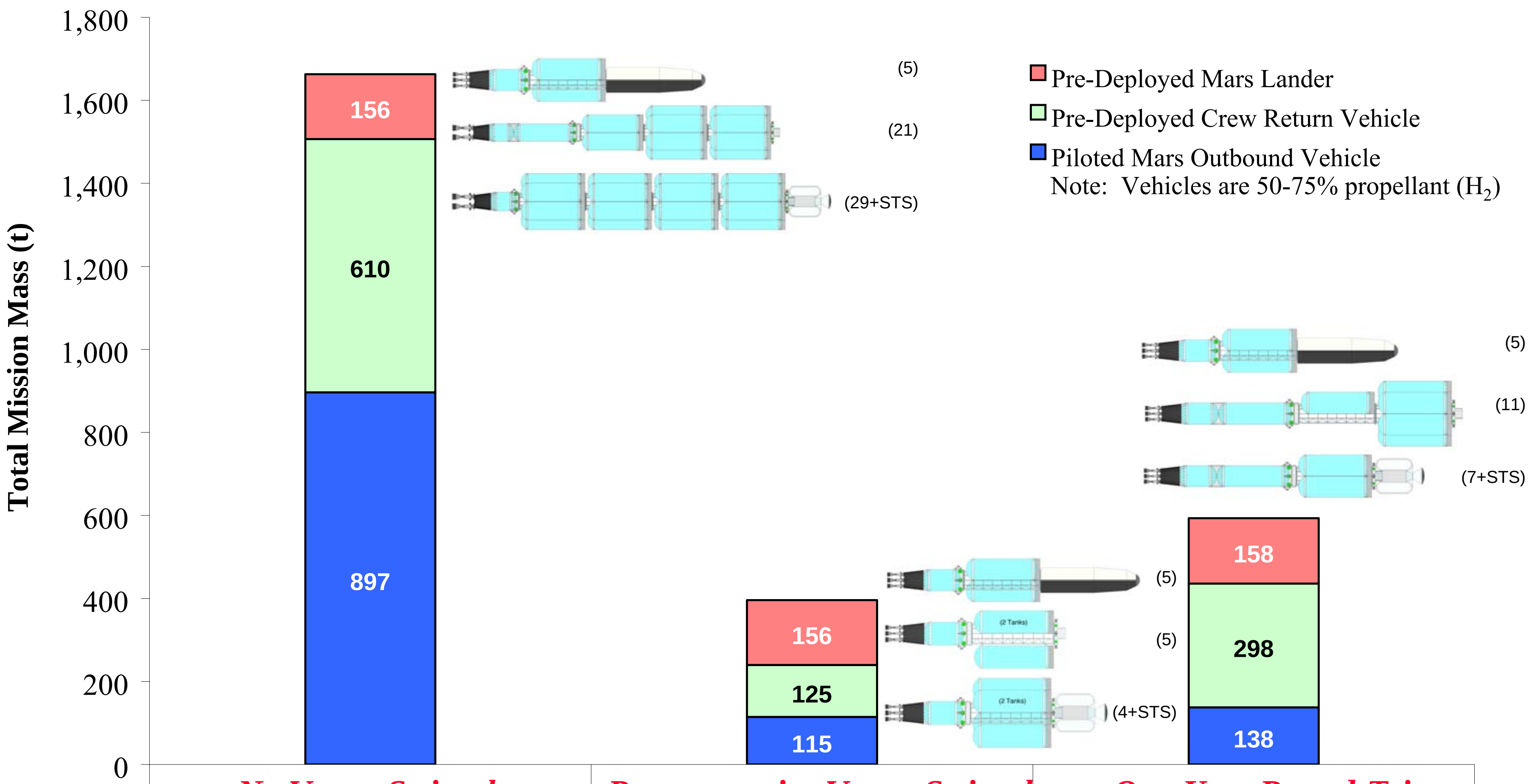


Total Mission ΔV vs Earth Departure Date

Short-Stay Mars Missions



Comparison of Mission Trajectories
Initial Mass and NTR Vehicle Complexity



No Venus Swing-by	*Representative Venus Swing-by*	*One-Year Round-Trip*
2026 (Worst Case)	2016 Launch Opportunity	2018 (only)
460 Days (180-40-240)	479 Days (179-40-250)	365 Days (109-40-216)
Pre-Deploy Lander and Return Vehicle	Pre-Deploy Lander and Return Vehicle	Pre-Deploy Lander and Return Vehicle

Ref. Glenn Research Center

Technology Driven Capabilities

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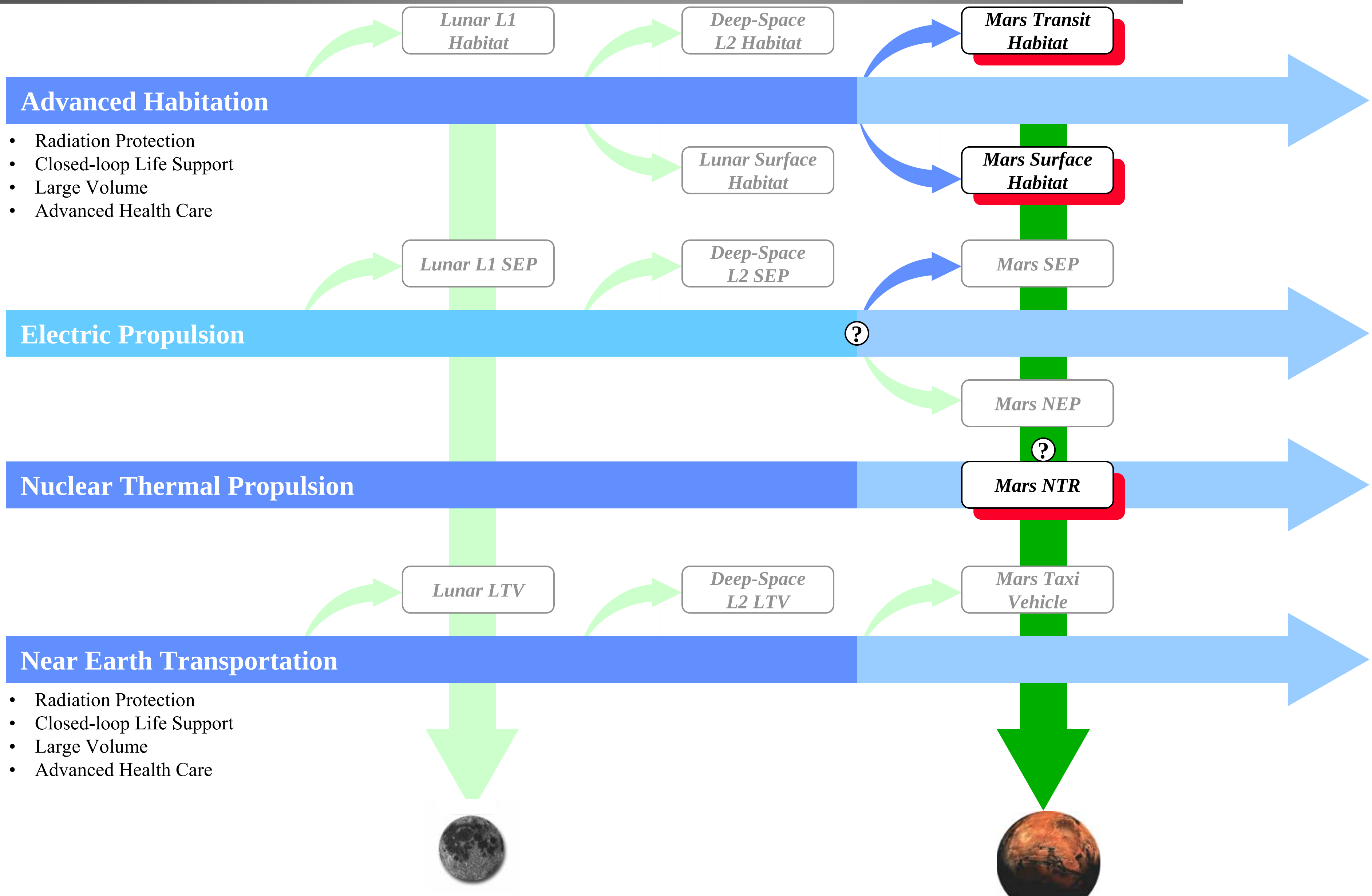

Mars Short-Stay Transit Habitat

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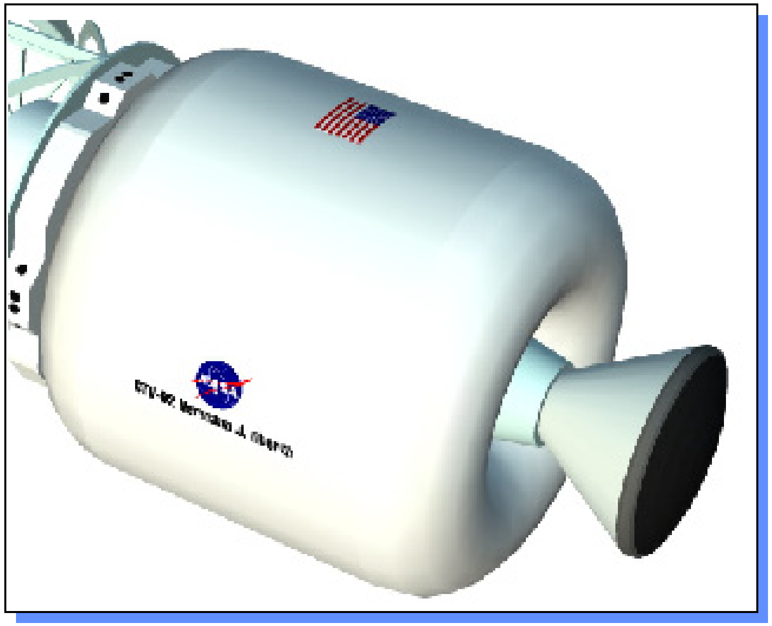


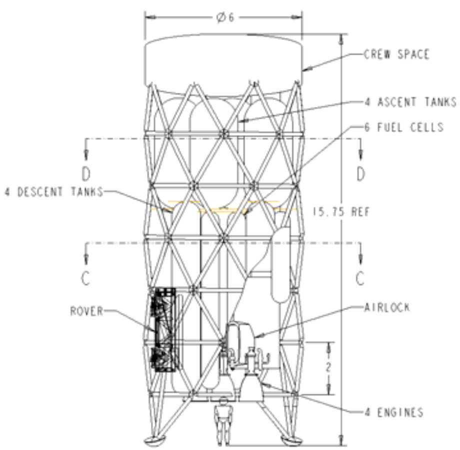
Transit Mass (4 Crew, 650 total days)	TRANSIT HABITAT Mass (kg)	Stowed Vol. (M3)
1.0 Power System	2362.6	0.000
2.0 Avionics	287.0	0.140
3.0 Environmental Control & Life Support	3948.9	19.133
4.0 Thermal Management System	1257.3	5.260
5.0 Crew Accommodations	3396.1	21.235
6.0 EVA Systems	879.9	3.653
7.0 Structure	817.3	0.000
Margin (20%)	2426.4	9.884
Crew	372.0	- - - - -
Food (Return Trip)	2600.0	9.043
Food (Outbound Trip)	2600.0	9.043
Food (Contingency)	0.0	0.000
Total Transit Habitat Mass	**20947.5**	**77.392**
Earth Return Vehicle	**4270.6**	**0.000**
Total Mass	**25218.1**	

- Supports mission crew of four for up to 365-650-days round-trip missions to and from Mars
- Crew consumables and support systems tailored for mission duration
- Zero-g configuration with integrated deep-space radiation protection
- Power generation provided by the bi-modal NTR vehicle
- Closed-loop (air and water) life support system
- Advanced health care systems
- Advanced materials for primary and secondary structures
- Advanced MEMS / wireless avionics for increased reliability and redundancy
- Earth return vehicle for crew return

Ref. Johnson Space Center

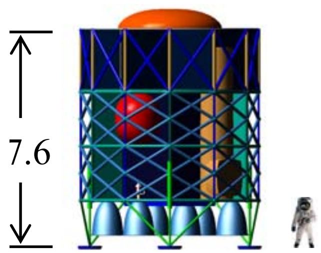
Mars Descent / Ascent Vehicle

- Small shroud of the EELV-H has significant impact on the Descent / Ascent Vehicle
- Vertical lander configuration is not viable for small launch shrouds
  - Packaging and volume problems
  - High center of gravity increases landing stability problems
  - Assembled vehicles have larger c.g. uncertainty – increases aerocapture and aeroentry precision
  - Ingress / Egress difficulties
  - Launch vehicle shroud cannot be used as the Mars aerobrake or aeroentry shield
  - Parachute deployment speeds: Parachutes cannot be used due to high deployment speeds (M=4.5) due to high ballistic coefficient
  - Aerobrarke on-orbit assembly and checkout required or other concepts which utilize deployed systems are needed
- Large 8 x 30 m shroud assumed for vehicle elements

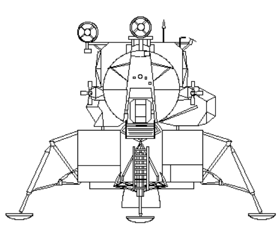


6 m Delta-IV H

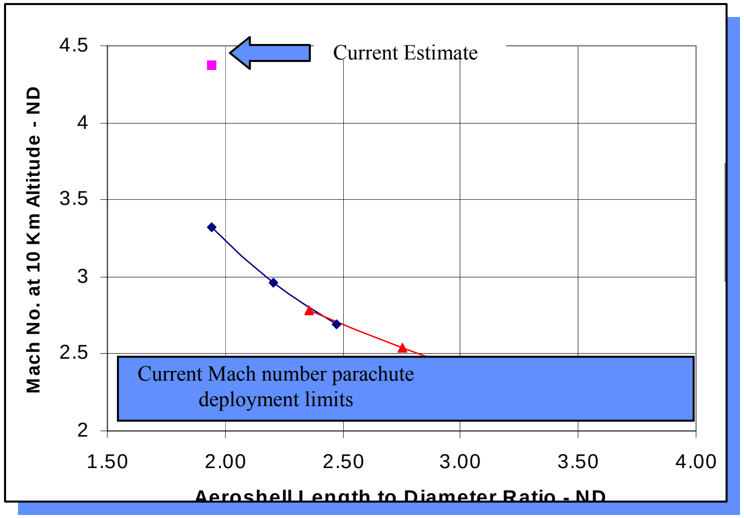
(Not Standard)



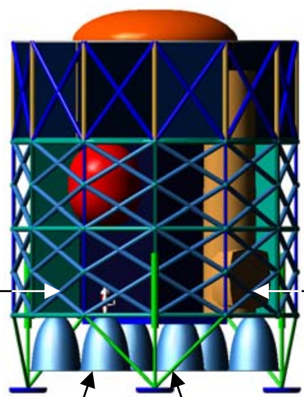
8 m Diameter Shroud



Parachute deployment speeds



Short-Stay Mars Descent / Ascent Vehicle

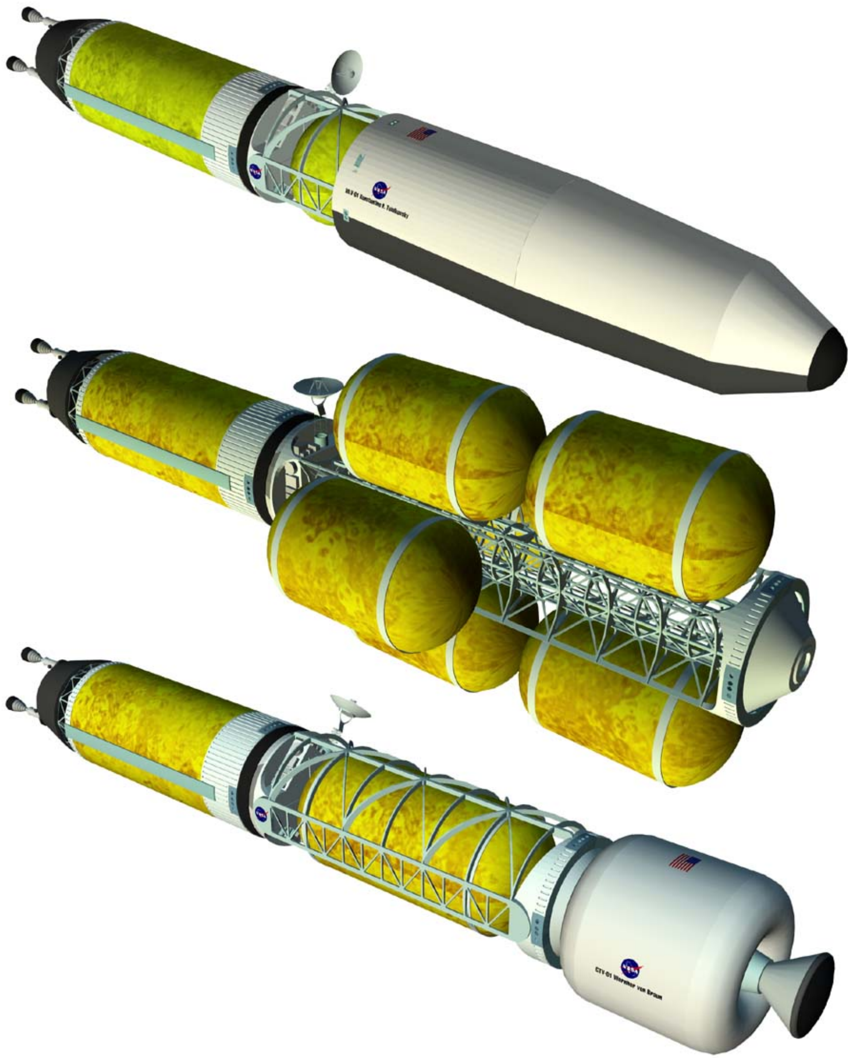


High Mars Orbit Option	DESCENT/ASCENT LANDER Mass (kg)	Stowed Vol. (M^3)
Payloads and Systems	**13276.4**	**36.640**
1.0 Power System	4226.0	0.000
2.0 Avionics	153.0	0.279
3.0 Environmental Control & Life Support	1037.6	3.983
4.0 Thermal Management System	527.4	2.350
5.0 Crew Accommodations	727.7	5.776
6.0 EVA Systems	1073.9	7.539
7.0 In-Situ Resource Utilization	0.0	0.000
8.0 Mobility	1350.4	8.171
9.0 Science	301.2	1.600
10.0 Structure	1339.8	0.000
Margin (20%)	1807.4	5.689
Food	360.0	1.252
Crew	372.0	- - - - -
Ascent Stage (Two Stage)	**31442.7**	**1.000**
Crew Module	1617.5	1.000
Stage	161.3	0.000
Propulsion	4675.6	0.000
Propellants	24988.2	0.000
Descent Stage	**17237.2**	**0.000**
(Payload Down)	*44719.1*	- - - - -
Stage	1242.3	0.000
Propulsion	4658.9	0.000
Propellants	11336.0	0.000
Aerobrake	**10184.1**	**0.000**
Total Mass	**72140.4**	

- Transports four crew from Mars orbit to the surface and return to Mars orbit
- Vehicle supports crew for 30-days
- Two-stage design for high Mars orbit staging
- Regenerative air, open water life support system
- Advanced EVA and mobility
- Crew health and maintenance, including exercise equipment, for adaptation to martian gravity

"Bimodal" NTR Transfer Vehicles for Mars Cargo and Piloted Missions

Graphics Shown : One-year round-trip mission (2018) utilizing 80 mt launch vehicle



Cargo Mission 1

Descent / Ascent Lander

IMLEO = 123 - 157 mt

Cargo Mission 2

Crew Return Vehicle

IMLEO = 250 - 612 mt

Piloted Mission

Crew Transfer Vehicle

IMLEO = 104 - 896 mt

Ref. Glenn Research Center

Architecture Unique Technology Needs

Short-Stay Mars Mission

- ***Human Support***
  - Advanced health care systems for long periods away from Earth (22 months)

- ***Advanced Space Transportation***
  - Advanced interplanetary propulsion: Options include:
    - Bi-Modal Nuclear Thermal Propulsion (925 sec Isp, 15 kWe)
    - High Power Nuclear Electric (Ion, MPD, or VASMIR at multi-MW power levels) ?
  - Large volume / large mass Earth-to-Orbit transportation
  - Very high rate payload and launch vehicle processing land launch capability
  - Advanced LEO automated rendezvous, assembly, checkout, and verification facilities and techniques
  - Long-term storage of hydrogen in space

- ***Advanced Space Power***
  - Nuclear power reactor 15-30 kWe for high-latitude scientific investigations

- ***Miscellaneous***
  - Integrated vehicle health maintenance for vehicles unattended for long periods (21-22 months)
  - Advanced reliability for long vehicle operations (up to 44 months excluding LEO assembly ops)

Architecture Comparison Criteria

Short-Stay Mars Mission

Criteria	Value
Architecture Evolution Potential	Focus on short stay limits evolution
Architecture Commonality	Very little propulsion system commonality
Initial Mass in Low-Earth Orbit	522-1665 mt
Mass to Mars Surface	13 mt
Number of Crew	4
Number of Cargo Launches	17-55
On-orbit Assembly Required?	Yes
Number of Crew Launches	tbd
Architecture Redundancy	No overlapping of resources
Architecture Complexity	Very complex LEO mission
Architecture Sensitivity	High
Crew Hazards	Mars orbit rendezvous, 365-650-day long mission
Time in Interplanetary Space	620 total days
Time on Surface	30 total days

Mars-Short Stay Mission Architecture Summary

Strengths

- One-year mission is possible in some opportunities
- Shorter total mission reduces reliability requirements
- Accomplish mission events quicker allowing crew return phase to begin sooner
- Shorter mission reduces crew time spent beyond Earth orbit (365-650 total days)
- Minimizes surface infrastructure

Weaknesses

- Large initial mass in LEO
- Large variation in mass; large sensitivity to mass, level of redundancy, and technology changes
- Science return is local "focus" oriented (10 km)
- No overlap of mission/vehicle resources
- Launch facilities and launch rate impacts as well as on-orbit assembly and checkout issues
- Majority of mission is spent in zero-g radiation environment (95%)
- Close sun passage increases radiation dose to the crew (0.35-0.7 AU)
- Short surface stay allows less time for contingencies and re-planning (30 days)

Architecture Issues and Follow-on Work

- Results are due to the short-stay mission constraints and are not due to the NTR system performance. The trends of these results will be similar for all advanced propulsion options.
- Small launch vehicle constraints force large levels of on-orbit assembly and checkout in low-Earth orbit which significantly increases mission complexity, mission risk, and cost.
- Separating crew from their return vehicle increases risk to the crew (survival)
- Requirements of the short stay mission poses a significant mission, design, assembly, and risk challenge for minimal return
- Additional analysis is required to determine feasibility
  - Finalize trajectory options
  - Update vehicle concepts
  - Launch/assembly impacts
  - Operations concepts
  - Risk analysis
  - Crew health and performance
  - Parking orbit analysis
  - Power strategy

Mars Short-Stay Architecture Analysis
Remaining Work

- **Finalize Mars Short-Stay Mission Trajectory Options**
  - Variation and sensitivity across the entire synodic cycle
  - Vehicle and crew impacts of heliocentric passage
  - Parking orbit arrival/departure constraints for short Mars vicinity stay
- **Launch Vehicle / Assembly Assessments**
  - Launch vehicle impacts
  - On-orbit assembly / checkout concepts
  - Vehicle support concepts (fuel depot?)
- **Probabilistic Risk Assessments for leading architecture concepts**
- **Operations Concepts**
  - Launch operations, vehicle, and payload processing
  - Flight and surface mission
  - Abort concepts
- **Crew Health and Performance Assessments**
  - Radiation and zero-g for various total mission durations
  - Crew health and countermeasures for long-outbound transits
- **Power System Strategy**
  - Strategy to meet high latitude, mobility, and science requirements
- **Update Vehicle Concepts**
  - Mars Descent / Ascent Vehicle
  - NTR Piloted Vehicles

Backup

Short-Stay Mars Mission Implications

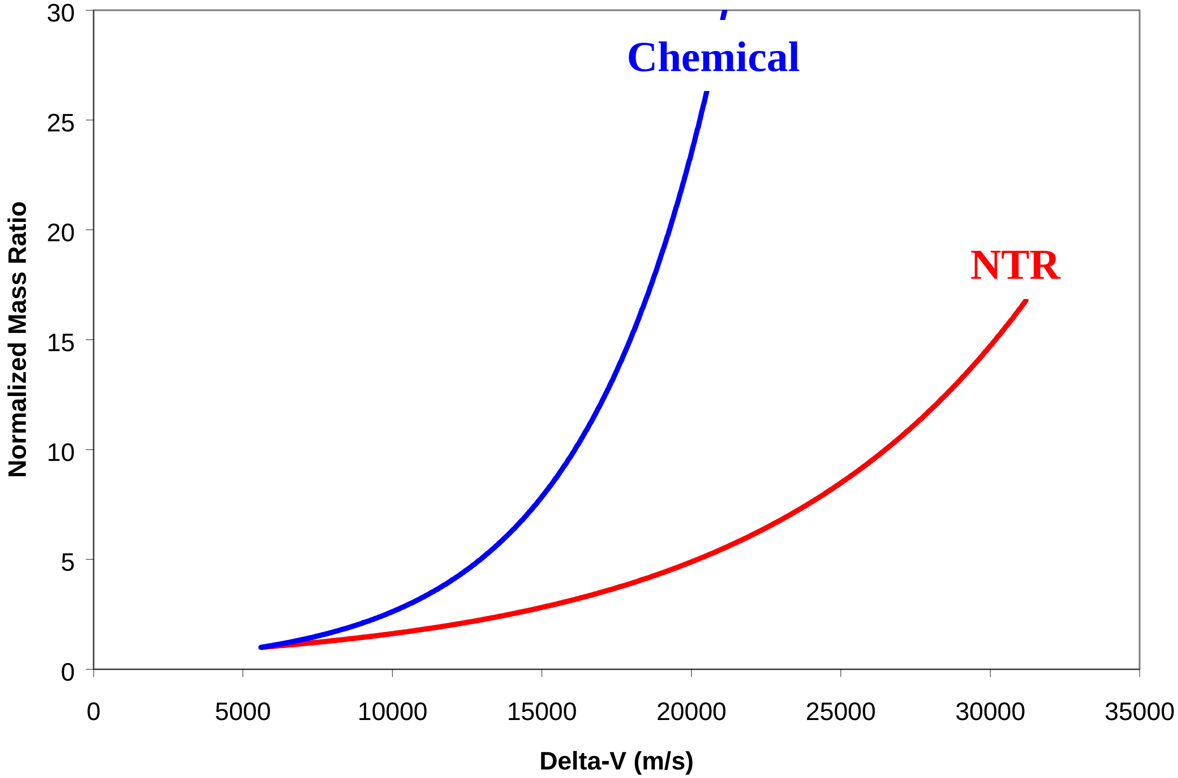
- ***Large energy requirements increases mission vehicle size dictates need for advanced propulsion technology***
- ***Significant variation of propulsion requirements for the Short-Stay mission across synodic cycle (100%)***
  - Significant impacts to vehicle design and certification due to wide variation of vehicle size
- ***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 12-22 months***
  - System reliability still critical to crew survival
  - Life support system reliability
  - Short (one-year) missions are possible, but limited to single opportunities over the 15-year synodic cycle (2018)
- ***Venus swing-by's can reduce propulsive requirement (and thus mission mass)***
  - Pass within 0.35-0.72 AU of the sun (increases radiation and thermal load)
  - Longer total mission duration in interplanetary space environment

Normalized Mass Ratio

- Provides a top-level comparison of the relative initial mass in LEO
- Derived from the rocket equation

$$\frac{M_f}{M_i} = \frac{\Delta V}{g * Isp}$$

M_f	Final Mass (kg)
M_i	Initial Mass (kg)
ΔV	Velocity Change (m/s)
g	Gravitational Acceleration (m/s^2)
Isp	Specific Impulse (s)



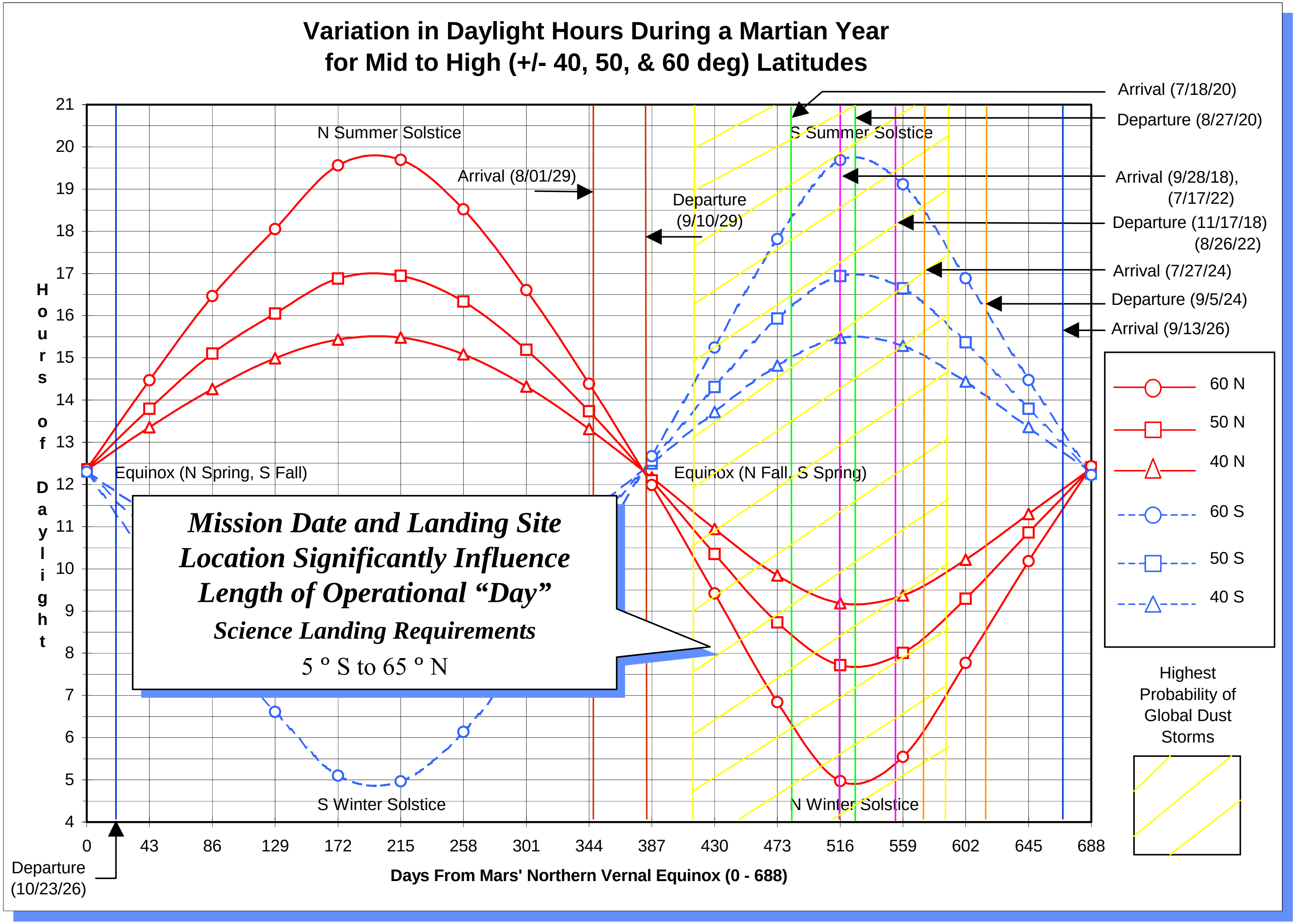
Short-Stay Operational Considerstions

- Need to maintain abort gap closure for all interplanetary propulsion options considered
- A separate Earth Return Vehicle (ERV) remains an important safety and mission success asset, and should be retained in this architecture
- Mars orbital operations (capture, rendezvous, phasing for departure, etc.) needs further assessment
- Short-stay surface adaptation story is mixed:
  - Short-stay allows for simpler surface spacecraft, but
  - will generate pressure to get on with the exploration phase early (adaptation issues)
  - Initial operations (g-transition, vehicle safing, appendage deployments) must occur without crew exertion
- Entry, Descent, and Landing (EDL) precision for this mission is primarily for mission success (along with rendezvous with pre-deployed robotic systems)
- 10 km radius has been established as a reasonable traverse radius about the landing zone (walkback). Unpressurized rover(s) is assumed to be used during this mission due to the short-stay
- Surface mission likely similar to an extended and very complex ISS assembly mission
- Shorter exposure window to radiation and dust storm events on the surface, but due to visibility restrictions, the crew may get to Mars and be NO GO to land due to dust storms in the landing zone.
- Initial timeline assessment: 21 EVAs of 6.5 hour duration are supported:
  - 5 local area (acclimation, area science, rover assembly)
  - 5 rover-assisted traverses
  - 11 Core drills at three different sites (Core A is assumed to take only 3 EVAs, the others require 4 each)
  - This timeline is considered optimistic

Variation of Daylight Hours

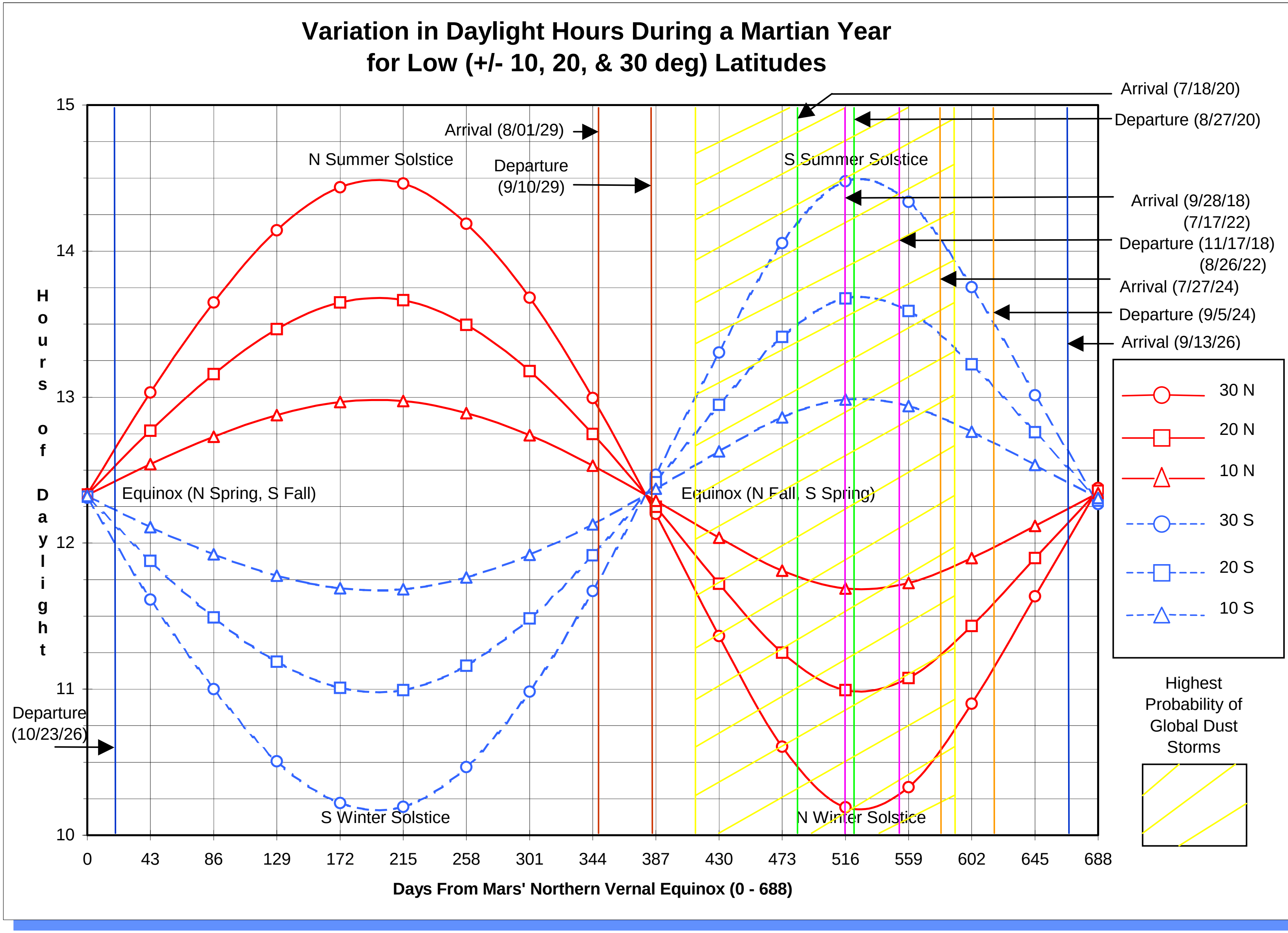
High Latitude Landing Sites

Exploration Office

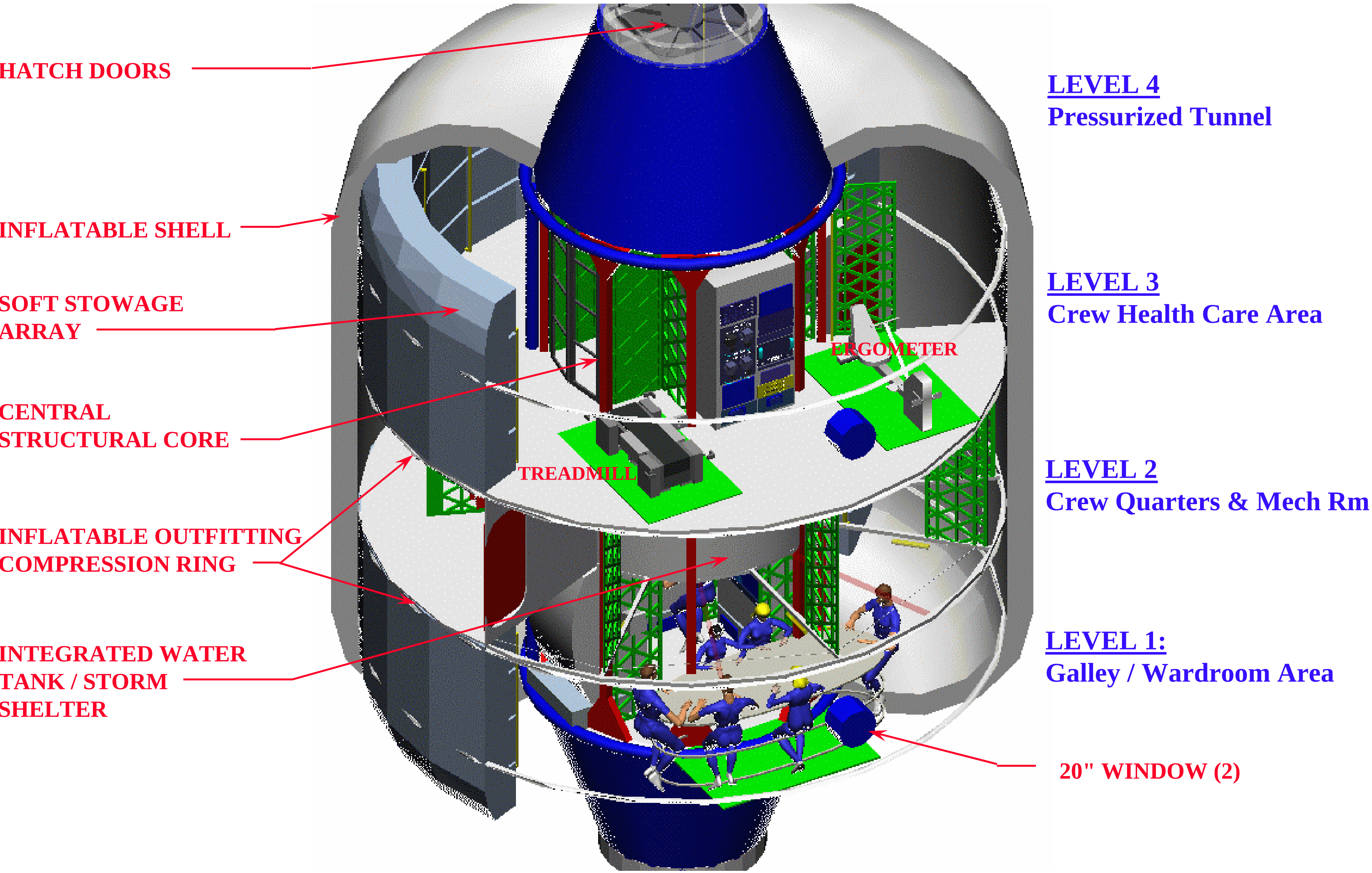


Variation of Daylight Hours

Low Latitude Landing Sites

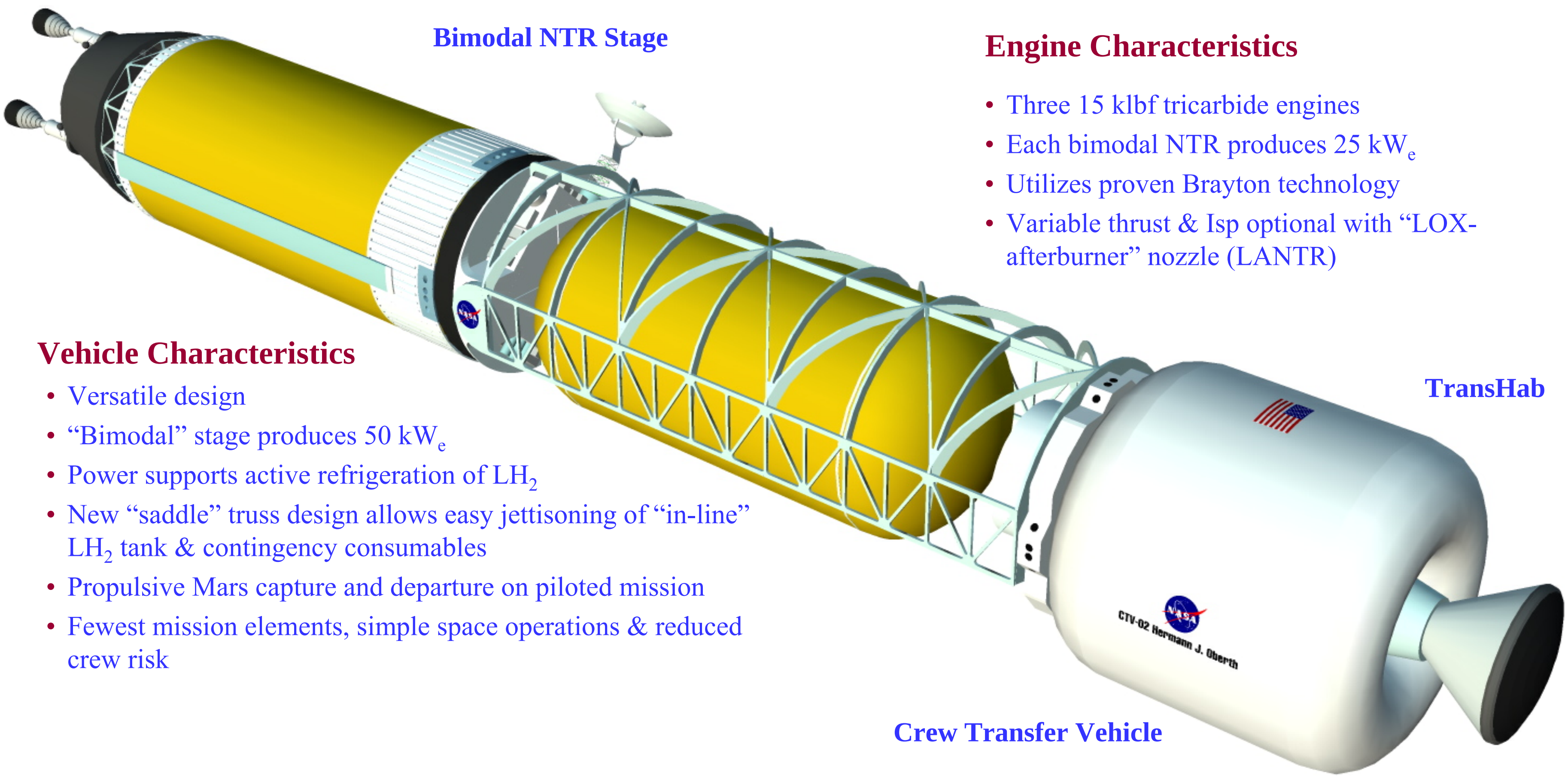


Mars Transit Habitat



Modular "Bimodal" NTR Transfer Vehicle Designs Developed for Mars Cargo and Piloted Missions

Bimodal NTR: High thrust, high Isp propulsion system utilizing U^{235} produces thermal energy for propellant heating and electric power generation enhancing vehicle capability



Engine Characteristics

- Three 15 klbf tricarbide engines
- Each bimodal NTR produces 25 kW_e
- Utilizes proven Brayton technology
- Variable thrust & Isp optional with "LOX-afterburner" nozzle (LANTR)

Vehicle Characteristics

- Versatile design
- "Bimodal" stage produces 50 kW_e
- Power supports active refrigeration of LH_2
- New "saddle" truss design allows easy jettisoning of "in-line" LH_2 tank & contingency consumables
- Propulsive Mars capture and departure on piloted mission
- Fewest mission elements, simple space operations & reduced crew risk

Ref. Glenn Research Center

DPT Mars Long-Stay Mission

Architecture Status

Mid-Term (2018) Nuclear Thermal Propulsion and Solar Electric Propulsion System Options

Bret G. Drake
NASA/Johnson Space Center

July 11, 2000

Outline

- Architecture Overview
- Ground Rules and Assumptions
- Detailed Mission by Phase
- Capability Evolution
- Systems
  - Transit Habitat
  - Surface Habitat
  - Descent / Ascent Vehicle
  - Interplanetary Transportation
  - Launch Vehicle
- Architecture Features
- Technology Needs
- Architecture Summary

Evolution of the Long-Stay Mission Philosophy

1988: Case Studies

- Short Surface Stay
- Chemical / Aerobrake
- Split Sprint Missions

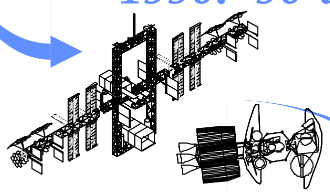
* Short-stay missions are energy intensive
* On-orbit assembly increases mission complexity
* Large masses/volumes require large launch vehicle

1989: Case Studies

- Short Surface Stay
- Chemical / Aerobrake
- All-up Mission Profile

* "Free-Return trajectories not beneficial
* Crew acclimation for short stay missions needs further investigation
* Large masses/volumes require large launch vehicle

1990: 90-day Study



- Short Surface Stay
- Split Sprint Missions
- Various propulsion options

* NTR propulsion, Aerobraking and ISRU are promising technologies to pursue
* Large masses/volumes require large launch vehicle

1991: Synthesis Group

- Short Surface Stay
- Nuclear Thermal Propulsion
- Heavy lift launch vehicle

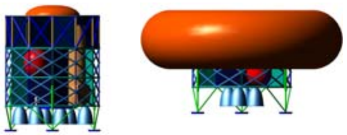
* "Key" Technologies identified
* Large masses/volumes require large launch vehicle

1997: DRM 1.0

- Long Surface Stay
- Nuclear Thermal Propulsion
- Heavy lift launch vehicle

* Crew exposure to interplanetary space limited
* Large masses/volumes require large launch vehicle
* Functional redundancy maximized

1999: Dual Landers



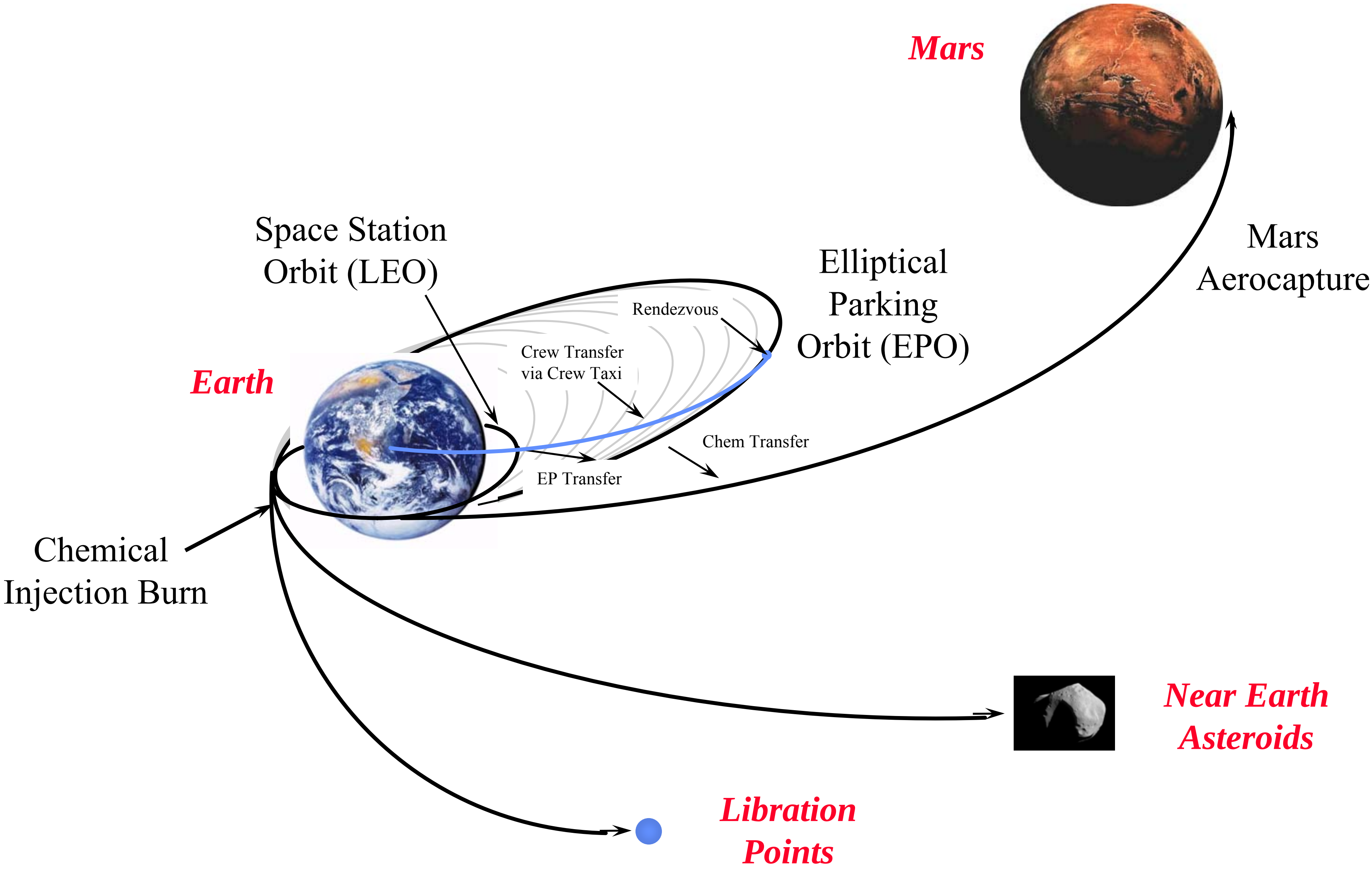
- Long Surface Stay
- NTR or SEP
- Enabled Global Access

* Lowest mass approach
* Crew exposure limited
* Science return maximized
* "Shuttle Compatible" launch vehicle

Mars Long-Stay Mission Significant Features

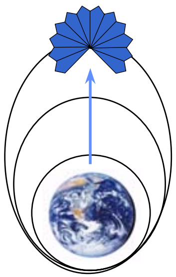
- Balances technical, programmatic, mission, and safety risks
- Lowest number of launches per human mission
- Simple LEO operations – automated rendezvous and docking of two elements
- High scientific return (500+ days on Mars) with continuous collaboration with colleagues on Earth
- Minimizes exposure of crew to interplanetary environment (zero-g and deep-space radiation)
- Maximizes reuse of mission elements: SEP and surface habitat (if desired)
- Vehicle design independent of mission opportunity (Small variation (10%) in vehicle size for every Mars opportunity)
- Enables global surface access if desired

High Earth Orbit Staging Mission Scenarios



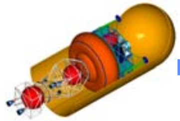
Mars Mission Overview
(SEP Option)

Exploration Office



Habitat Lander and Ascent/Descent Vehicles delivered to Low Earth Orbit with "Shuttle Class" launcher. Solar Electric Propulsion stage spirals cargo to High Earth Orbit. Chemical injection used at perigee. SEP spirals back to LEO for reuse.

Surface Habitat and exploration gear aerocaptures into Mars orbit

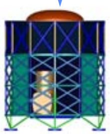


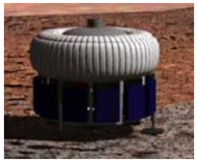
Ascent/Descent Vehicle aerocaptures and remains in Mars orbit for the crew

Crew rendezvous with Descent/Ascent Vehicle in Mars Orbit then lands in vicinity of Habitat Lander

Surface Habitat lands and performs initial setup and checkout - Initial outpost established

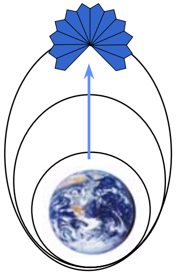
30 days provided to satisfy "long-stay" criteria.





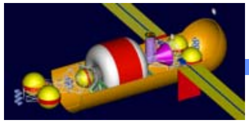
Mars Surface

Crew ascends and rendezvous with waiting Transit Habitat



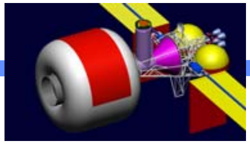
Transit Habitat vehicle delivered to LEO with "Shuttle Class" launcher. SEP spirals Transit Habitat to High Earth Orbit. Crew delivered to vehicle via crew taxi. SEP spirals back to LEO for reuse.

Crew travels to Mars in "fast transit" 180-206 day transfer. Aerobrakes into Mars orbit



Habitat remains in Mars orbit

Crew returns to Earth on "fast transit" 180-206 day transfer. Direct entry at Earth

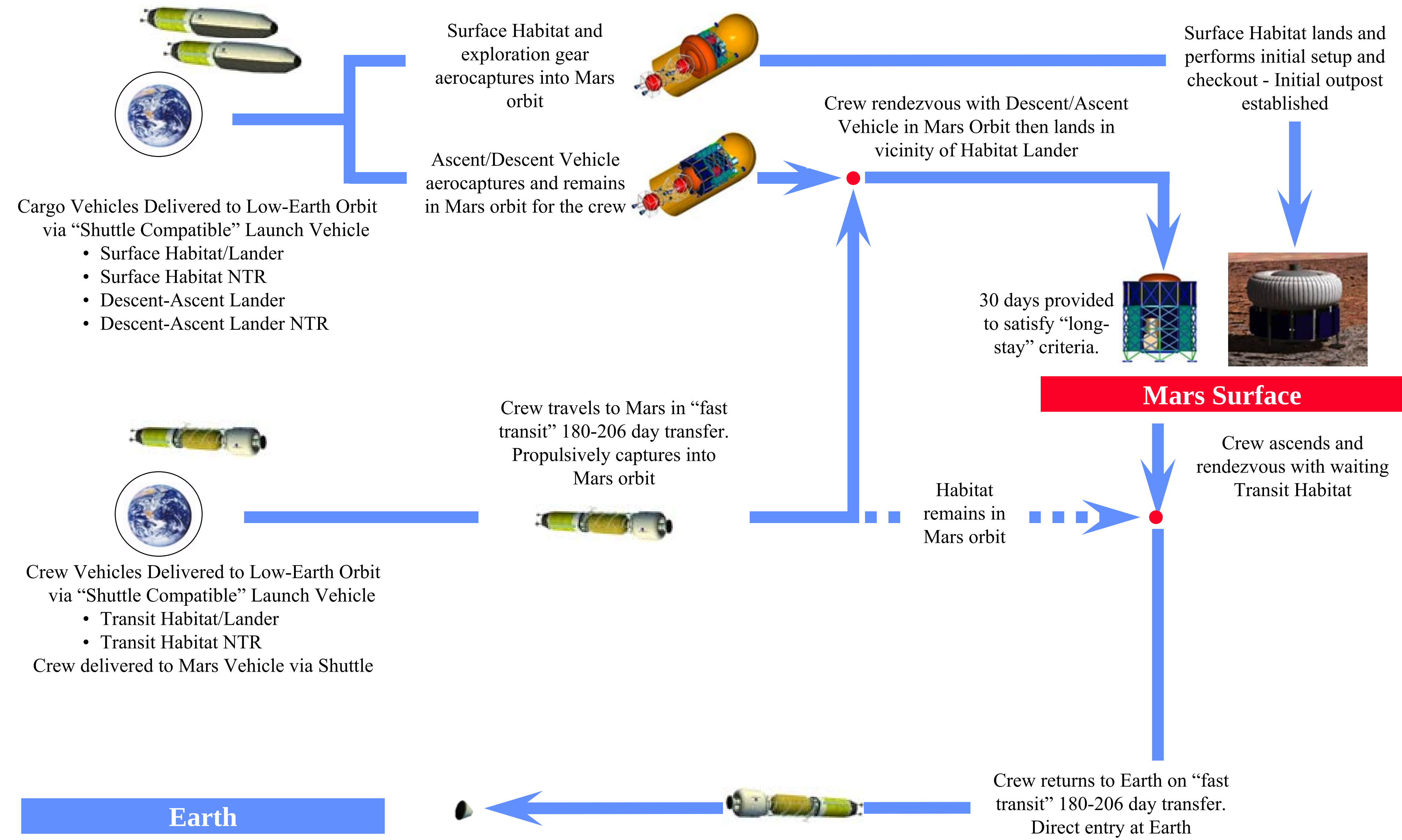


Earth

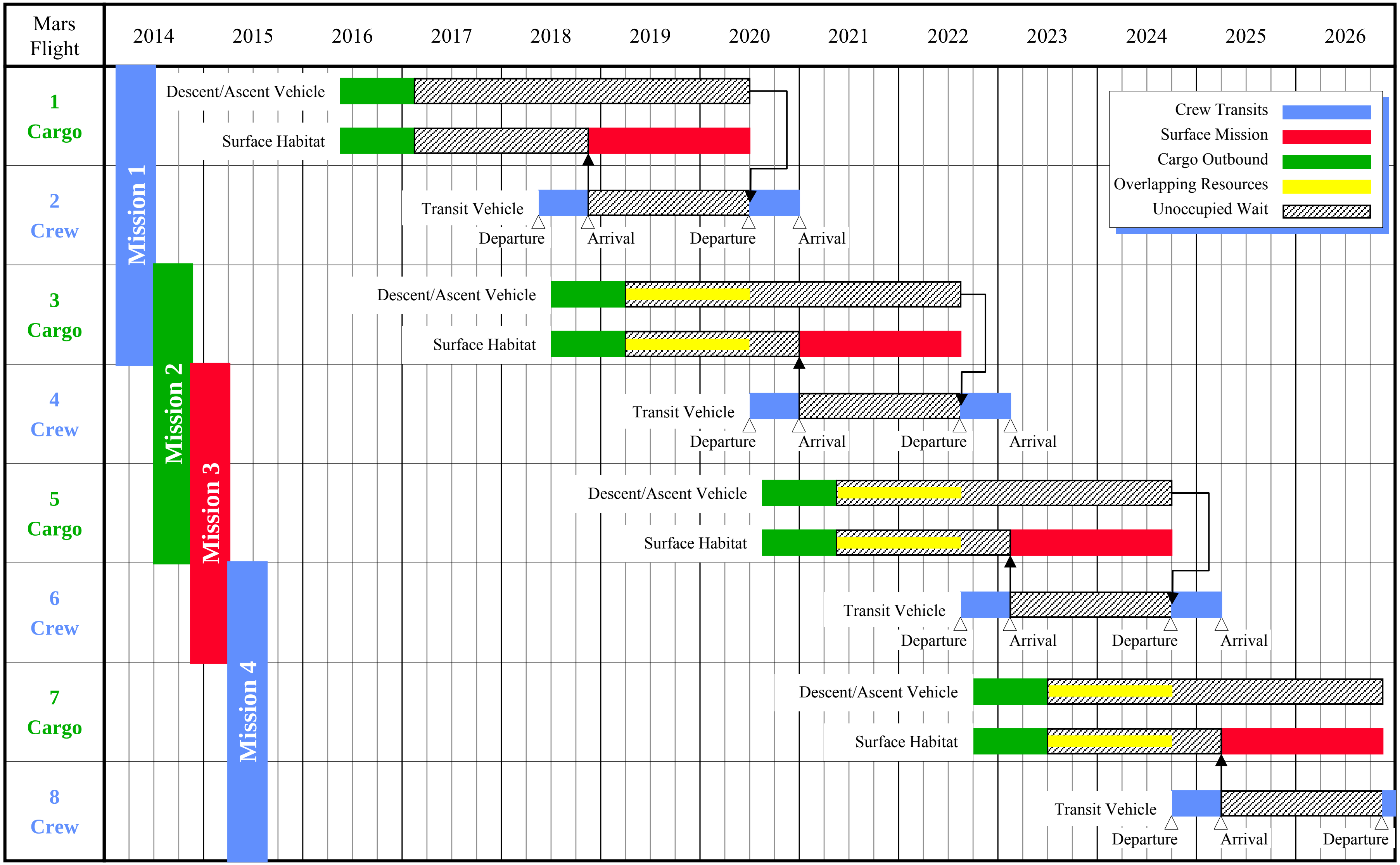
Mars Mission Overview

(NTR Option)

Exploration Office

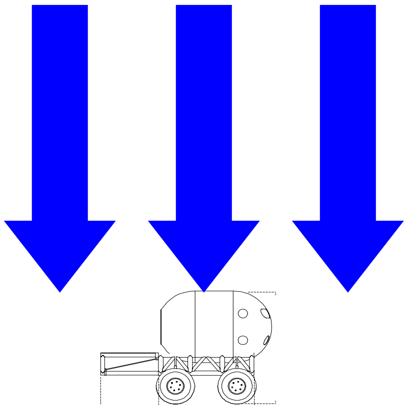


Long-Stay Mission Sequence

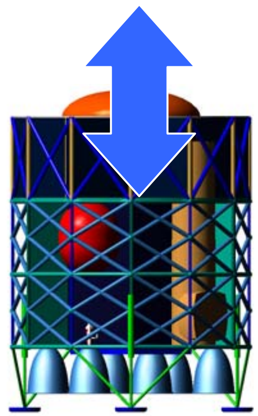


Surface Architecture

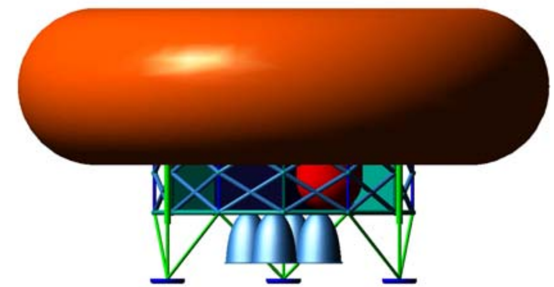
Outpost Missions (Bite Size Chunks)



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

Mars Long-Stay Ground Rules and Assumptions

- Detailed GR&A provided in the "Mars Long-Mission GR&A" document dated 4-20-2000
- Primary DPT GR&A which drive this architecture include:
  - First cargo mission 2016, First human mission 2018
  - Short transits to/from Mars (180-206 days) with long surface stay
  - Six crew
  - Zero-g transits
  - Technology freeze to TRL 6 by 2011
  - Factor of nine improvement for primary and secondary structures
  - Advanced mobility and scientific laboratory capability for enhanced science
  - Transportation Assumptions
    - "Shuttle Compatible" launch vehicle for cargo (80 mt)
    - Both SEP and NTR investigated
    - Aerobraking at Mars
    - Long-term cryogenic fluids storage

Mission Sequence
High Earth Orbit Boost Phase

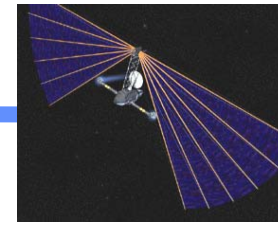
Exploration Office

UNPILOTED VEHICLES

Cargo Launch 2
SEP launched to low Earth orbit

Cargo Launch 3
Descent/Ascent vehicle, aerobrake, and TMI stage launched LEO

Cargo Launch 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 (contingency)

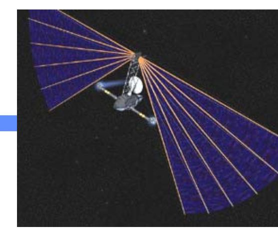
PILOTED VEHICLES

Cargo Launch 1
Transit Habitat launched to low Earth orbit

STS 1 & 2
Transit Habitat outfitting missions

Cargo Launch 5
Transit Habitat SEP vehicle launched to low Earth orbit

Cargo Launch 6
Transit Habitat propulsion stages launched to low Earth orbit



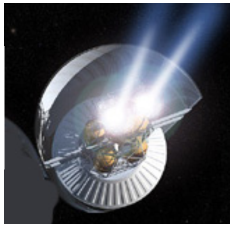
SEP vehicle boosts Transit Habitat to High Earth Orbit

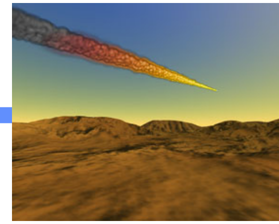
STS 3 / Taxi
Transit Habitat servicing mission in High Earth Orbit (contingency)

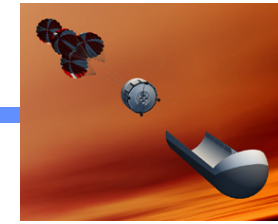
Mission Sequence

Trans-Mars Injection / Mars Arrival Phase

Surface Habitat Lander

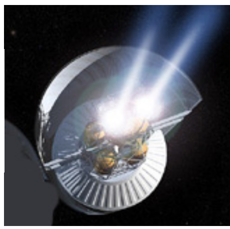




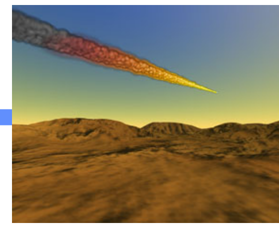


Surface Habitat performs deorbit, entry, descent, and precision landing on Mars

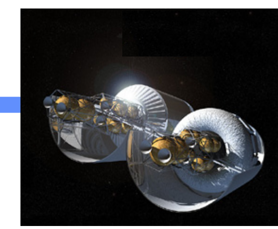
Descent/ Ascent Vehicle



Unpiloted Vehicles injected toward Mars on near minimum energy transfers



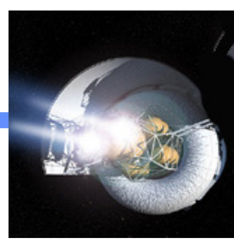
Unpiloted vehicles aerocapture into Mars orbit prior to the crew



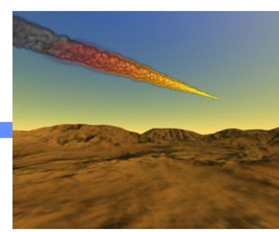
Transit Habitat performs rendezvous with Descent/Ascent vehicle in Low Mars Orbit.

Crew transfers to Descent/Ascent Vehicle

STS 5 / Taxi Flight Crew Delivery to Transit Habitat



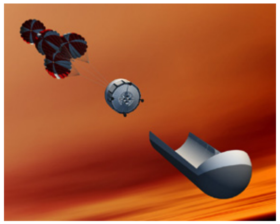
Transit Habitat Trans-Mars Injection (180-206 day transfers)



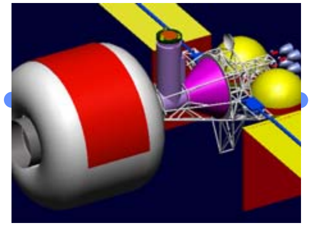
Transit habitat aerocaptures into Mars orbit

Mission Sequence

Surface Mission / Mars Ascent / Return Phases



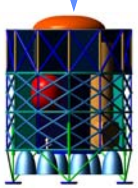
Crew performs deorbit, entry, descent, and precision landing on Mars in Descent / Ascent Vehicle



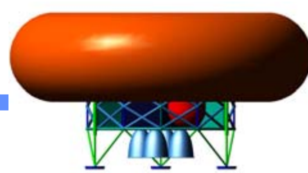
Low-Mars Orbit Wait
Transit Habitat remains in low-Mars Orbit during surface mission (unmanned)

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

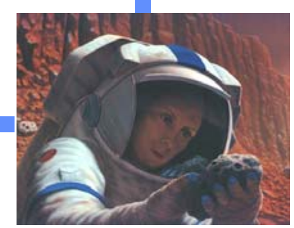
Earth Return
Direct Earth entry at end of mission



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

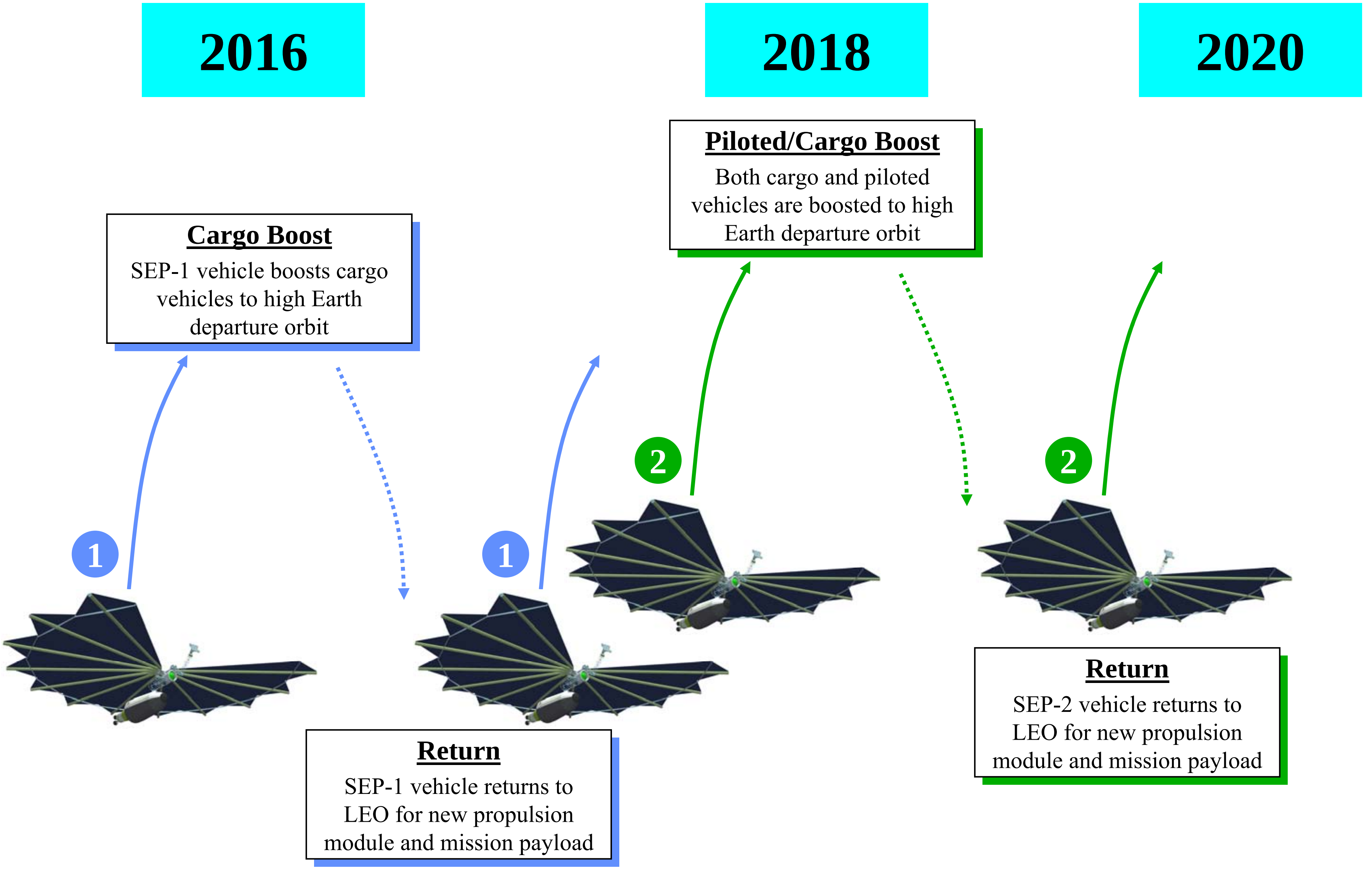


Initial Habitat Operations
Safe vehicle, habitat inflation, power system deployment, habitat outfitting and systems checkout.

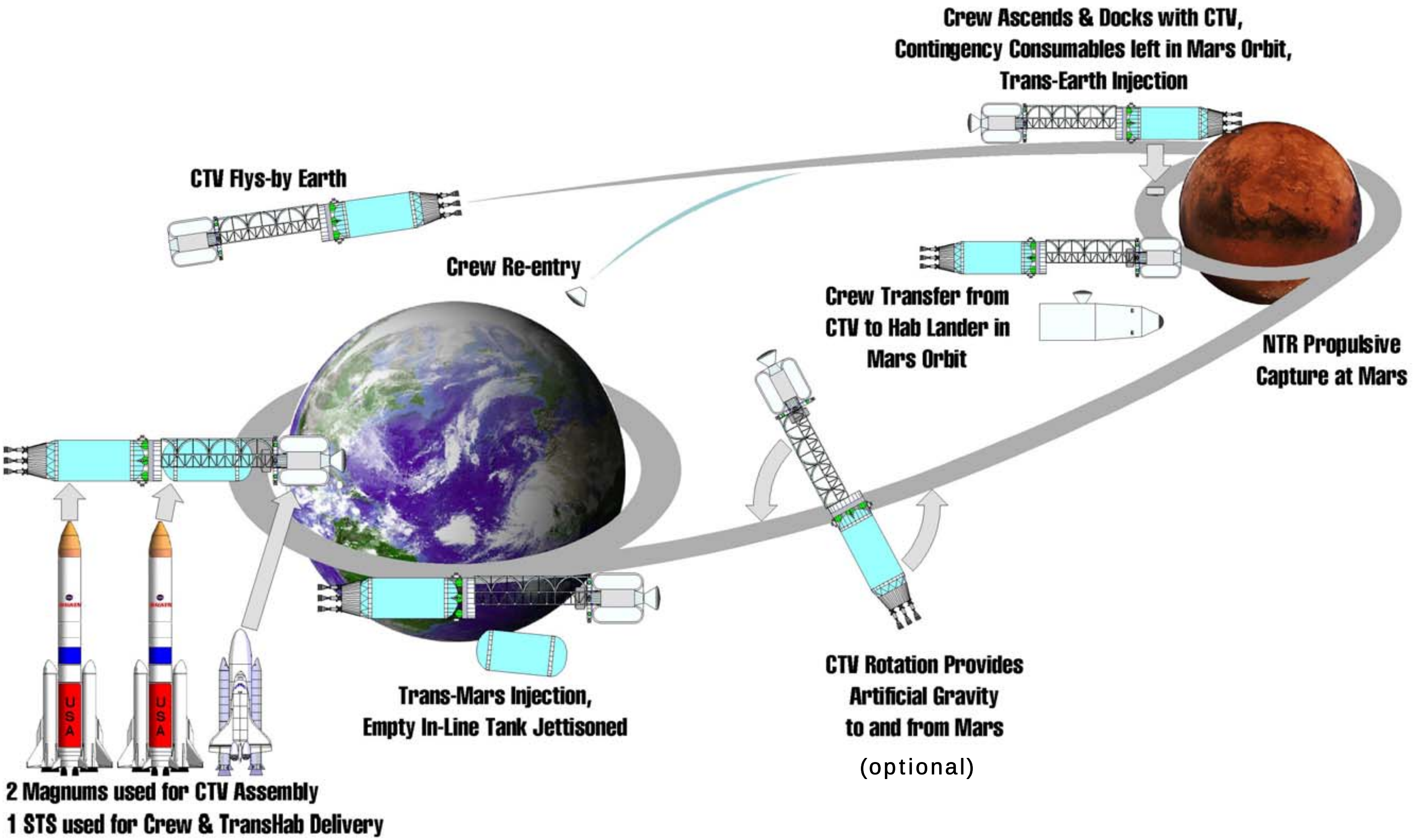


Surface Exploration
Concentrates on the search for life, drilling, geology, and microbiology investigations (up to 18 months long)

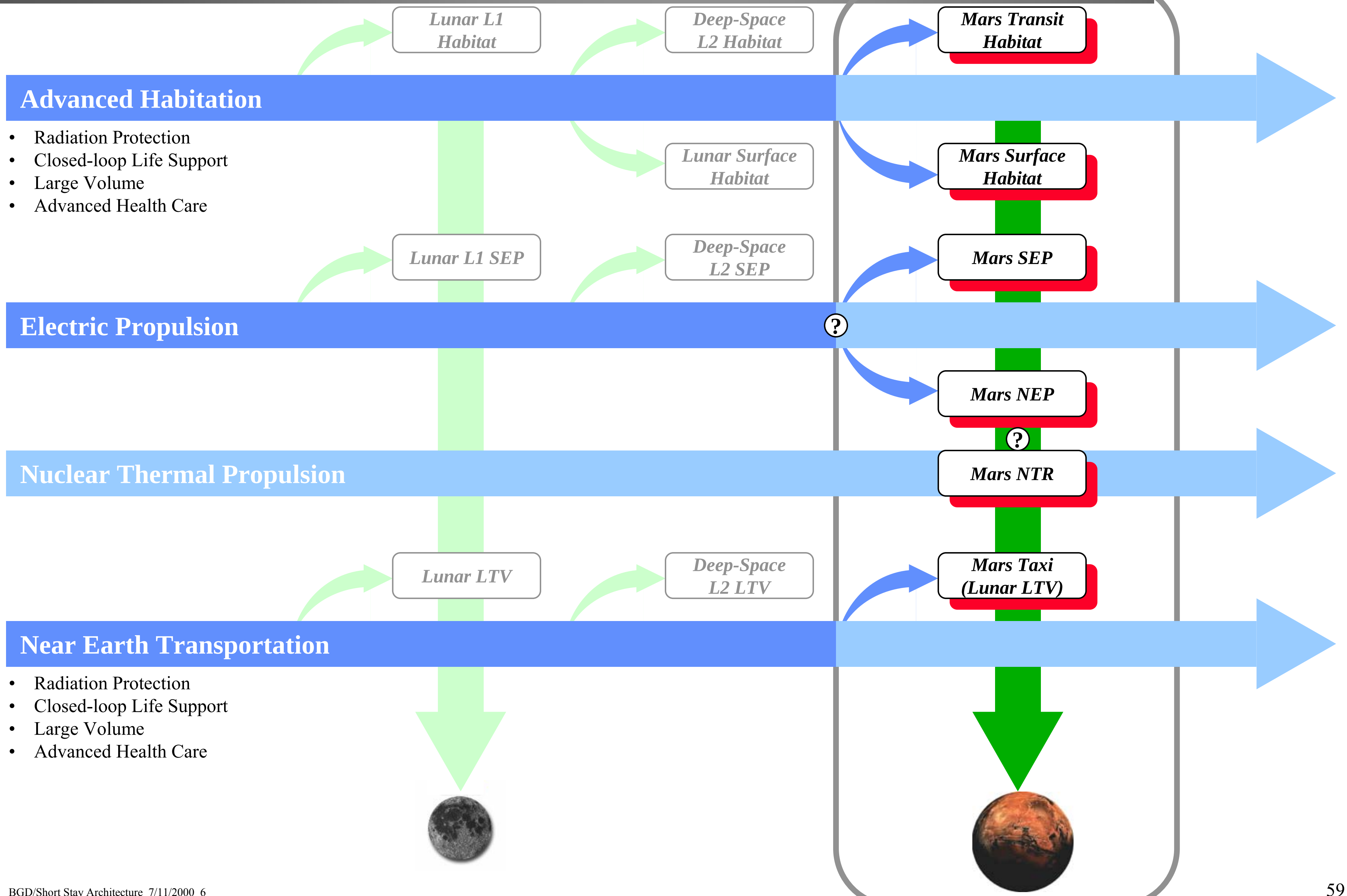
Solar Electric Vehicle Transportation Concept



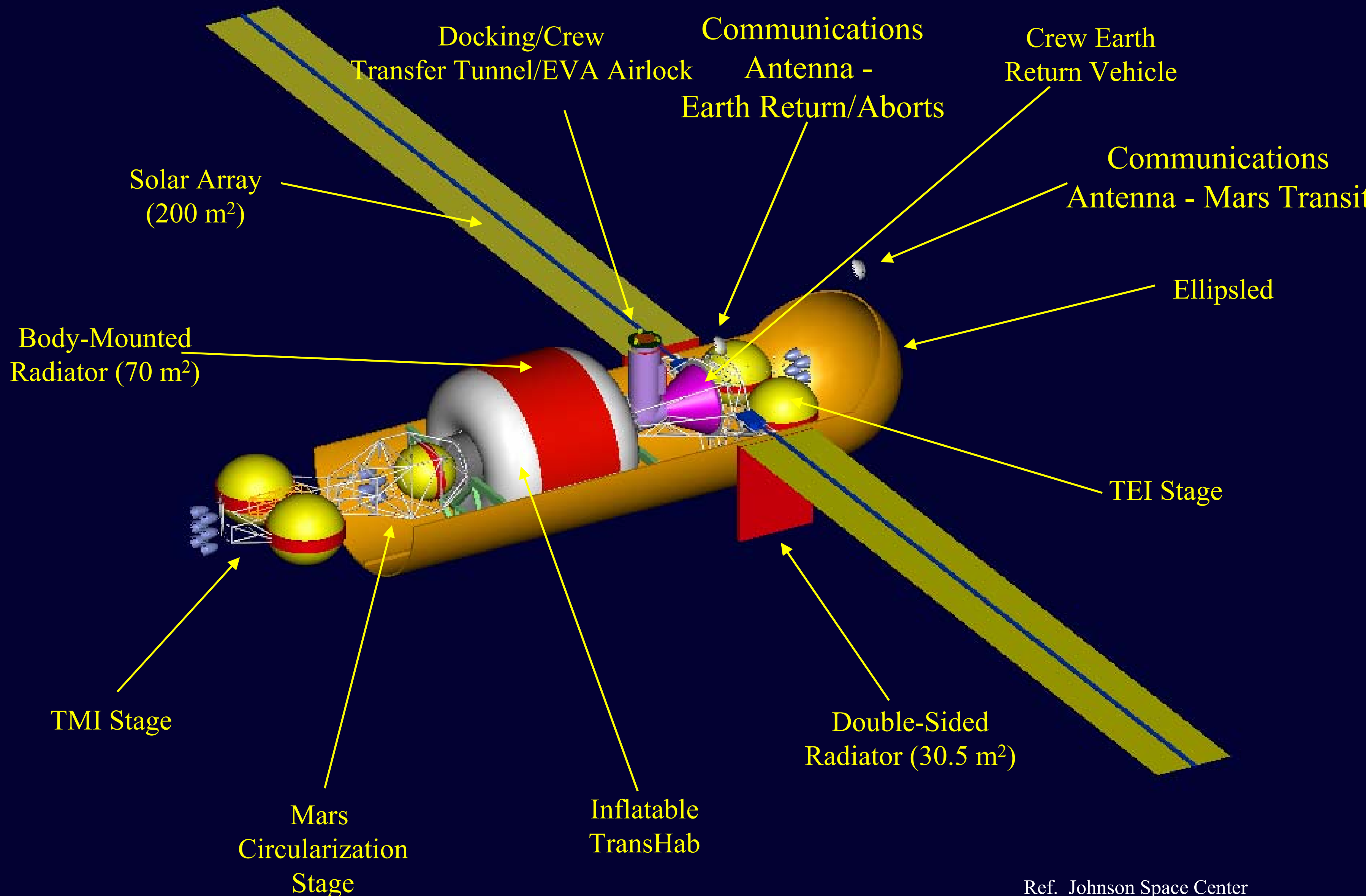
"Bimodal" NTR Crew Transfer Vehicle (CTV) Mission Scenario



Technology Driven Capabilities



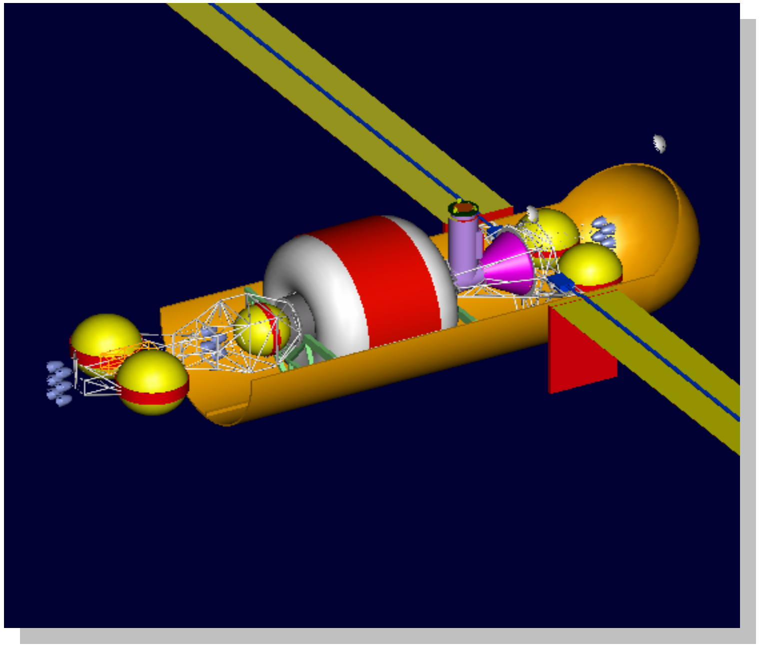
Mars Transit Habitat Configuration



Ref. Johnson Space Center

Mars Transit Habitat

Exploration Office



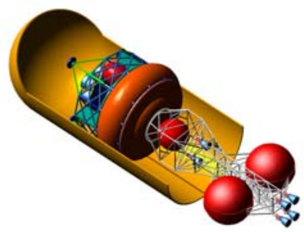
- Supports mission crew of six for up to 200-day transits to and from Mars
- Provides zero-g countermeasures and deep-space radiation protection
- Return propulsion stage integrated with transit system
- Provides return-to Earth abort capability for up to 30 hours post-TMI

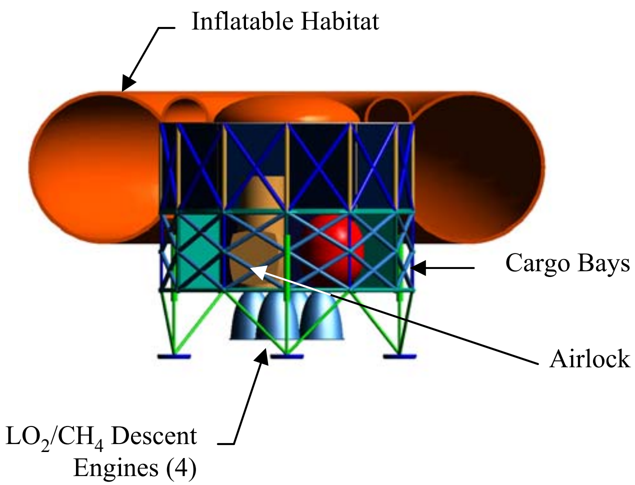
TRANSIT HABITAT	Mass (kg)	Stowed Vol. (M3)
1.0 Power System	5834.6	0.000
2.0 Avionics	287.0	0.140
3.0 Environmental Control & Life Support	3948.9	19.133
4.0 Thermal Management System	1257.3	5.260
5.0 Crew Accommodations	4309.9	30.719
6.0 EVA Systems	868.7	2.922
7.0 Structure	896.9	0.000
Margin (15%)	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**	

Ref. Johnson Space Center

Mars Habitat Lander

LEO Configuration





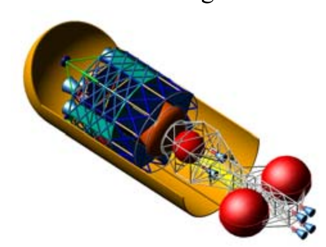
- Vehicle supports mission crew of six for up to 18 months on the surface of Mars
- Provides robust exploration and science capabilities
- Descent vehicle capable of landing 36,000 kg

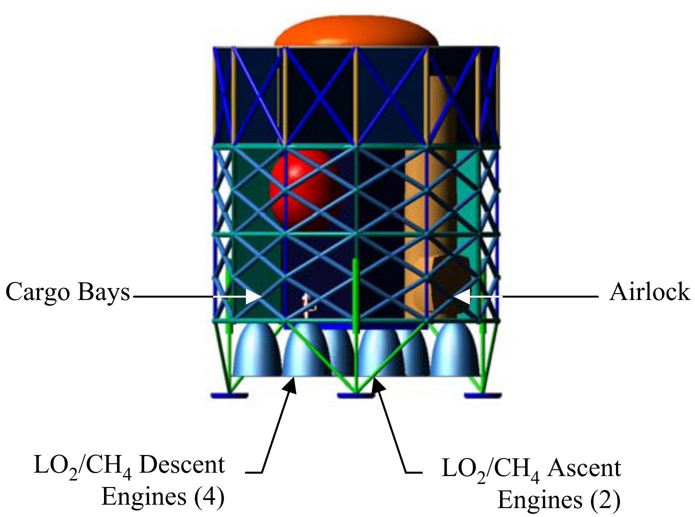
	HABITAT LANDER	
	Mass (kg)	**Stowed Vol. (M^3)**
Payloads and Systems	**30325.2**	**99.996**
1.0 Power System	5988.0	0.000
2.0 Avionics	153.0	0.279
3.0 Environmental Control & Life Support	3948.9	19.133
4.0 Thermal Management System	2912.1	9.020
5.0 Crew Accommodations	3502.9	26.369
6.0 EVA Systems	1174.4	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**	

Ref. Johnson Space Center

Mars Descent / Ascent Vehicle

Exploration Office



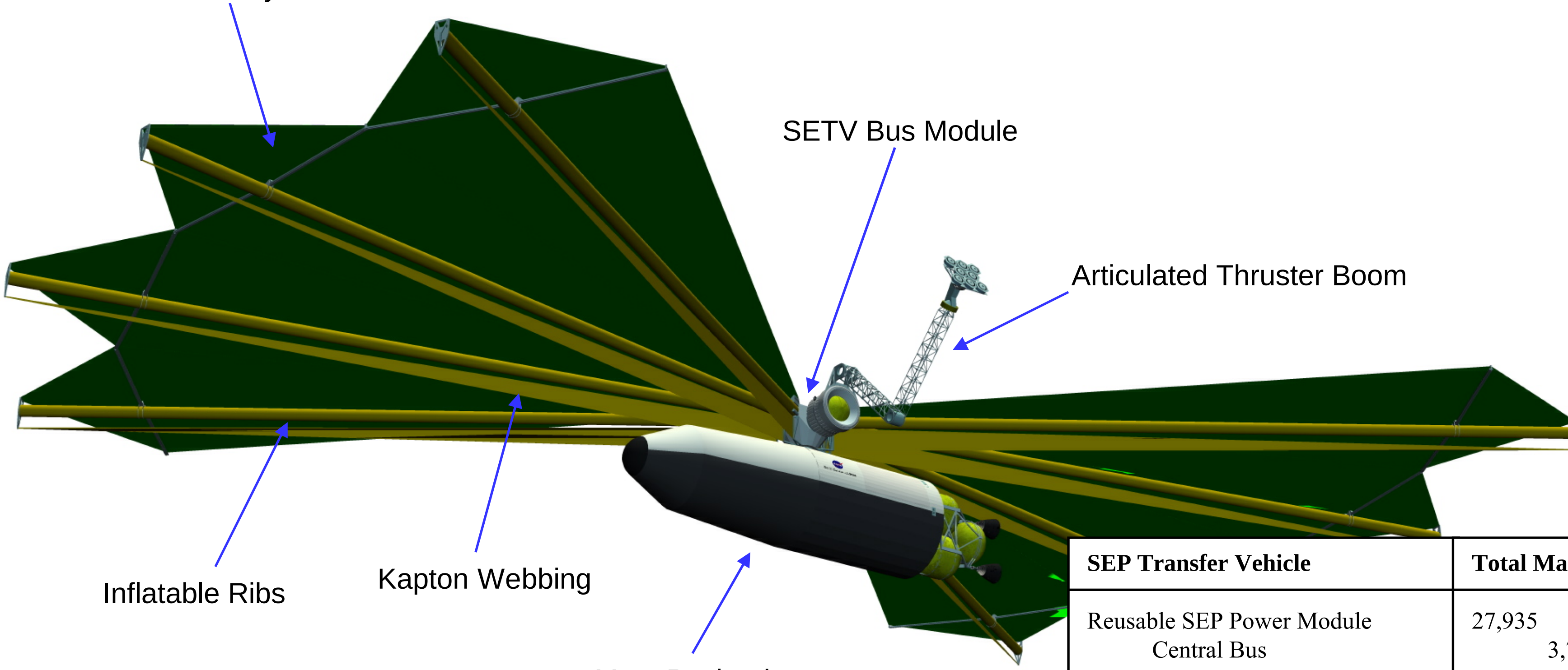


- Transports six crew from Mars orbit to the surface and return to Mars orbit
- Provides contingency abort-to-orbit capability
- Vehicle supports crew for 30-days
- Vehicle capable of utilizing locally produced propellants

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

SETV Deployed with Mars Payload Element

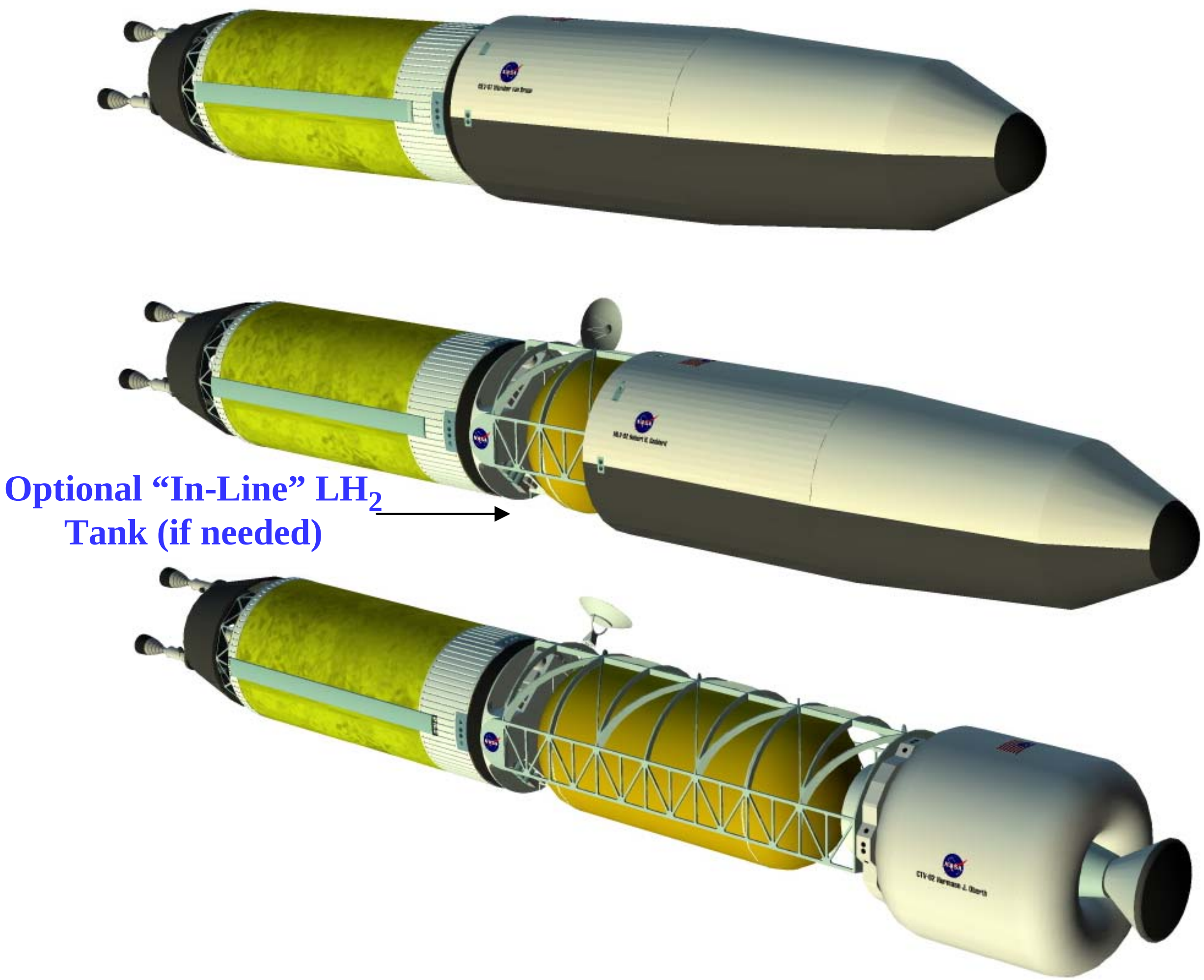


SEP Transfer Vehicle	Total Mass (kg)
Reusable SEP Power Module	27,935
Central Bus	3,770
Power System	12,370
Manipulator Arm	11,795
SEP Propulsion Module	7,730
Propulsion Platform	3,900
Propellant Feed System	3,830
Maximum Propellant Load	64,335

Ref. Glenn Research Center

"Bimodal" NTR Transfer Vehicles for Mars Cargo and Piloted Missions

(6 Shuttle Compatible Launch Vehicles plus Shuttle for Crew and TransHab Delivery)



2016 Cargo Mission 1
Habitat Lander
IMLEO = 131.5 mt

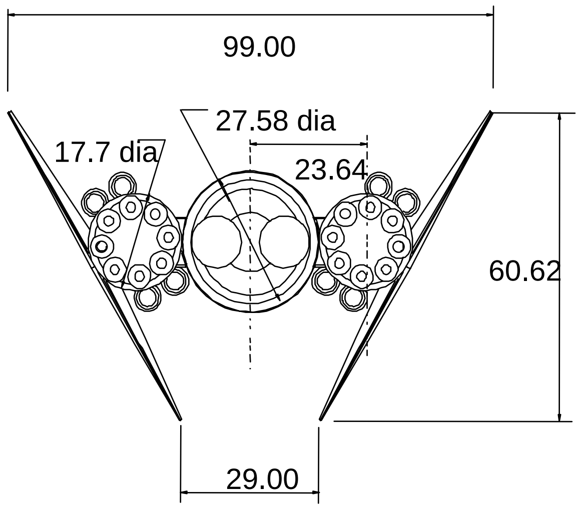
2016 Cargo Mission 2
Cargo Lander
IMLEO = 132.5 mt

2016 Piloted Mission
Crew Transfer Vehicle
IMLEO = 168.5 mt

Ref. Glenn Research Center

Launch Vehicle

- Cost effective delivery of large mass and large payload
- Maximizes the cost effective use of common Shuttle boosters and launch facilities
- Shuttle compatible
  - Core equal to the diameter of the External Tank (27.6 mt)
  - Common Pad Hold Down System
  - Common Use of ET Handling & Manufacturing Hardware
  - Same mobile launch platform (modified flame trenches)
- Common Boosters
- Similar GLOW: Use of Shuttle Crawlers & MLPs



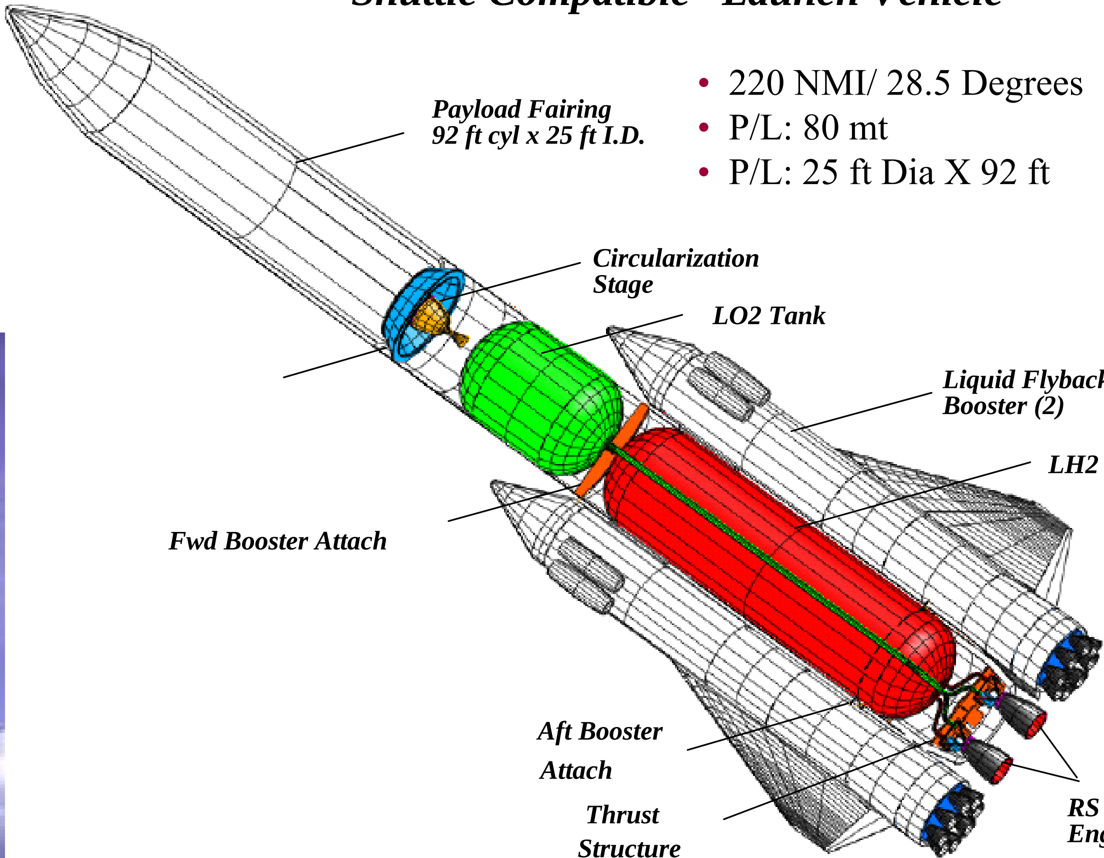
Engine Configuration

"Shuttle Compatible" Launch Vehicle
RFS Configuration

Exploration Office

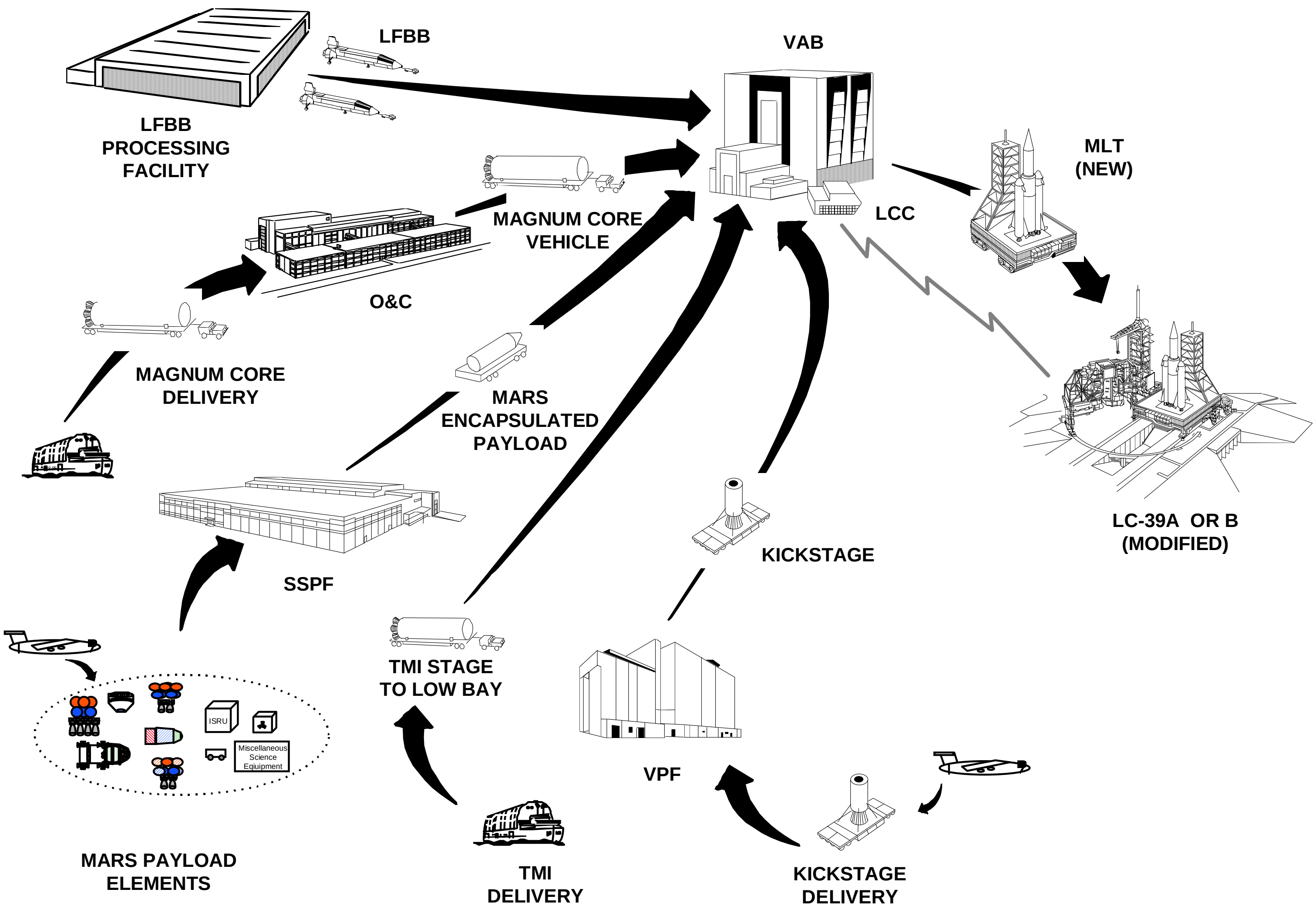
"Shuttle Compatible" Launch Vehicle

- 220 NMI/ 28.5 Degrees
- P/L: 80 mt
- P/L: 25 ft Dia X 92 ft



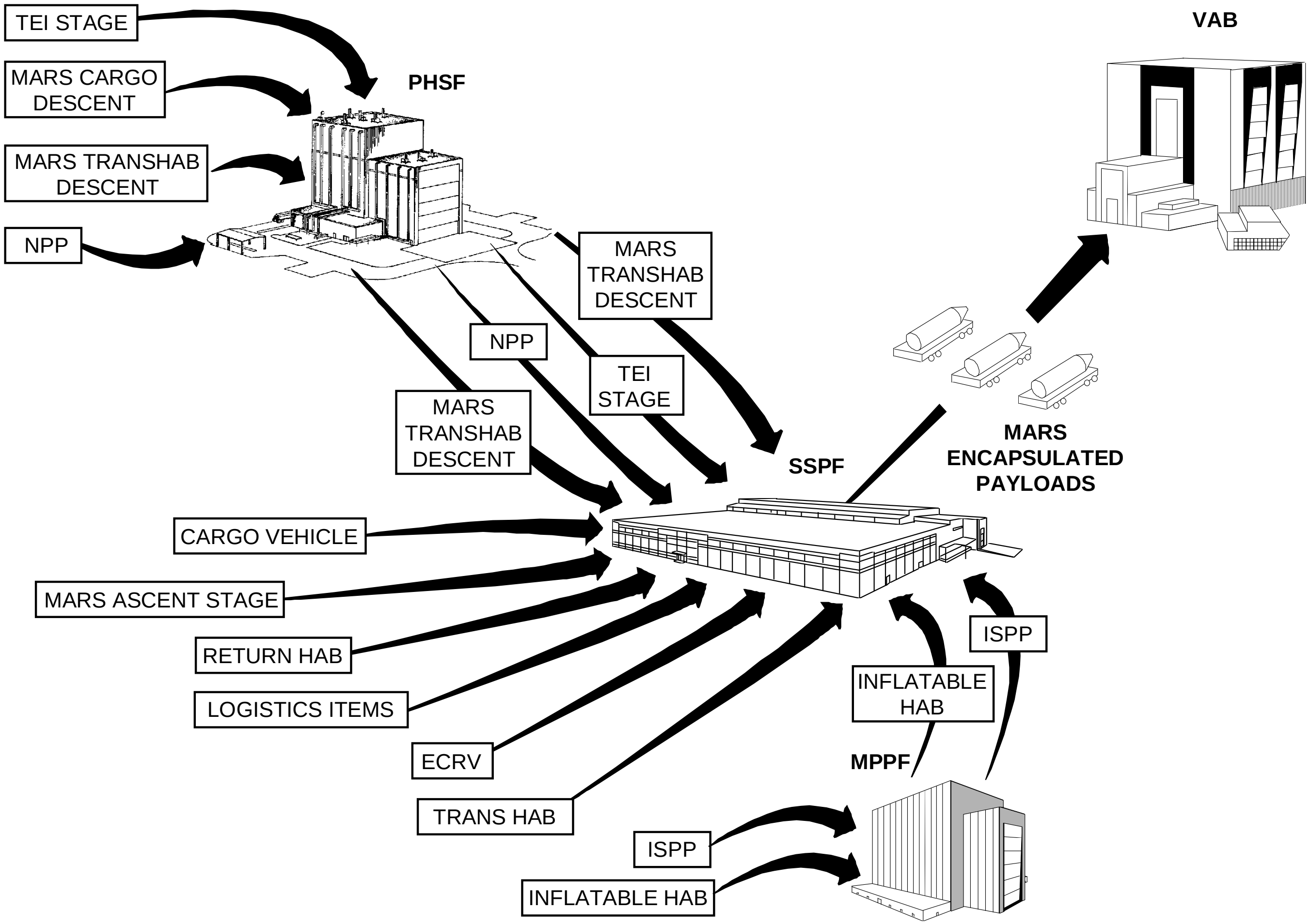
Baseline Processing Option

MARS PROCESING FLOW



Ref. Kennedy Space Center

MARS PAYLOAD PROCESING



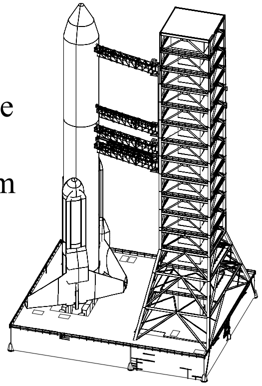
Ref. Kennedy Space Center

KSC Facility Modifications

- *The KSC Operations Assessment team has developed a processing concept that requires an additional Mobile Launcher Platform but does not require construction of new facilities*
  - Minor modifications to existing infrastructure can adequately accommodate the processing of the maximum inventory of flight hardware to support the launch campaign

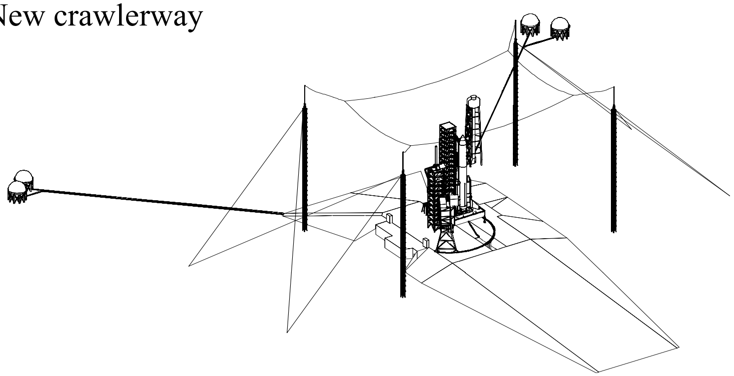
Mobile Launch Platform

- Two Mobile Launcher Platforms (MLPs) will be required to support the "Shuttle Compatible" and not interfere with the Space Shuttle Program
- New MLP
- Modify existing MLP 1



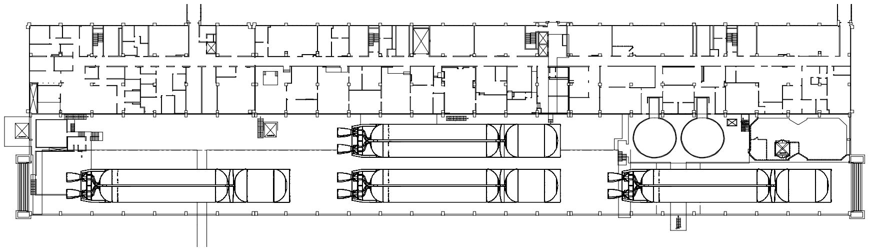
Pad Modifications

- One pad will require modifications for both Shuttle and "Shuttle-Compatible" Launches
- New crawlerway



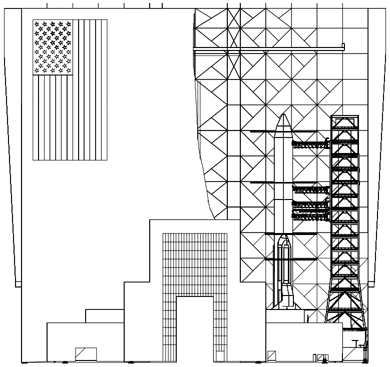
Operations and Checkout Building

- No modifications required



Vehicle Assembly Building

- Only platform modifications are required



Ref. Kennedy Space Center

Low-Earth Orbit Rendezvous and Docking

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

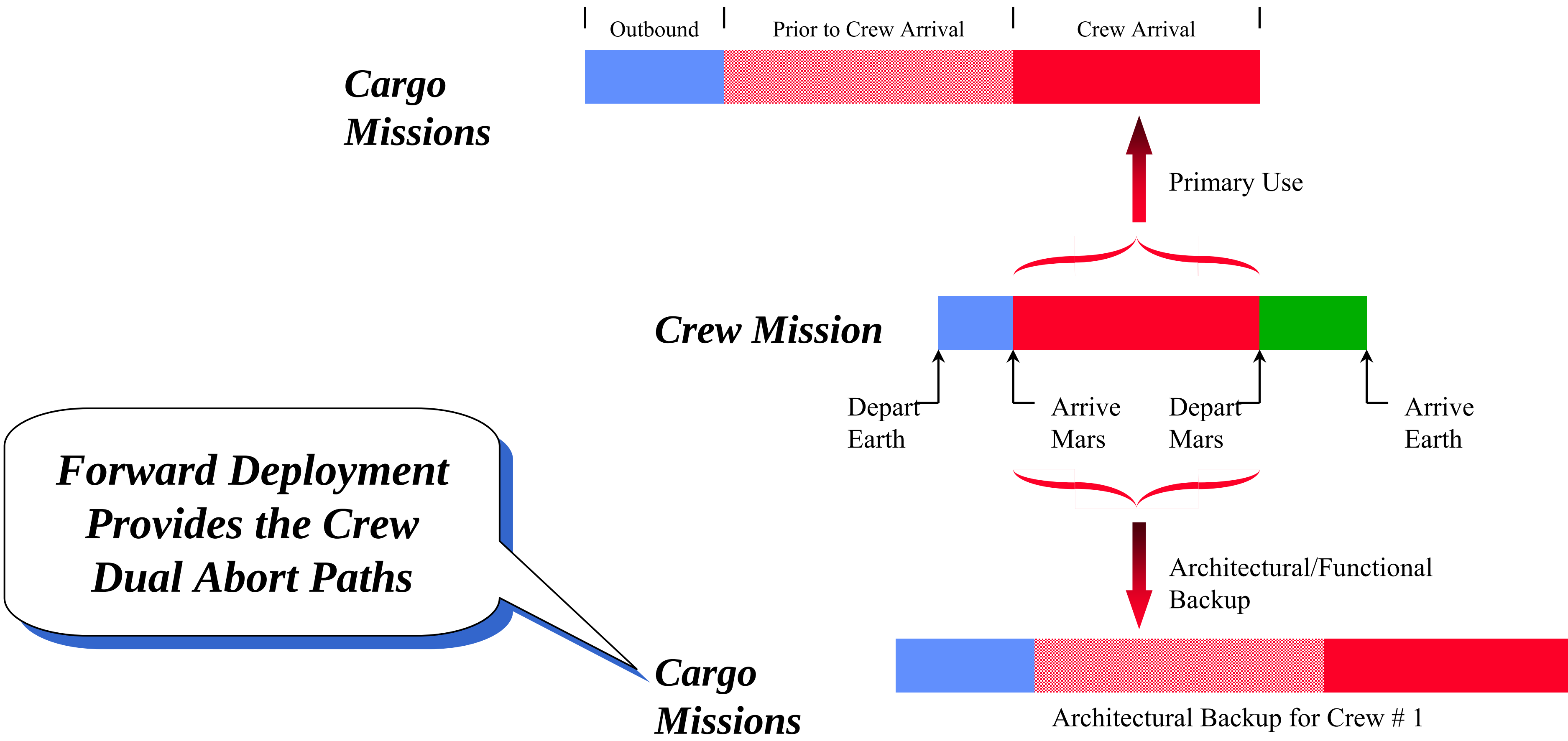
- Both Earth surface and LEO based navigation and control infrastructure utilized to enable LEO operations

- 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

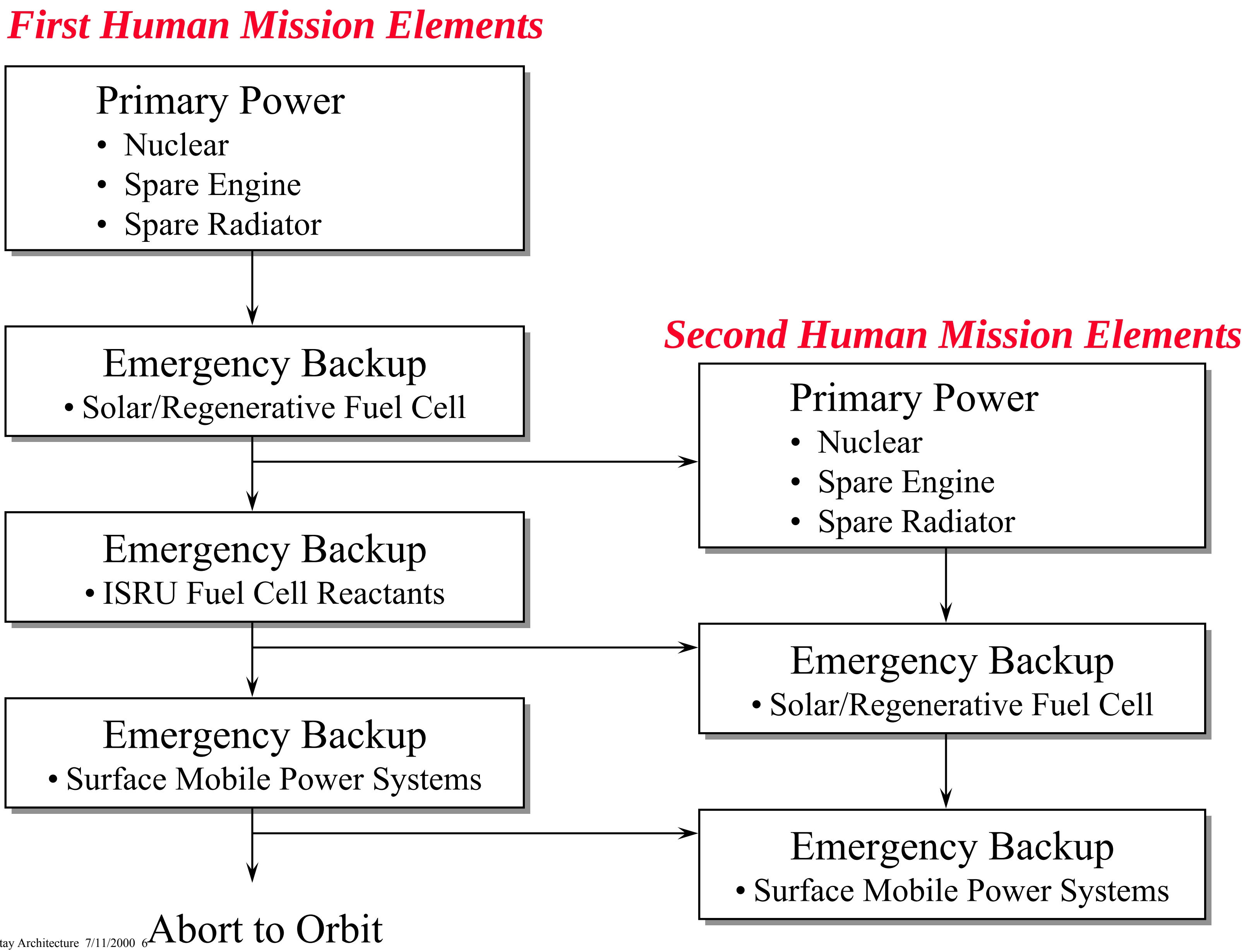
- Vehicles remotely checked out in LEO prior to initiating Trans-Mars Injection maneuver

The Forward Deployment Strategy

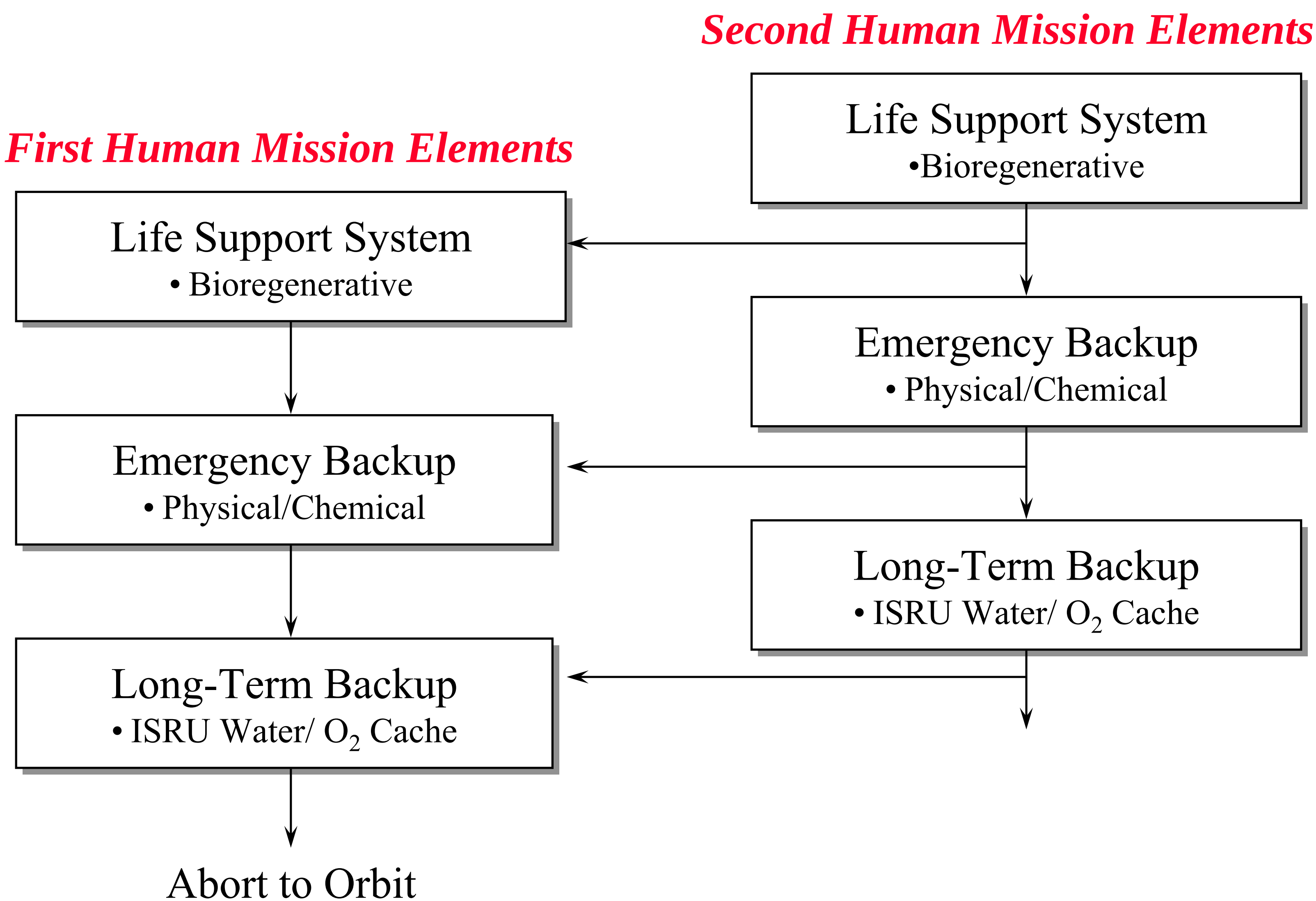
Exploration Office



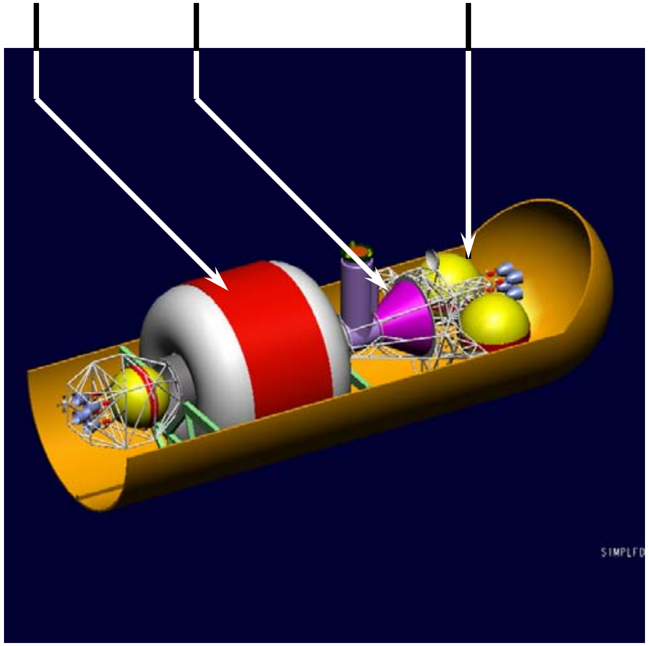
Example Power System Redundancy



Example Life Support System Redundancy



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

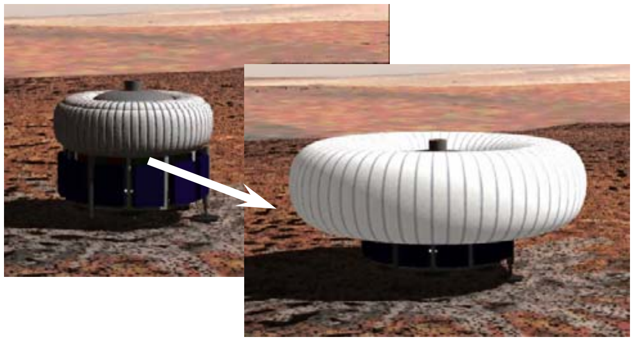
① Long Return Option (within 8 hrs of TMI)
- Crew lives in Transit Habitat after abort declaration
- Crew returned to Earth in the Earth Return Vehicle up to 30 days later

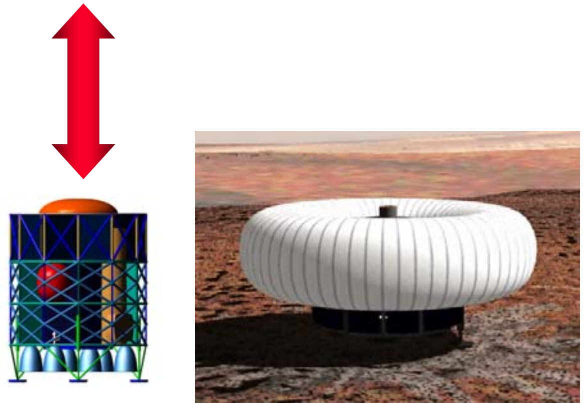
② Quick Return Option (within 30 hrs of TMI)
- Crew returned in the Earth Return Vehicle
- Return transit time 1-2 days

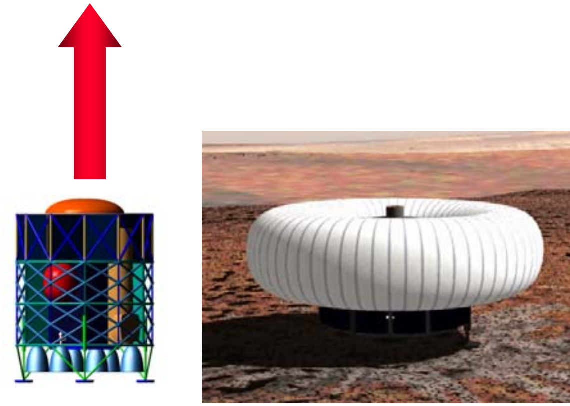
③ Heliocentric Aborts (1-2 months after TMI)
- Return transit times range from 360-570 days
- Crew lives in the Transit Habitat during return - direct Earth entry via Earth Return Vehicle
- Can perform this abort only for some (3 of 7) opportunities (2014, 2016, 2018) with the current TEI size (33% increase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

Mars Vicinity Abort Options

System Pre-Deployment	Initial Operations (30 days)	Full Surface Mission (600 days)







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.

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

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.

Mars-Long Stay Launch Strategy

Shuttle Compatible Launch Vehicle Option

Assumptions:

- Cargo launch concept based on Shuttle compatible systems
- 80 mt lift capacity due east
- Shroud 8 x 30 m
- Rendezvous and docking of two exploration elements
- Launch rate shown does not support continuous exploration (cargo launches must be supported in the 2018 launch opportunity)
- Detailed analysis of payload processing, payload and vehicle flows, facility impacts and modifications, schedule impacts, and cost assessments complete.

	Launch #	Descent / Ascent Vehicle	Vehicle Type
2016 Cargo	1	Wet Descent / Ascent Vehicle	Shuttle Compatible
	2	Wet NTR Stage	Shuttle Compatible
		Habitat Lander	
	3	Wet Habitat Lander	Shuttle Compatible
	4	Wet NTR Stage	Shuttle Compatible
2018 Crew		**Transit Habitat**	
	5	Transit Habitat	Shuttle
	6	Habitat Consumables / NTR Core	Shuttle Compatible
	7	NTR Tank Set	Shuttle Compatible
	8	Checkout Crew	Shuttle
	9	Flight Crew	Shuttle
2018 Cargo		Cargo launches for next mission	

Mars-Long Stay Launch Strategy
EELV-H Option

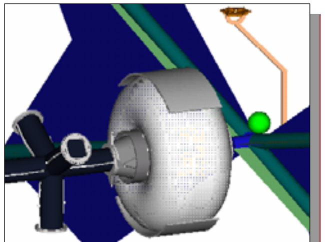
Assumptions:

- Evolved commercial EELV
- Heavy lift option with exploration unique upper stage
- 35 mt lift capacity due east (assumed performance - no data yet)
- Non-standard large shroud (8 x 30 m)
- Only hardware and volume launch considered thus far
- Crew support for on-orbit assembly, outfitting, and checkout not yet taken into account.
- Launch rate shown does not support continuous exploration (cargo launches must be supported in the 2018 launch opportunity)
- Detailed analysis not yet complete

	Launch #	Descent / Ascent Vehicle	Vehicle Type
2016 Cargo	1	Ascent Stage	Delta IV-H
	2	Aerobrake / Deorbit Descent Stage	Delta IV-H
	3	NTR Core Stage	Delta IV-H
	4	NTR Propellant Tank	Delta IV-H
	5	NTR Propellant Tank	Delta IV-M
		Habitat Lander	
	6	Ascent Stage	Delta IV-H
	7	Aerobrake / Deorbit Descent Stage	Delta IV-H
	8	NTR Core Stage	Delta IV-H
	9	NTR Propellant Tank	Delta IV-H
	10	NTR Propellant Tank	Delta IV-M
2018 Crew		**Transit Habitat**	
	11	Transit Habitat	Delta IV-H
	12	Habitat Consumables / ERC / Shadow Shield	Shuttle
	13	NTR Core Stage	Delta IV-H
	14	NTR Tank Set 1	Delta IV-H
	15	NTR Tank Set 2	Delta IV-H
	16	NTR Tank Set 3	Delta IV-H
	17	Checkout Crew	Shuttle
	18	Flight Crew	Shuttle
2018		Cargo launches for next mission	

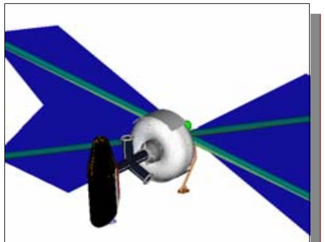
Human Exploration of Mars
Evolution of Common Capabilities

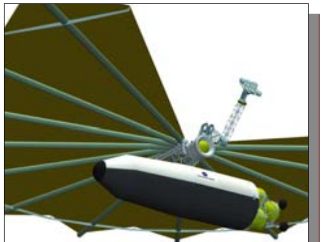
L1/L2 Gateways → Mars Habitats



Long duration support of mission crew in interplanetary environment with limited resupply capabilities

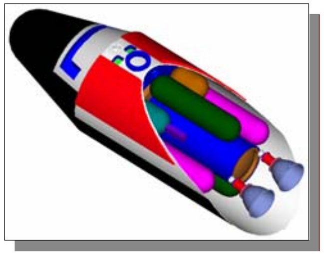
L1/L2 SEP → Mars SEP

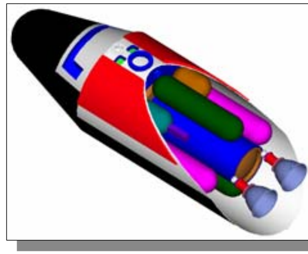




Transports mission payloads from low-Earth orbit to mission destination and return

L1/L2 Transfer Vehicle → Mars SEP Taxi





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

Lunar EVA → Mars EVA

Enables routine access to the planetary surface and expands the range of access for exploration

Architecture Unique Technology Needs
Long-Stay Mars Mission

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

- ***Advanced Space Transportation***
  - Advanced interplanetary propulsion: Options include:
    - Solar Electric Propulsion (1.7 Mwe, 18 % efficiency thin film solar)
    - Bi-Modal Nuclear Thermal Propulsion (925 sec Isp, 25 kWe)
  - Large volume / large mass Earth-to-Orbit transportation
  - 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 15-30 kWe for high latitude 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)

Architecture Comparison Criteria

Long-Stay Mars Mission

Criteria	Value
Architecture Evolution Potential	Long-stay human expansion
Architecture Commonality	High propulsion system commonality (SEP)
Initial Mass in Low-Earth Orbit	430 mt
Mass to Mars Surface	33 mt
Number of Crew	6
Number of Cargo Launches	6
Number of Crew Launches	1
On-Orbit Assembly Required?	No
Architecture Redundancy	Full architectural redundancy (vehicle overlap)
Architecture Complexity	Long surface mission
Architecture Sensitivity	Low
Crew Hazards	Surface mission, 900-day long mission
Time in Interplanetary Space	360-380 total days
Time on Surface	540 total days

Mars-Long Stay Mission Architecture Summary

Strengths

- Low initial mass in LEO (430 mt)
- Small variation in mass; less sensitive to mass, level of redundancy, and technology changes
- Science return is regional "discovery" oriented
- Crew time spent in free space zero-g/radiation environment is minimized (360 days total)
- Potential for reuse of surface mission assets
- Functional overlap of mission resources
- Paced architecture allows for contingencies and re-planning
- Rendezvous and docking of two elements in low-Earth orbit

Weaknesses

- Long mission requires high reliability (30 months)
- Long surface mission (18 months)
- Many unknowns and crew health issues of long surface mission and surface environment (radiation, dust, gravity, etc.)
- Long-range roving capabilities for regional science (1000 km desired)
- Development of new 80-mt launch vehicle
- Crew productivity and challenges during long mission

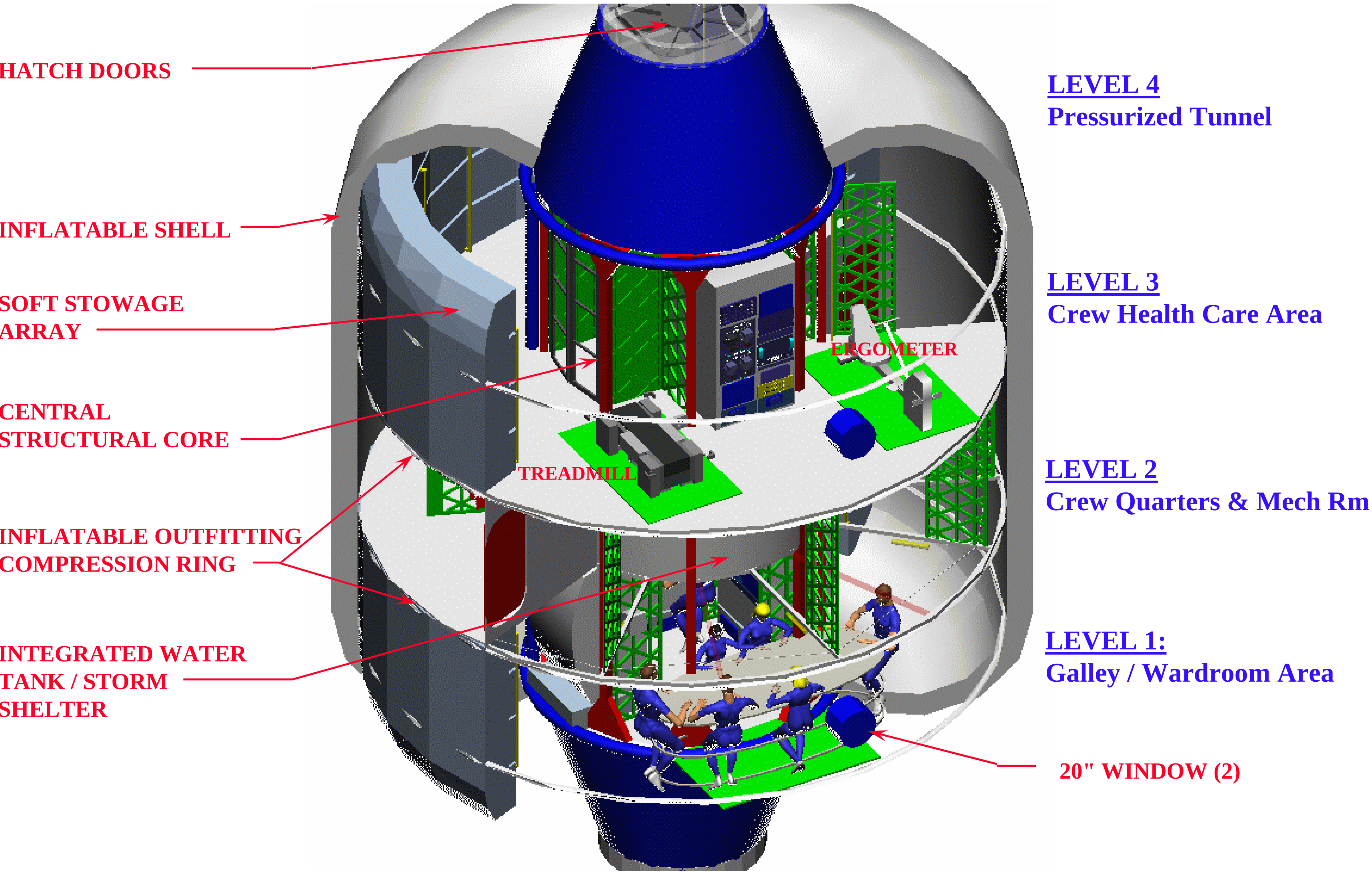
Backup

Mars Long-Stay Mission Objectives

- Balance technical, programmatic, mission, and safety risks
- Provide an operationally simple mission approach emphasizing the judicious use of common systems
- Provide a flexible implementation strategy
- Limit the length of time that the crew is continuously exposed to the interplanetary space environment
- Define a robust planetary surface exploration capacity capable of safely and productively supporting crews on the surface of Mars for 500-600 days each mission
- Enable the capability to live off of the land
- Design systems capable of performing in each launch opportunity
- Examine at least three human mission to Mars

Mars Transit Habitat

Exploration Office

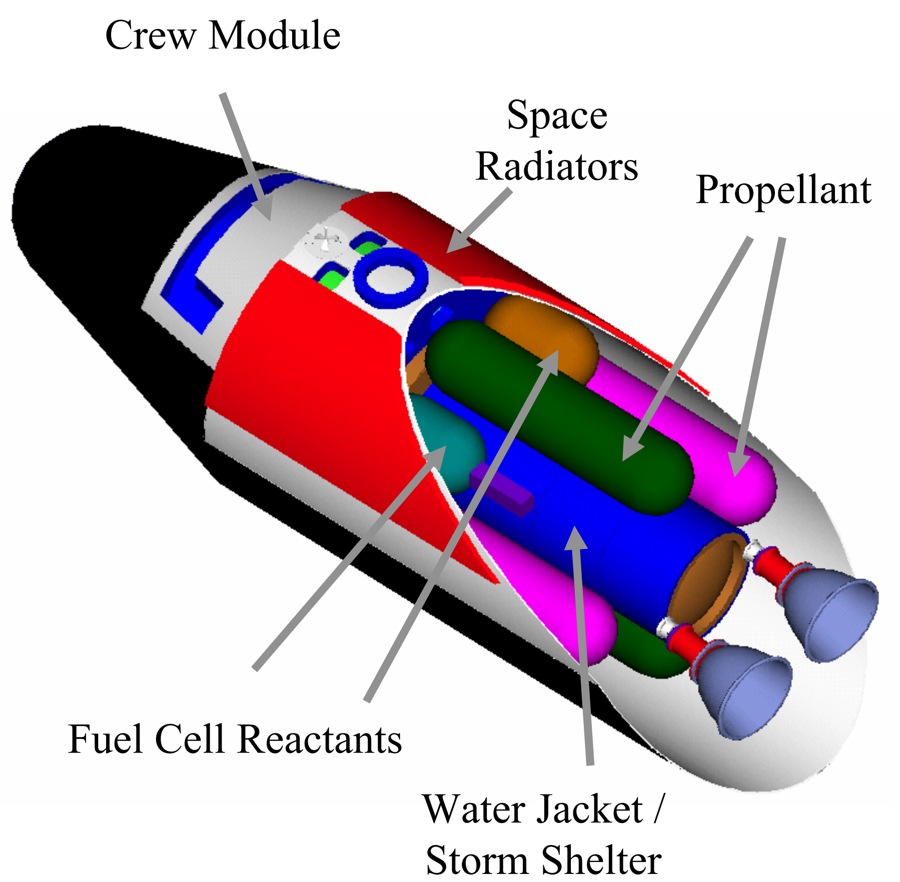


Ref. Johnson Space Center

Crew Taxi Vehicle for the SEP Architecture

- "Requirements"
  - Launch and recovery in Space Shuttle or Based at ISS
  - Utilizes space storable propellants
  - Crew of 6 with ΔV capability of >3100 m/s
  - Ten day upper limit for orbit phasing, rendezvous, and missed rendezvous
  - Aerocapture maneuvers at lunar return speeds to ISS orbit

- Preliminary Concept
  - Lifting body for crew g reduction
  - Integral LOX/CH_4 propulsion system
  - Lightweight docking system

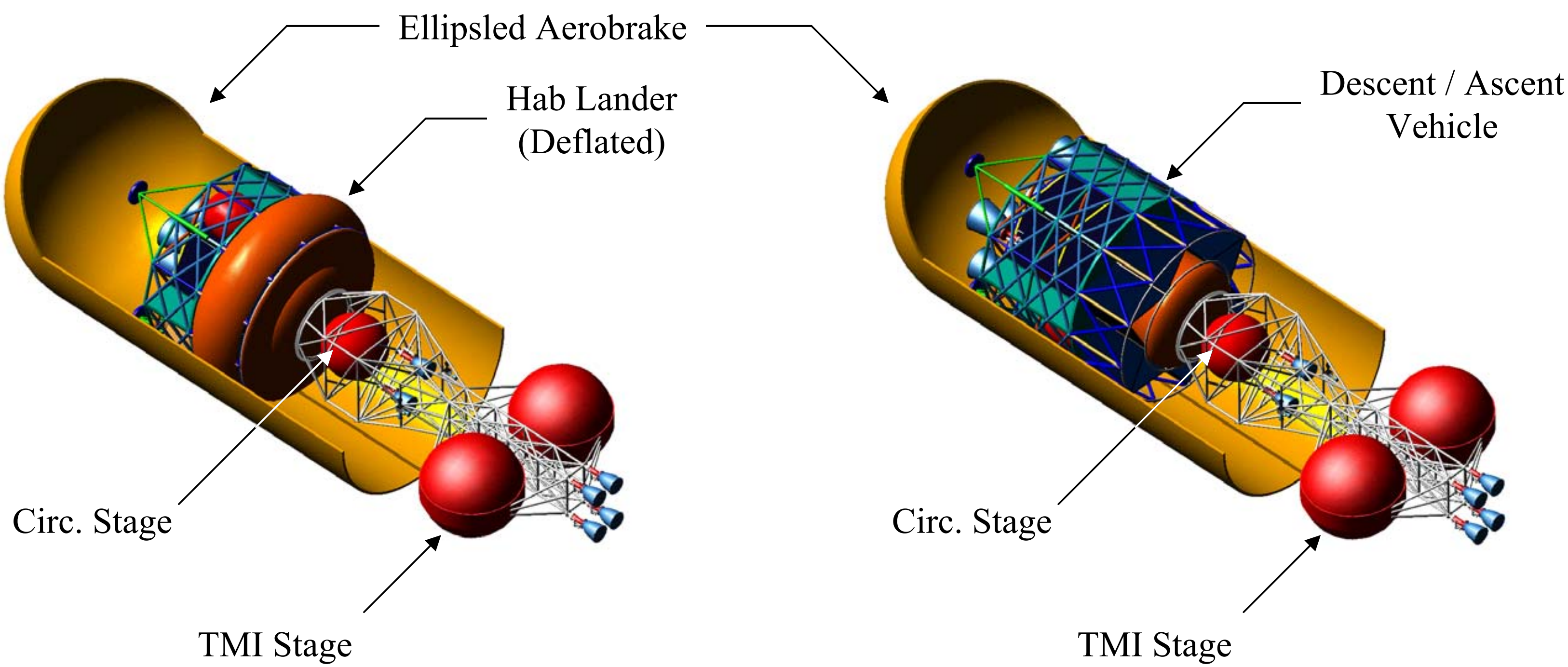


Ref. Johnson Space Center

Dual Lander Configurations

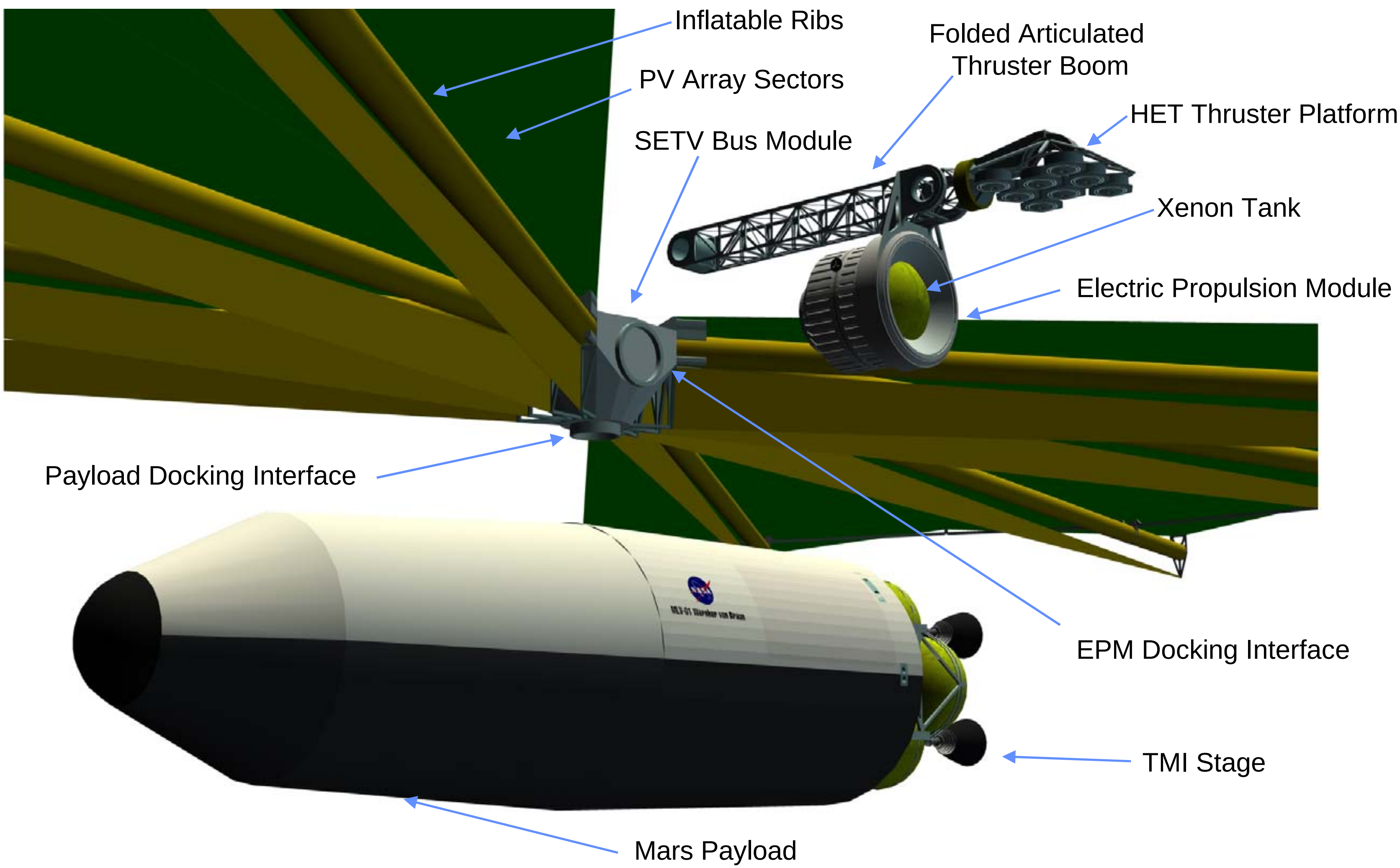
Surface Habitat

Descent / Ascent Vehicle

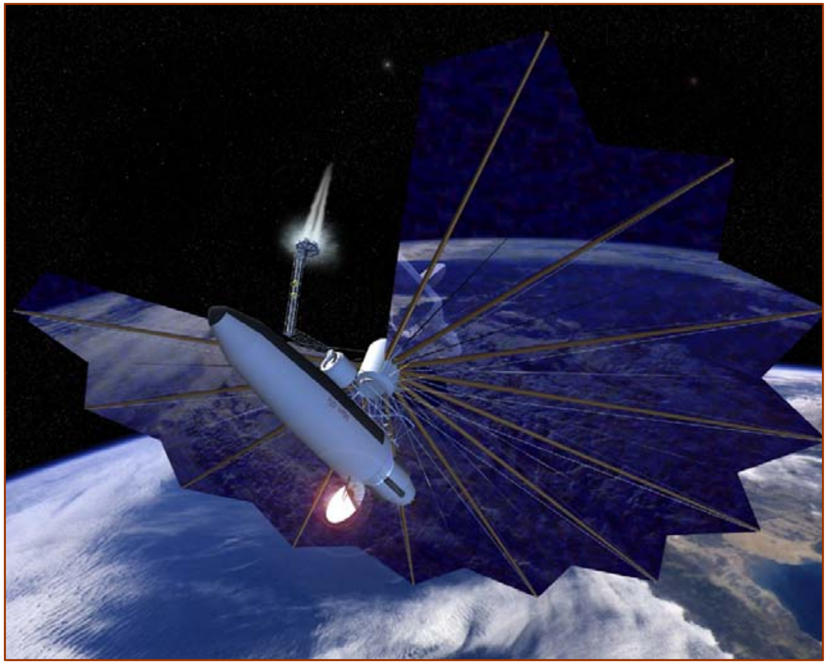


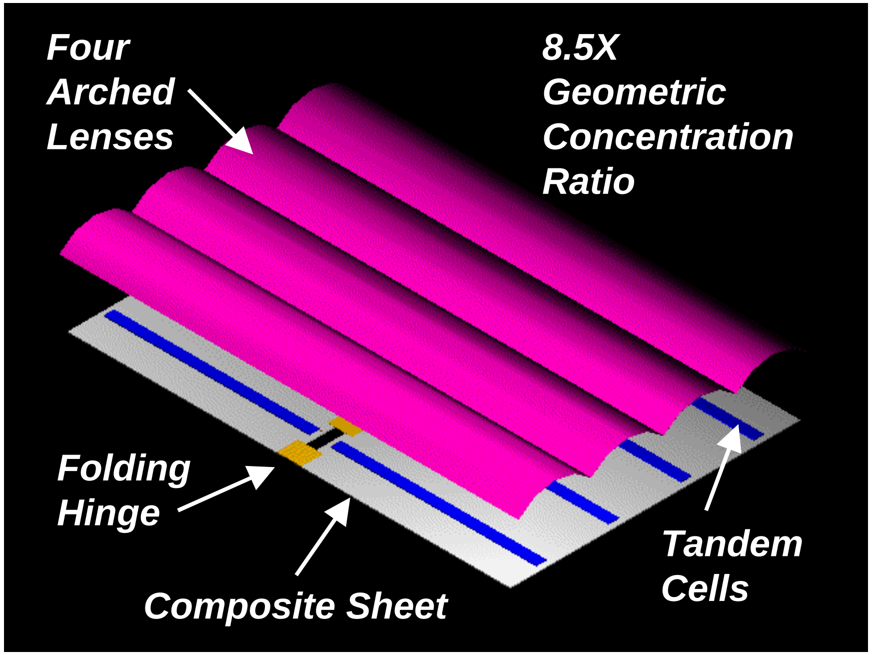
Ref. Johnson Space Center

SETV Resupply Proximity Operations



Emerging Solar Array Technology



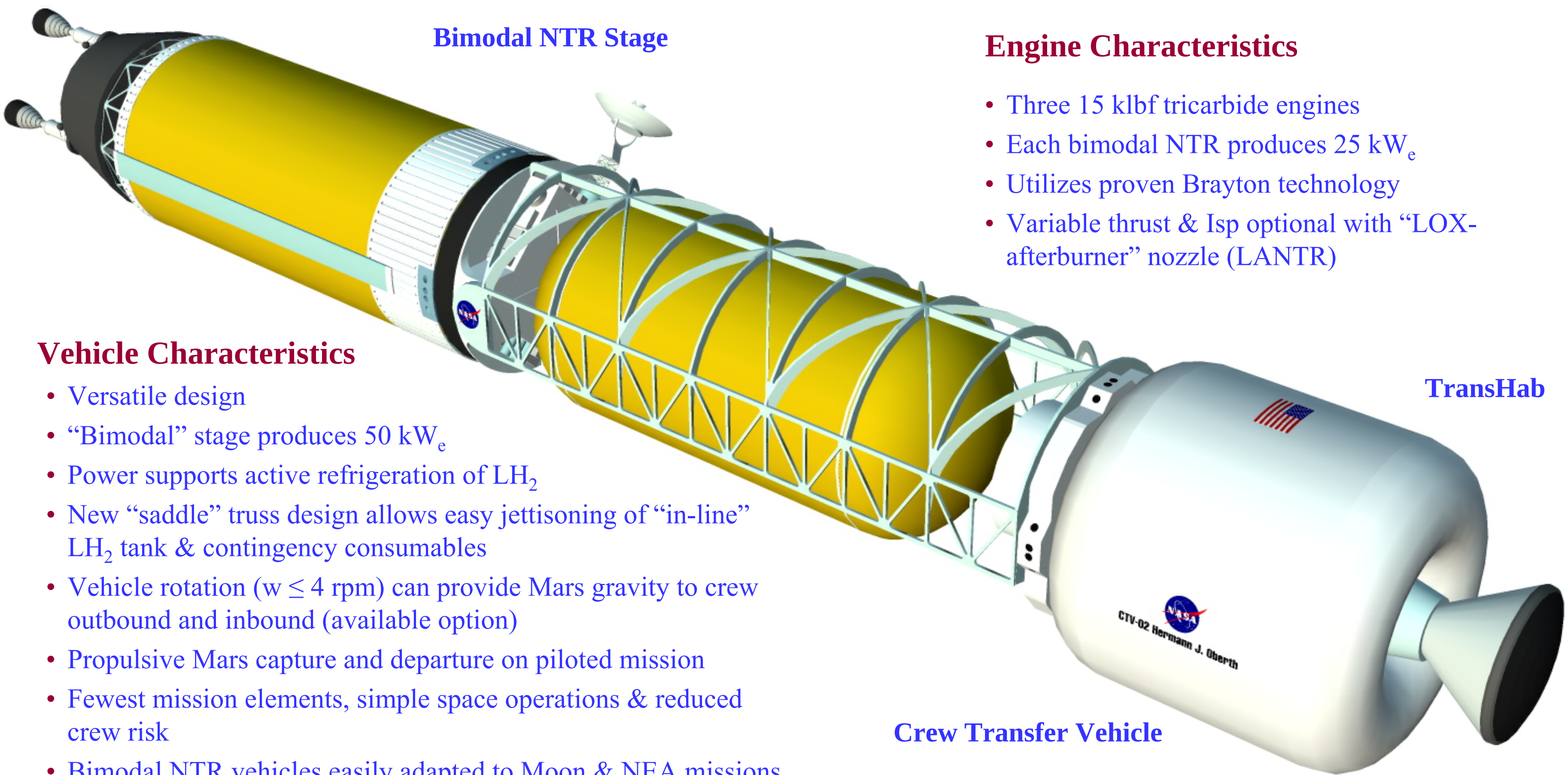


- Current SEP concept assumes thin film arrays
- Loose pointing requirements
- Requires 14,700 m^2

- In the near term, lab demonstrations of 300 W/m^2 for flexible concentrators
- Tight pointing requirements
- Area reduced to 6700 m^2

Modular "Bimodal" NTR Transfer Vehicle Designs Developed for Mars Cargo and Piloted Missions

Bimodal NTR: High thrust, high Isp propulsion system utilizing U^{235} produces thermal energy for propellant heating and electric power generation enhancing vehicle capability



Engine Characteristics

- Three 15 klbf tricarbide engines
- Each bimodal NTR produces 25 kW_e
- Utilizes proven Brayton technology
- Variable thrust & Isp optional with "LOX-afterburner" nozzle (LANTR)

Vehicle Characteristics

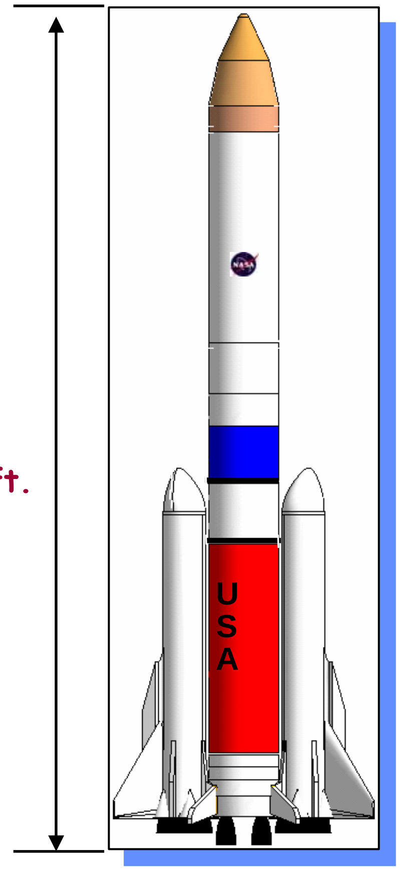
- Versatile design
- "Bimodal" stage produces 50 kW_e
- Power supports active refrigeration of LH_2
- New "saddle" truss design allows easy jettisoning of "in-line" LH_2 tank & contingency consumables
- Vehicle rotation (w ≤ 4 rpm) can provide Mars gravity to crew outbound and inbound (available option)
- Propulsive Mars capture and departure on piloted mission
- Fewest mission elements, simple space operations & reduced crew risk
- Bimodal NTR vehicles easily adapted to Moon & NEA missions

Ref. Glenn Research Center

“Shuttle Compatible” Launch Vehicle Configurations

Large Payload Missions to LEO
(HMM w/ Expendable Shroud)

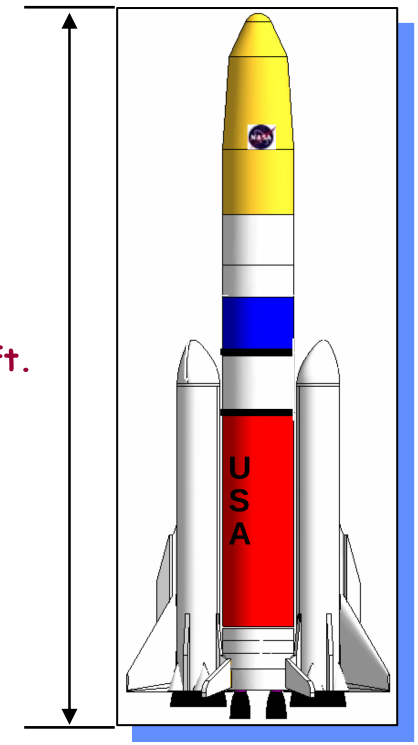
322 ft.



Payload = 188 klb
(to 220 nmi circ @ 28.5°)

HMM with Integrated Shroud/Aerobrake

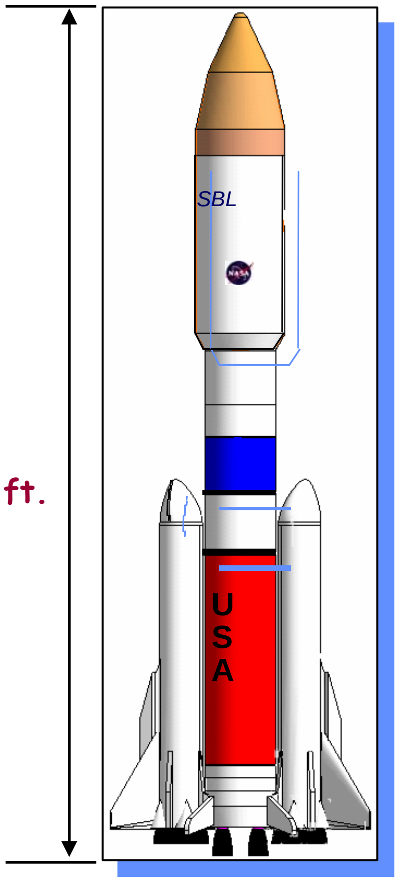
272 ft.



Payload = 197 klb
(to 220 nmi circ @ 28.5°)

Space Based Laser (SBL) Delivery

327 ft.



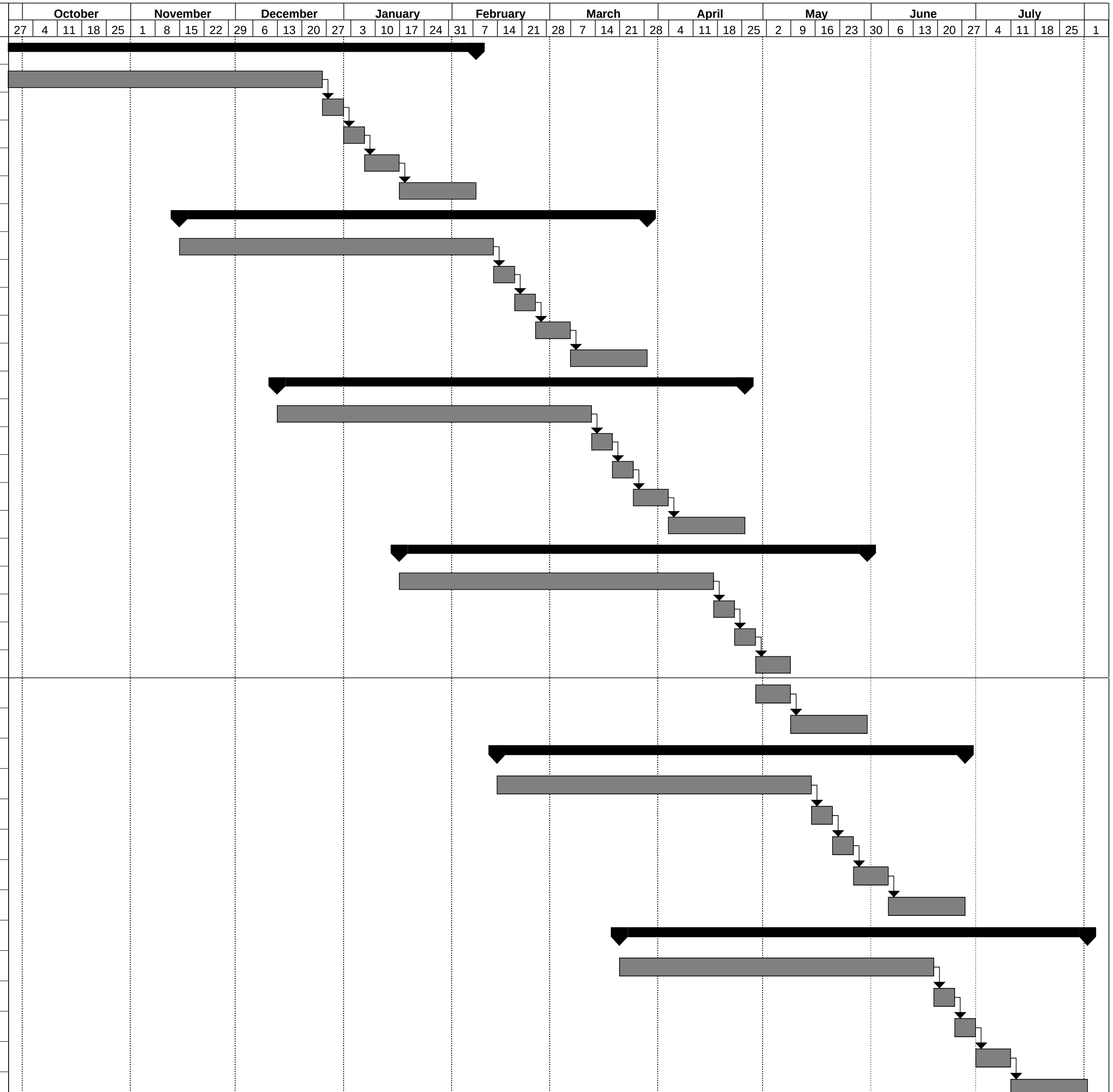
Payload = 139 klb
(to 700 nmi circ @ 40°)

Ref. Marshall Space Flight Center

Payload/Vehicle Processing

Exploration Office

ID	Task Name
1	**Magnum #1**
2	Magnum #1
3	Magnum Stack
4	Kick Stage Mate
5	Payload Mate
6	Pad Ops
7	**Magnum #2**
8	Magnum #2
9	Magnum Stack
10	Kick Stage Mate
11	Payload Mate
12	Pad Ops
13	**Magnum #3**
14	
15	Magnum Stack
16	Kick Stage Mate
17	Payload Mate
18	Pad Ops
19	**Magnum #4**
20	Magnum #4
21	Magnum Stack
22	Kick Stage Mate
23	Payload Mate
23	Payload Mate
24	Pad Ops
25	**Magnum #5**
26	Magnum #5
27	Magnum Stack
28	Kick Stage Mate
29	Payload Mate
30	Pad Ops
31	**Magnum #6**
32	Magnum #6
33	Magnum Stack
34	Kick Stage Mate
35	Payload Mate
36	Pad Ops



Mars Long-Stay Mission Risk Reduction and Functional Redundancy

- ***Reliability and survivability of critical systems will be a major challenge for all Mars missions***
  - Long-duration missions
  - No capability for resupply
  - Limited abort capabilities

- ***Risk reduction achieved by several techniques***
  - Architectural redundancies through mission design
  - Functional redundancy by dis-similar means to accomplish same end result
  - Early development and implementation of systems (time on systems)
  - Proper systems designs

- ***Selection of proper technique(s) requires cost/benefit analysis***

Hierarchy Process

① Mission Design

- Forward deployment (overlapping of mission resources)
- Verification and checkout prior to crew departure
- Mission mission approaches

② Resource Sharing and Technologies

- Advanced technologies (unique products and robust capabilities) provides cross-strapping of resources between systems

③ Operational Concepts

- Conservation of resources (power, consumables, etc.)
- Modularity of systems
- In-flight maintenance and sparing
- "Hanger Queen"
- Procedures and concepts

④ Systems Designs

- Flexibility of designs (unanticipated uses)
- Experience of previous and current programs
- Reliability
- Robustness of mission elements and capabilities
- Dual paths, isolation, interlinking, crossfeeding, etc.

Resource Sharing

Example: Power and Consumables