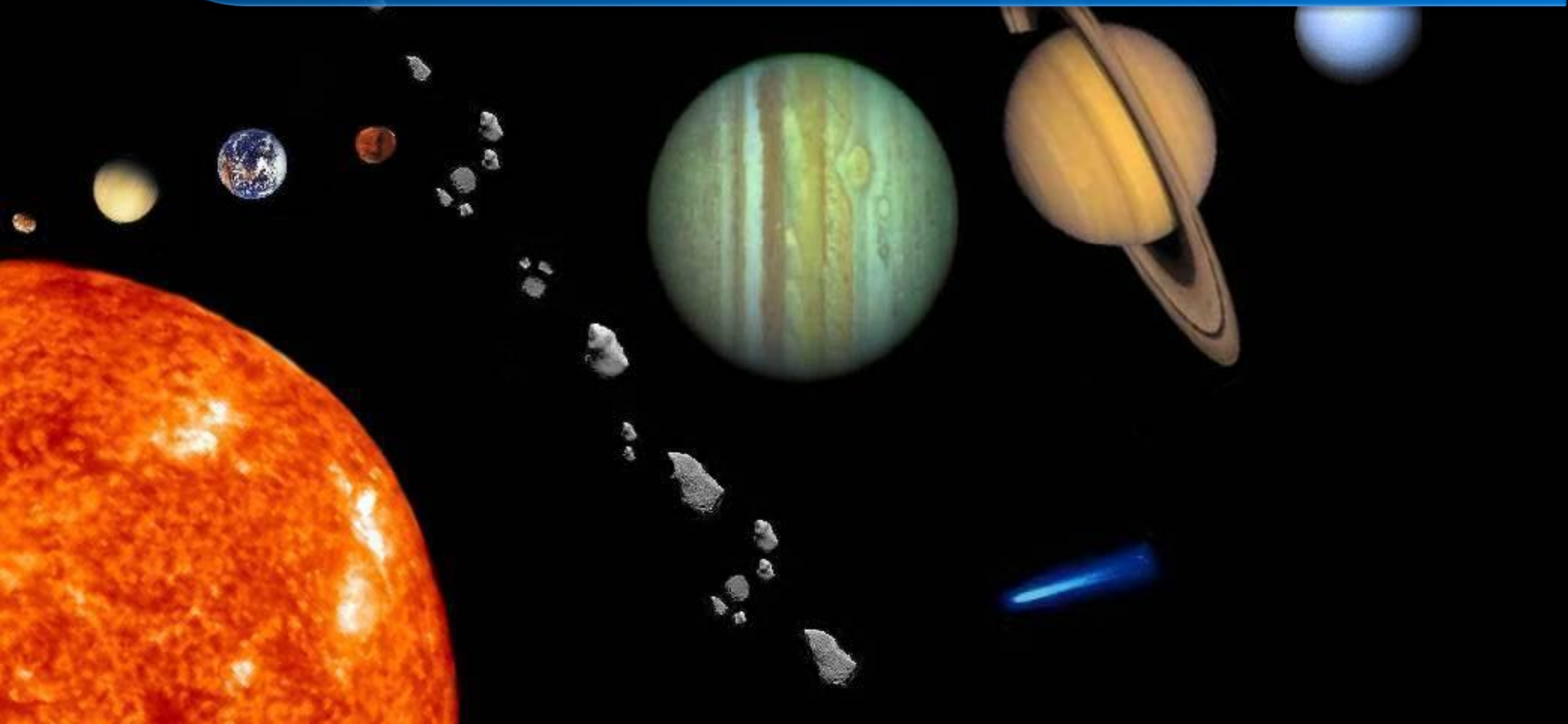
The Single Habitat Module Concept for Exploration



The SHM Concept for Exploration - Joe Chambliss Biography

- Serves in the EC Special Projects Branch as a Technology Development Engineer
  - More than 38 years of experience joining NASA as a civil servant in 1994
    - Worked with Lockheed, Rockwell, McDonnell Douglas in support of NASA JSC
  - Worked on shuttle, ISS, technology development, and Constellation programs
  - NASA career started as the System Manager for the International Space Station (ISS) Thermal Systems Development for the first 6 years of ISS
  - Managed efforts in technology development for life support and thermal control
  - Provided support for Cx Orion, Altair and Lunar Surface Systems projects.
  - Deputy manager for Exploration in NASA's Crew and Thermal Systems Division (CTSD) at the JSC
  - Deputy manager for Exploration (originally Advanced) Life Support Technology Development.
  - Lead for Life Support for the Advanced Exploration Systems (AES) Habitation Systems Project
  - Contributed to VASIMR rocket heat rejection system design development via SAA with AdAstra
- Bachelor of Science from the University of Texas at Austin
  - Aerospace engineering
- Two Master of Science degrees from Rice University:
  - Aerospace engineering
  - Space physics and astronomy.

The SHM Concept for Exploration Background

- SHM resulted from months of thinking on implications of the FY10 presidential direction
  - Change focus to Exploration
  - Develop and Employ new technologies
- SHM advocated to NASA Leads for detailed study and direction
  - HAT in June 2010
  - OCT in September 2010
- Presented to several forums
  - Innovation Day 2011
  - Knowledge Capture in July 2011
  - International Conference on Environmental Systems July 2012
  - AIAA Space 2012 in September 2012
- Trajectory assessment addressed in Summer 2012 with JSC EV
- Working with JSC EP on mass estimates for Habitat Propulsion System
  - Will use calculated HPS Mass to iterate trajectory
- Worked with MSFC Nuclear Propulsion Team to understand Nuclear Powerplant

The SHM concept of a different approach to crew accommodations and mission conduct

- Puts new concepts together in a way that can make exploration more efficient, less costly, and nearly eliminate the waste of mission resources
- SHM combines the following approaches and technologies:
  - CCiCAP (or Orion) access of crew to LEO
  - Heavy-lift launch vehicle (HLV) launch of large payloads (now funded as the Space Launch System (SLS) Program)
  - Fueling (later refueling) (and assembly) in space
  - Closed Loop Life Support (CLLS)
  - Interplanetary space propulsion (ISP) (probably nuclear powered)
  - Green technology (reuse mission assets, liquid methane for habitat propellant)
  - Aerocapture - Trade
  - ISS utilization - Trade
- As of 2012, NASA is pursuing all of those new technology and vehicle development efforts as currently funded projects or in future plans
  - The CCiCAP, Orion, and SLS projects are well under way

SHM Assumptions

- HLV, and Fueling or refueling in space
  - Makes starting a mission fully fueled possible
  - Makes it possible to deliver major elements and fuel to assemble in space
- High specific impulse (Isp) ISP initiatives are realized
  - High Isp In Space Propulsion (ISP)
    - Makes acceleration and deceleration to and from destination practical
    - Shortens time to and from destination
    - Enables trajectory options that aren't available via fire-then-coast propulsion
    - Dramatically reduces propellant required
      - Increases Isp from below 500 to over 5000
- Chemical propulsion can address getting SHM habitat and MMSEV to and from destination surface (from low destination orbit)

SHM Assumptions

- Focus for exploration is on NEAs and Mars
  - Mars is the “ultimate” destination
  - Lunar exploration pursued as validation of readiness to go to Mars
- Colonization and commercialization are to be addressed after exploration has established the best location

Single Habitat Module Concept

- Recognizes that crew support requirements for transit and while at a destination are roughly the same and thus could be addressed with a single module
- Starts with assembly at a location near Earth
  - Uses the capabilities humanity has developed and demonstrated in creating and operating the ISS
- The SHM vehicle will include
  - Habitation to address crew support requirements
  - An efficient Interplanetary Space Propulsion (ISP) system for propulsion to and from an exploration destination

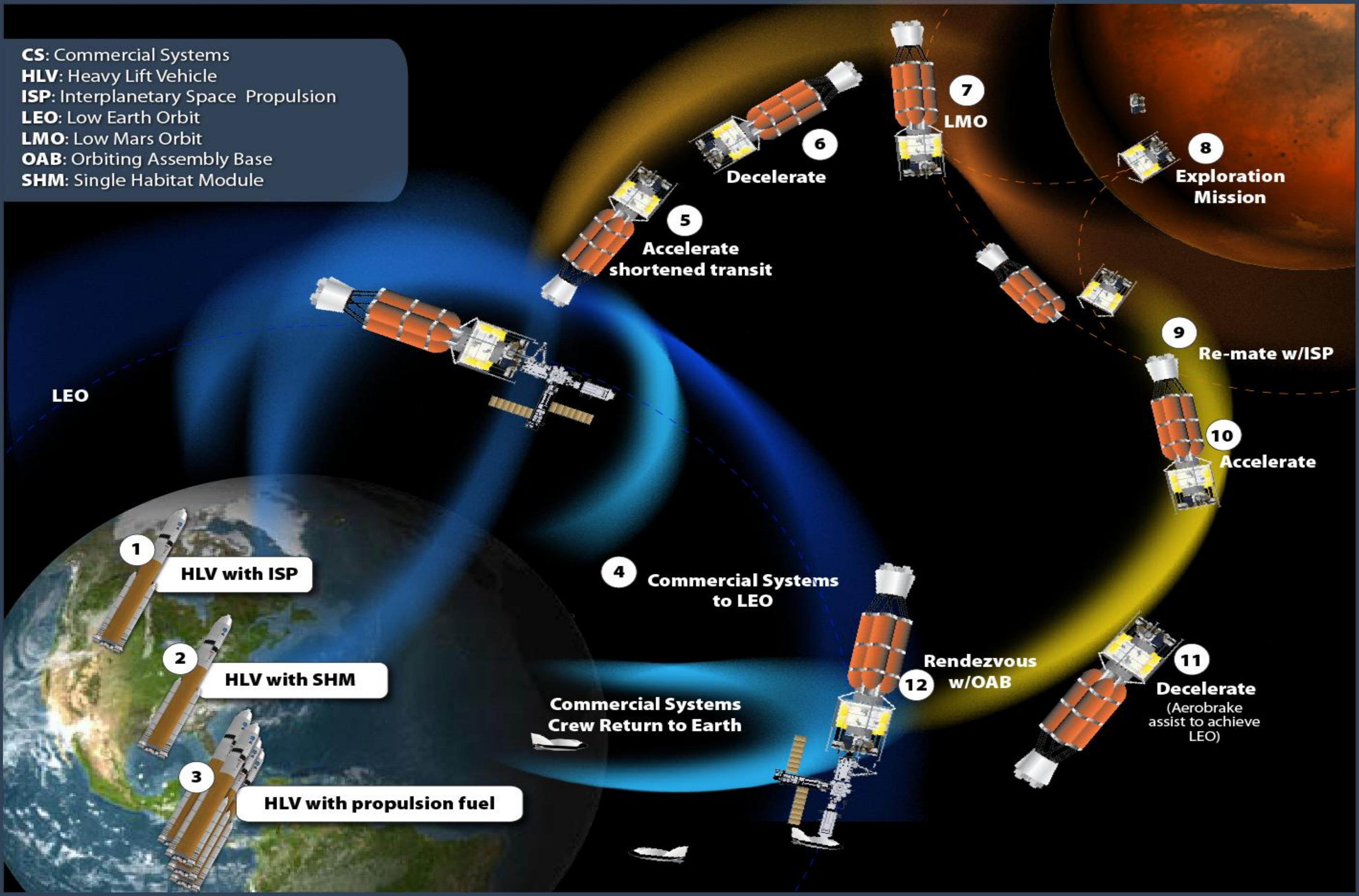
Overview

- Introductory comments and basics of the concept
- Description of the SHM concept
  - Essentials of the SHM concept
  - Ideas on how the concept could be implemented
    - Combines new technologies and past exploration program concepts
  - An estimate of the mass of the habitat
  - A plan for how total SHM vehicle mass can be calculated
- Top level, qualitative comparison of the SHM with recent concepts for conducting exploration missions
  - Provided to better understand the concept
- Qualitative assessment of the benefits of the SHM approach
- Recommended of forward work

Basics of the SHM Concept

- Assembling and fueling the integrated vehicle near Earth provides the capability to start exploration missions fully fueled to meet the requirements of the mission
  - Makes it possible to leave the vicinity of Earth with enough fuel to return a habitat from an exploration destination
- Employing only one habitat can dramatically simplify mission conduct and make it possible to reuse mission assets
  - The end of a SHM exploration mission results in the ISP system and habitat being returned to the near-Earth staging site
    - Refurbish and refuel in space, then reuse for subsequent exploration missions
- SHM could make exploration more affordable and possibly realizable sooner
    - Focuses development on the fewest possible number of exploration elements
      - Habitat and ISP
- SHM provides an infrastructure that can address many exploration goals

Single Habitat Module Concept for Transit and Surface Operations



Single Habitat Module Concept Mission Operations

- 1 thru 3 – Assemble and fuel the mission elements near Earth
  - Check out each element at the in-space assembly station
- 4 – Deliver the exploration crew to man the vehicle via Orion or Commercial Crew Integrated Capability (CCiCAP)
- 5 and 6 – Transit to the deep space destination via the ISP system
  - Accelerate roughly ½ the way to destination then decelerate the rest of the transit to achieve low orbit at destination (use aerocapture assist to decelerate at Mars to aid in achieving low orbit)
- 7 – Separate the habitat with its habitat propulsion system (HPS) from the ISP system
- 8 – Use the HPS to descend and land at the exploration site on the destination surface
  - Conduct surface operations using the SHM as the base of operations and the MMSEV
  - This is what it is all about !!
- 9 – Ascend to low destination orbit via the HPS and rendezvous with the ISP system
  - Discard the HPS after re-mating with the ISP system to reduce return mass
- 10 and 11 – Use the ISP system to return to Earth vicinity orbit
  - Accelerate roughly ½ the way to Earth then decelerate the rest of the transit to Earth vicinity
- 12 – Rendezvous with the in-space assembly base
- 13 – Transfer crew to Orion (or CCiCAP) and use Orion (or CCiCAP) to return crew and samples to Earth

Single Habitat Module Essentials

- It is critical to return the habitat module and the MMSEV to destination orbit then back to Earth since both the habitat and the MMSEV are essential for crew support and/or to address potential contingencies throughout the mission
  - The habitat module of the SHM concept will need to address all life support and crew habitability and command functions for each entire exploration mission
    - Provide enough resources for the crew to function during the long zero gravity (or very low acceleration of the ISP) of the to-and-from transit phases
    - Also be compatible with the long-duration surface exploration phase in the partial gravity of Mars or the moon
- Cabin atmosphere leak or contamination and contingencies must be addressed
- EVA and mobility capabilities are required to enable exploration at the destination

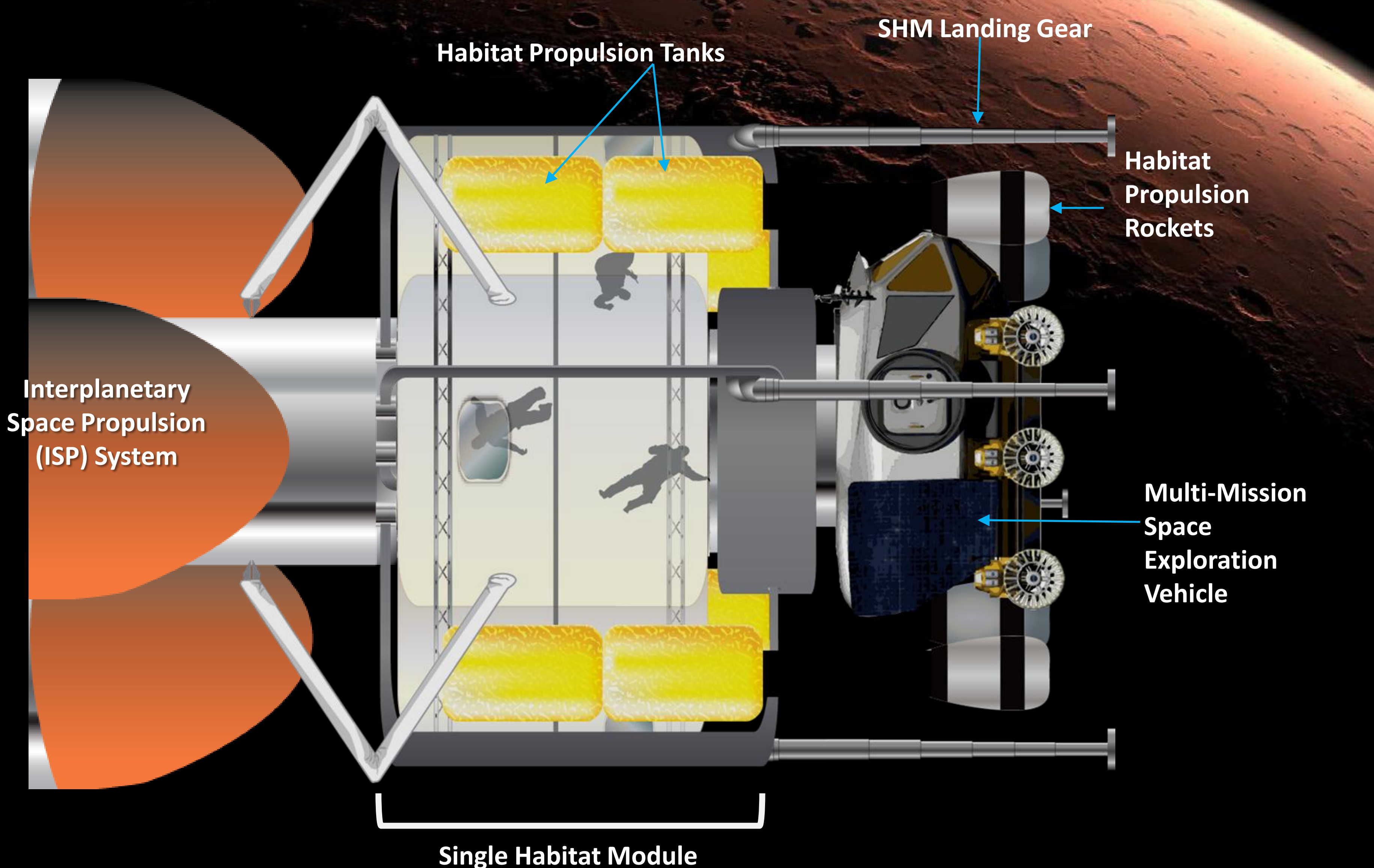
Single Habitat Module Essentials

- Design driving case - Mars landing and surface exploration followed by return to Earth
  - Mars surface exploration requires the Habitat have:
    - Propulsion capability to descend from Low-Mars Orbit (LMO) to land at a designated exploration site
    - The capability to support crew operations while on Mars
    - Propulsion capability ascend back to LMO to rendezvous with the ISP
- Enable reuse of the critical elements of an exploration mission
  - Reuse requires designing to meet the needs of the most difficult exploration mission envisioned
    - The most difficult mission currently envisioned is the surface exploration of Mars
    - Transit times for Mars missions will be many months
    - Exploration periods on Mars will also be months
  - The SHM for Mars surface exploration would be capable of missions to NEAs or the moon
  - Deceleration to achieve return to Earth vicinity
    - Crew to depart via Orion to return to Earth at start of spiral
    - SHM continues spiral to return to Earth vicinity

SHM Implementation

- When implemented, the SHM concept will have a program to develop the best design for the variety of elements
  - Start with the relevant parts of prior programs (such as CX) to use applicable concepts
  - The best mix of US and International contributions
  - Use the best technology options
- Mass minimization and safety will be key design considerations
  - CLLS, thermal control, EVA, habitation, and command capabilities need to be as efficient as possible to minimize mass of both equipment and consumables
    - Needed to support the crew during the entire mission
    - Long-duration missions have been shown in exploration trade studies to greatly benefit from regenerating resources
    - The longer the mission, the more beneficial regeneration of resources becomes
    - The most reliable solution will be employed, combined with appropriate redundancy and sparing.
    - The CLLS will minimize waste products, which will partially address planetary protection issues
    - Address the most demanding of the environments, whether that occurs in transit or during surface operations.
    - Thermal control radiators must address the peak heat loads in transit and at Mars
      - Radiators that work efficiently in deep space may also work well in a convective Martian atmosphere
- The following implementation ideas integrate Cx concepts and address issues such as redundancy and radiation protection

SHM Concept Implementation



SHM Implementation (continued)

- EVA capabilities will be required at the exploration destination
  - EVA interfaces would need to be robust to address the dust environment and provide the isolation needed for the crew from potential Martian contamination
    - The suit port concept provides very efficient EVA capability and would address the dusty environment
    - The same EVA system can address potential contingencies during transits and at the destination.
- Including a MMSEV would address exploration mobility and EVA capabilities needed at the destination
  - The MMSEV would be capable of addressing many potential cabin contingencies
    - Can function for an extended period of time as an independent spacecraft
    - Offers independent EVA capabilities.
- Landing gear is required for the lunar and Mars missions
  - The landing gear could be detached and left on the surface to reduce return mass

Habitat Propulsion System Implementation

- **Cx exploration scenarios to the moon or Mars required a propulsion system that had to deliver a long-duration habitat for crew occupation to the surface - The SHM concept requires that the habitat be returned to orbit to rendezvous with the ISP**
  - The propulsion system planned for Cx missions (which has been assessed to be feasible) had significant capability
  - The primary difference between the Cx and SHM concepts is in the amount of fuel the habitat propulsion system requires to perform the ascent

- **Addressing propulsion system redundancy**
  - Cx concepts had not addressed the need to have redundancy in the descent and ascent propulsion systems or long-term radiation exposure for a deep space mission
    - Deemed forward work when the Cx program was canceled
  - If the SHM propulsion system is provided in four modular rockets it could provide the capability to address a one-engine failure contingency during descent or during ascent at the destination.

Habitat Propulsion System Aspects

- Propulsion system considerations
  - Liquid methane/liquid oxygen (MOX) propulsion is probably the best
    - Long-term thermal storage of those propellants is feasible
      - Long-term storage of liquid hydrogen is problematic due to the extremely low (around 20 Kelvin (K) (-253°C (-423°F)) temperature required
    - Thermal conditioning via deep space cooling can address storage of liquid methane (approximately 111 K (-162°C (-259°F)) and liquid oxygen (90 K (-183°C (-297°F)))
      - Cryo-coolers may be required to address storage thermal conditioning while at either the moon or Mars

- **Addressing Radiation Protection**
  - Propellant tanks with MOX surrounding the habitat would provide a significant, high-quality radiation barrier
  - MMSEV at the front end of the SHM provides radiation protection while in transit both to and from the destination
    - Addresses access to the destination surface since it will be near to the surface after landing.
      - Lunar surface systems studies identified a significant problem with getting elements from the top of the descent stage to the surface
  - The ISP provides a radiation barrier at the aft end of the habitat

Interplanetary Space Propulsion (ISP) System Implementation

- ISP system efficiency is critical to the feasibility of deep space exploration
  - Chemical propulsion can work, but the mass required would be very high
  - Electric propulsion promises to provide a dramatic improvement in propulsion efficiency.
    - Very high specific impulse is achievable via electric propulsion
      - A factor of 10 less propellant might be required (versus Space Shuttle vintage chemical propulsion)
- High power is required to achieve both the high specific impulse and moderately high thrust desired for deep space transit
  - Probably requires that nuclear (versus solar electric) power be employed
- If thrust levels are high enough, dramatic changes in mission planning are achievable:
  - Gravity-assisted processes might become feasible during transit
    - Separation of gas and liquids - such processes might also be compatible with the partial gravity
  - The effect of low or zero gravity on bone density and muscle mass and strength would be lessened
    - The crew would be stronger at their destination and thus better able to conduct exploration.
  - The time required to reach destinations would be less
  - Different trajectories can be considered
    - Mission constraints related to Hohmann transfer trajectories may not be as significant to mission planning
  - The length of time the crews are exposed to space radiation is reduced, thus alleviating concerns of long-duration radiation exposure

SHM Mission Assessment

- Efficient, long duration propulsion with nuclear power has implications on trajectory
  - Assembly and operation of Nuclear components must be at Nuclear Safe Orbit (NSO)
    - Minimum of 500-km (311-mile) altitude
  - Slow acceleration results in spiral paths near Earth and near Mars
- Crew joins SHM in flight
  - SHM vehicle accelerates through most of the Earth departure spiral before the crew is launched on an Orion vehicle to catch and ingress the SHM before it departs from the vicinity of Earth
    - Gets the crew through the Earth's radiation belts quickly.
- Crew departs SHM at start of Earth return spiral
  - Orion is used during the SHM return to the vicinity of Earth to enable the crew to depart the SHM and return to Earth
    - The SHM continues its spiral to return to the NSO assembly orbit.
  - Aerocapture at Earth of the SHM is not acceptable due to the nuclear power plant and the NSO altitude constraint
- Aerocapture is acceptable at Mars and is planned to reduce the SHM velocity to enter an elliptical orbit
  - The Aerocapture/heat shield is also used to provide most of the deceleration of the habitat elements to land on Mars
  - Habitat elements would propulsively land using the HPS
- After surface exploration, the habitat would use the HPS again to propulsively ascend to rendezvous with the ISP
- Nuclear-powered electric propulsion approach results in a Mars mission that takes an estimated 585 crew days (813 total mission days) to complete.

Mission Mass Using Nuclear Electric

- Assumptions to start calculations
  - Time mission start for minimum transit time to Mars (12/12/2028)
    - Start at Nuclear Safe Altitude of 500 km
    - Crew of 4 ingresses SHM near the end of the departure spiral
  - 5 Mw capability for nuclear powerplant
    - Propulsion system Isp best for efficient use of fuel
  - Aerocapture of SHM into elliptical Mars orbit
    - Aerocapture assist to decelerate habitat prior to landing
  - Exploration on Mars 30 days
  - Crew egresses SHM at start of Earth arrival spiral
    - Orion rendezvous and return of crew to Earth
    - SHM continues spiral to return to NSO Earth orbit

Mars Mission Assumptions

- Crew ingresses vehicle just before Earth escape
  - Earth escape spiral time not counted toward the crew time
    - Minimizes crew time and thus radiation exposure
    - Gets crew thru Earth's radiation belts quickly
- Aerocapture at Mars
  - Mass of aero shield estimated at 20% of total vehicle mass
- Mars descent, landing, and ascent Delta V's included
  - Descent and landing
    - 800 m/s
    - Assume reuse of aero shield
- Mars escape spiral time is counted toward the crew time
- Aerocapture at Earth of a small crew module (likely Orion)
  - Mass of crew module not included
  - The rest of the vehicle will spiral down to a nuclear safe orbit (500km)
- Rendezvous, docking, and checkout (RDC) included
  - Earth departure
    - Crew time = 3 days
    - Propellant charged to the taxi vehicle
  - Mars departure
    - Crew time = 3 days
    - RDC Delta V = 100 m/s
- VASMIR engine, unlimited Isp

Mars Mission Assumptions (cont)

- Earth and Mars orbits = 500km circular
- Earth departure date 12/12/2028
- Power = 5Mw
- Efficiency = 0.8
- Powerplant specific mass = 6 kg/kw
- Powerplant mass = 30mt
- Structures and heliocentric tank mass = 15% of vehicle mass

- ❖ Since the aero shield and structure mass are being included, it becomes an iterative problem.
- ❖ Only one iteration pass has been completed to date
  - ❖ NASA JSC Propulsion is calculating the HPS mass
  - ❖ Will update mission profile when HPS mass is defined

Trajectory Results Summary

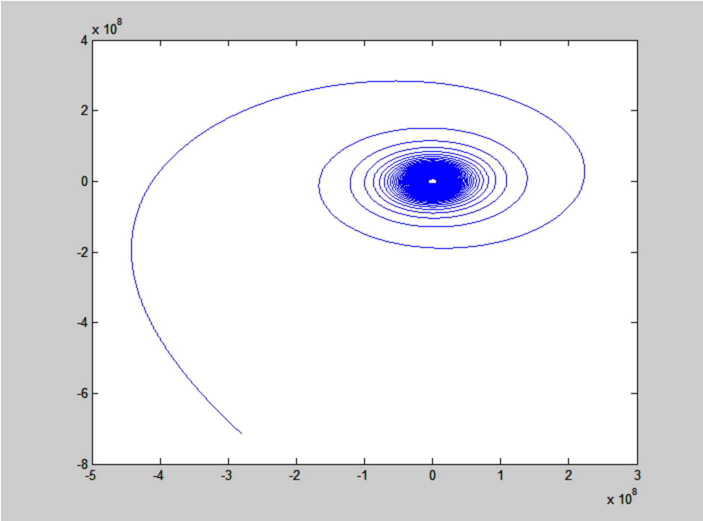
- Initial Mass at LEO = 249 mt
  - **Does not include habitat descent, ascent, or rendezvous propellant**
- Earth escape spiral
  - Assumed 7000sec Isp
  - Propellant mass = 25mt
  - Time = 165 days
- Earth-Mars heliocentric transfer
  - Departs 12/12/2028
  - Variable Isp
  - Propellant mass = 36 mt
  - Time = 248 days
- 30 Day Mars surface stay
- Mars escape spiral
  - Assumed 3000sec Isp
  - Propellant mass = 15 mt
  - Time = 18 days
- Mars-Earth heliocentric transfer
  - Departs 10/7/2029
  - Variable Isp
  - Propellant mass = 43mt
  - Time = 283 days
- Earth capture spiral
  - Assumed 7000sec Isp
  - Propellant mass = 10mt
  - Time = 66 days

Total Crew Time = 585 days

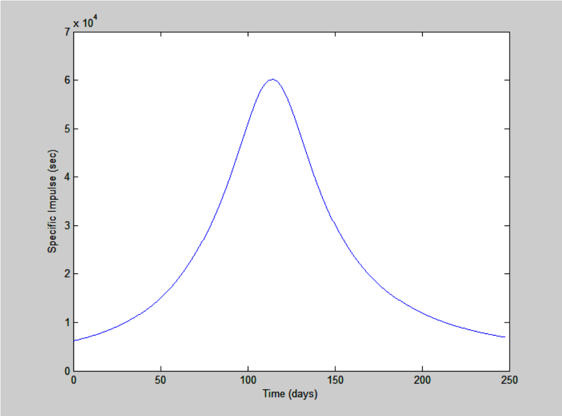
Total Vehicle Time = 813 days

Example of Departure Spiral

- Earth escape spiral (crew not on-board)
  - Initial mass = 249mt
    - Powerplant = 30mt
    - Structure = 29mt
    - Aero shield = 27mt
    - Propellant = 129mt
    - Payload = 34mt
  - Begins spiral 6/30/2028
  - Assumed constant 7000sec Isp
  - Propellant mass used = 25mt
  - Time = 165 days



- Earth-Mars heliocentric transfer (crew on-board)
  - Departs 12/12/2028
  - Variable Isp
  - Propellant mass used= 36 mt
  - Time = 248 days
  - Arrives at Mars 8/17/2029
  - Mass delivered to Mars = 188mt
- 30 day Mars surface stay



Approach for Evaluating the Single Habitat Module Concept

- A top-level evaluation of the concept can be performed to determine the merits of this concept versus other exploration approaches
  - Only qualitative assessments can be made currently
    - Details of the concept implementation have not been established
  - The top-level overall mission benefits of the SHM concept versus separate transit, descent and ascent, and surface habitats can be assessed
- Evaluation of the SHM concept can alternatively focus on the major elements of the SHM concept versus those of other exploration concepts
  - Such a comparison can establish the fundamental differences in approaches

Use a logical progression of information to estimate SHM mass

1) Evaluate mission duration using current implementation concept
   - Nuclear powered, electric propulsion, enough time to explore, Mars Earth locations
2) Establish habitat size and consumables mass based on mission length
3) Estimate, the habitat propulsion system capability and mass
4) Recalculate the capabilities and mass of the ISP system
5) Combine habitat, HPS, and ISP masses for the total SHM vehicle mass
6) Compare the SHM integrated to the Mars DRA masses
   - Assess savings on single Mars mission
   - Assess savings on series of exploration missions

Habitat Mass Estimate

Based on the May 2011 Deep Space Habitat

- Habitat, MMSEV and landing gear estimate
  - Total habitat plus consumables mass - 31,000 kg (68,200 lb)
    - Revised for a 4-crew 585-crew-day mission
  - Habitat landing system – 2000 kg (4409 lb)
    - Based on Cx Altair estimates
  - MMSEV for Mars – 6547 kg (14,400 lb)
    - Based on MMSEV estimates (assumes 28 day capability with 2 crew)
- Those elements result in an estimated mass of habitat, landing system, MMSEV of around 39,600 kg (87,120 lb)
- The HPS to safely land that equipment then return subset to LMO
  - Mass to be returned to LMO = 37,600 kg (70,548 lb)
    - Landing gear assumed left on the surface.

Comparison of Single Habitat Module Elements to Apollo and Constellation

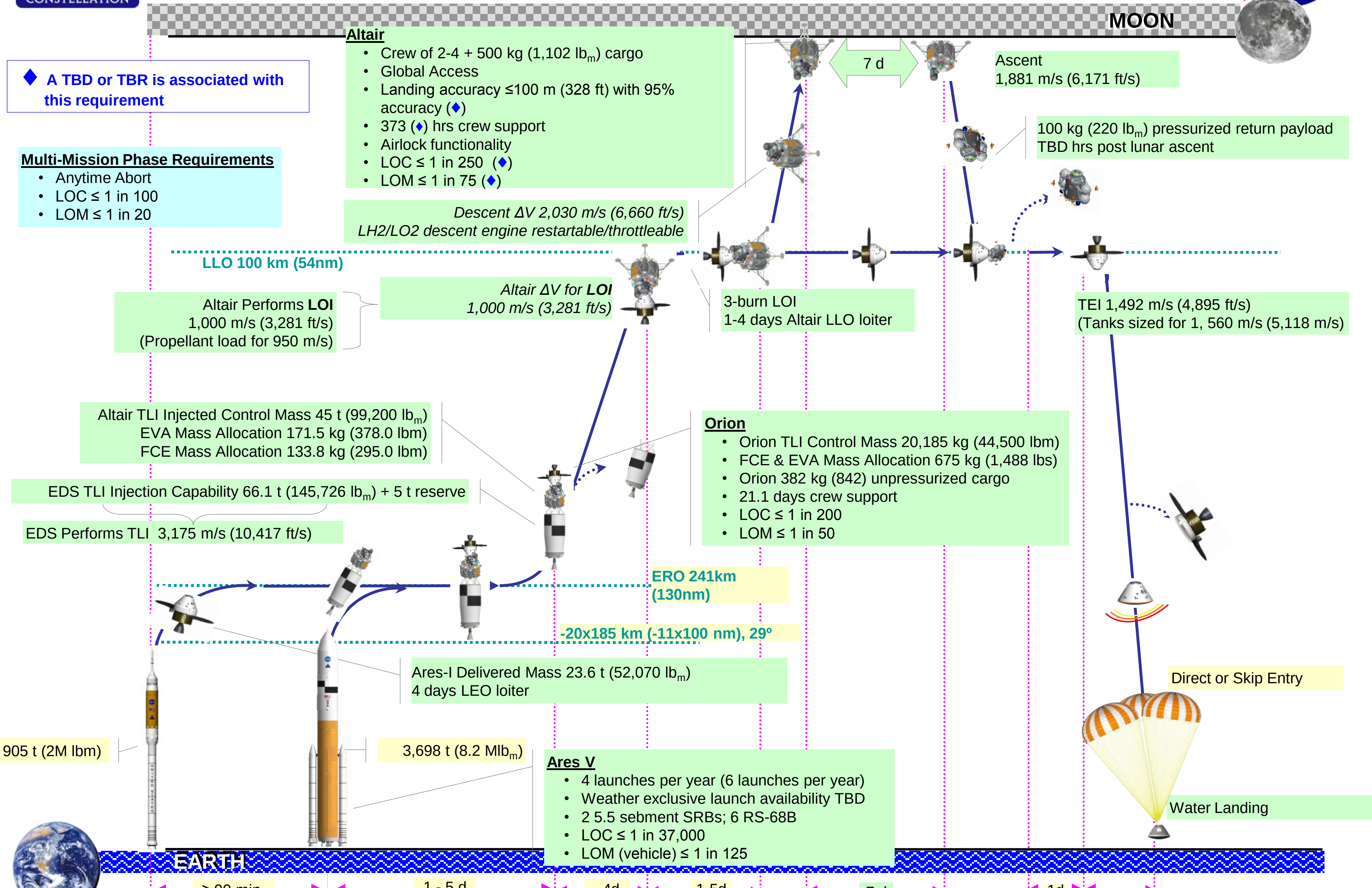
- The SHM concept is not directly comparable to past exploration approaches since it employs technology advances that were not considered in the past, and since it reuses mission assets
  - The SHM approach of developing an exploration capability that can be employed for any exploration destination results in a significantly different compliment of mission assets than other approaches
- SHM could be compared directly to Cx or HAT DRMs
  - Compare assets and thus understand the benefits
    - Cx Mars Design Reference Architecture
    - Lunar sortie mission
    - NEA mission proposals
  - Benefits of the mission simplification associated with the SHM single habitat have been identified
    - Such comparisons would be somewhat misleading since one of the benefits of the SHM concept is the reuse of mission assets and, when compared to a single mission, those benefits are not considered

Cx Approach for Lunar Exploration

- Lunar program Sortie missions
  - Ares 1 launch of the Orion CEV
  - Ares 5 launch of the Altair vehicle and a Earth departure stage
  - All Elements of the mission were to be discarded during the mission
    - Orion CEV might be reusable
- Other Lunar missions of CX were directed at developing a base on the moon as directed in 2004
- 2010 presidential direction was to focus on exploration
  - It is expected that several exploration missions would be conducted prior to new direction to establish a base at a location selected based on exploration findings

DRMs/Mission Key Driving Requirements Mapping

Lunar Sortie Design Reference Mission



Cx Approach for Mars Exploration

- Defined in the 2007 Mars DRM document
- Launches a base that is prepositioned
- Crew returns to Earth via a MPCV
- All mission elements are discarded
  - Possible exception is the MPCV

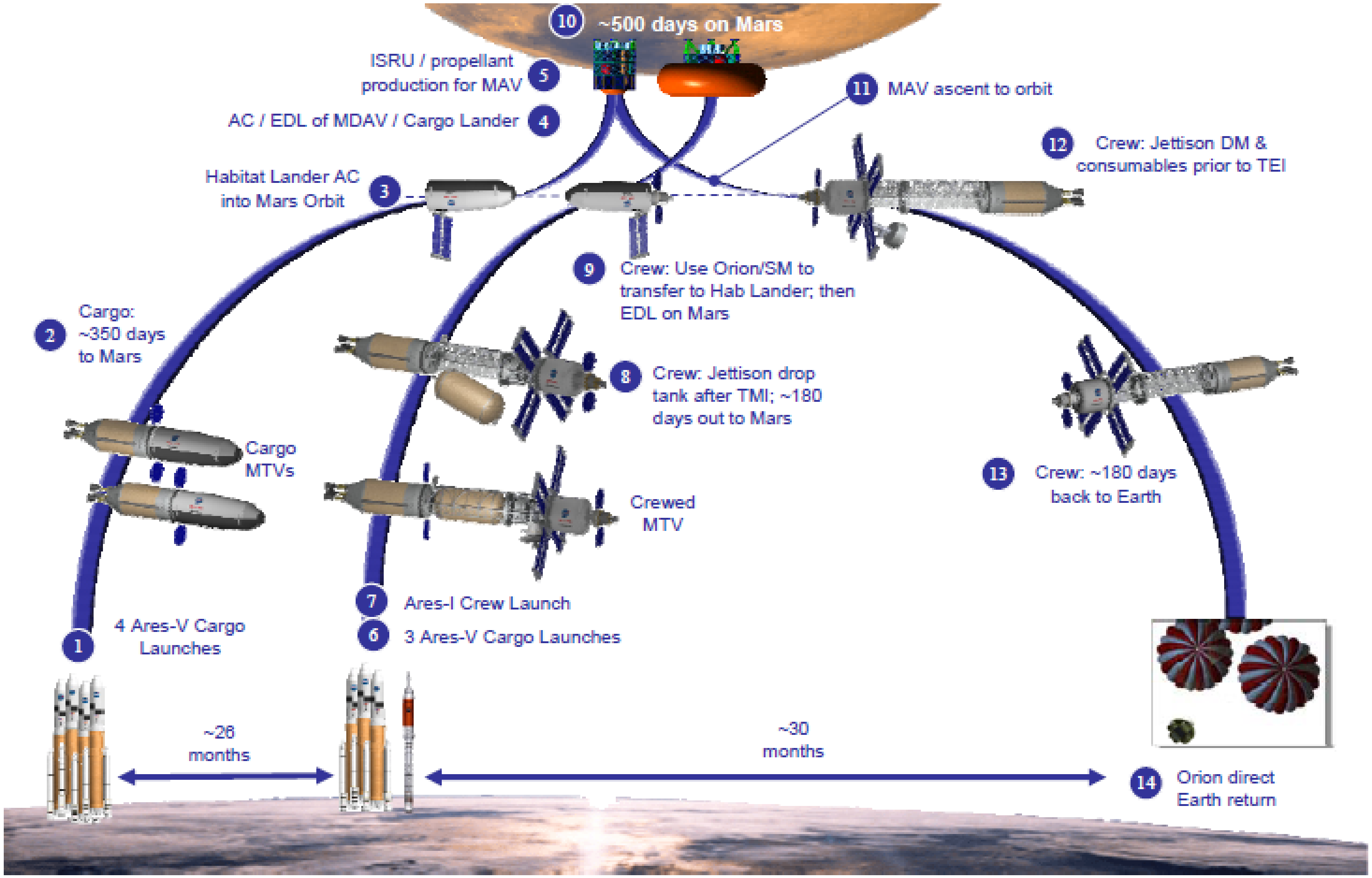


Figure 2-2. Mars Design Reference Architecture 5.0 mission sequence summary (NTR reference).

2.1 Surface Reference Mission

Several different surface architectures were assessed during the formulation of the Mars DRA 5.0, each of which

Top level comparison with Cx Mars DRA

- Cx Mars DRA requires
  - Separate crew accommodations for transit, descent, ascent, surface operations
  - Many elements to accomplish objectives
  - New vehicles for every mission

SHM Comparison to Cx and HAT For NEA + Moon + Mars Missions

- The most appropriate comparison of past approaches and SHM is to compare the combination of NEA, lunar landing, and Mars surface missions
  - SHM for the three missions – Habitat, MMSEV, ISP plus two refurbishment and refuel operations – plus probably several Orion Multi-Purpose Crew Vehicle (MPCVs)
  - HAT NEA – Orion, DSH, MMSEV, Solar Electric Propulsion, MPCVs
  - Cx Lunar Sortie mission – Orion, Altair (Lander, Ascent)
  - Cx Mars Surface mission – Orion, DSH, Surface Habitat, two Nuclear Thermal Rockets, SEV, Combined Descent and Ascent Vehicle, Mars Ascent Vehicle

Single Habitat Module Approach Benefits

- Simplifies the total mission
  - Supporting the crew through the entire mission in one habitat
  - Enables reuse of mission assets
  - Eliminates the need to develop new vehicles for subsequent missions
- Transportation of less mass to destination since fewer elements are required
- Vehicle dimensions are not constrained by launch vehicles
  - Allows architectural freedom to arrange mission elements
- Eliminates the need to preposition assets
  - Crew arrives at an exploration site that has not been explored robotically via prepositioned assets
    - Crew exploration is all new and not partially redundant
  - Reduces landing accuracy requirements
- Exploration community to use exploration resources to focus on exploring new destinations instead of building new vehicles
- The infrastructure in the Orbital Assembly Base could be used to conduct other near-Earth NASA or commercial operations between exploration missions

Single Habitat Module Approach Benefits (continued)

- Use of regenerative technologies minimizes mass via use for the entire mission
  - Eliminates the need for short-duration non-regenerative technologies
- Use of a high-power ISP that can shorten mission duration to 585 days versus the Mars DRA mission duration of more than 860 crewed days
  - Would reduce the amount of consumables required
  - Would partially address radiation protection by shortening crew exposure time
- The positioning of propellant around the habitat protects the crew from radiation

SHM Rationale for Quicker, Less Expensive Exploration

- Focuses on development of one habitat, one ISP and one MMSEV
  - One set of crew accommodations for an entire mission
- Project organizations are minimized
- After the first mission;
  - Only refurbishment and refueling are needed
  - Time between missions minimized
- Exploration focuses on exploration
  - Not expensive vehicle construction

Summary and Conclusion

- SHM concept could significantly simplify the conduct of exploration missions
  - Assessment of the use of high specific impulse propulsion has led to a better understanding of the implications that using such technology has on mission planning
- Reuse of mission assets for subsequent exploration missions could dramatically reduce the cost of exploration and could significantly reduce the time required to develop and conduct a Mars mission

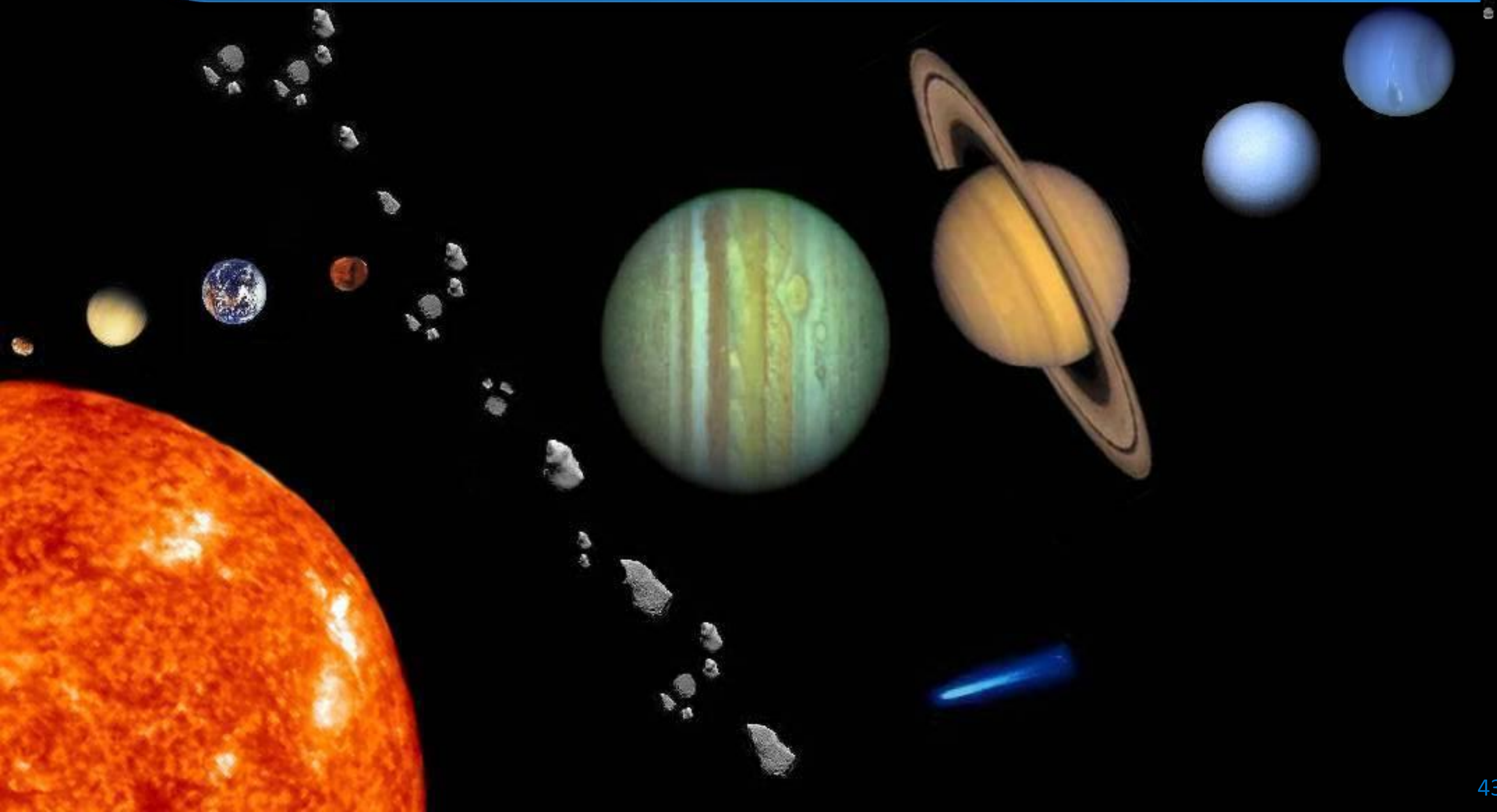
Forward Work

- More detailed studies should be conducted to confirm that the SHM concept will provide a significantly better way to conduct space exploration
  - Use the mass estimate of the Habitat and MMSEV to estimate the HPS and ISP propulsion system performance and mass
    - Calculation of the mass of the HPS is underway
  - Once confirmed, exploration programs should initiate
    - Development of the assembly station (or address repurposing of ISS as the assembly station)
    - Complete technology development to ready technologies for use in a SHM program of exploration

Acknowledgments

- Support and encouragement from the Crew and Thermal Systems division of NASA JSC
  - The division chief Patricia Petete
  - Branch managers Joe Gensler and Craig Dinsmore
  - Illustrator Jeannie Corte
- The planning for exploration missions done by the Cx Program that provided a moderate level of detail for exploration concepts
  - Lunar Surface Systems team lead by Chris Culbert and Gary Spexarth
  - Mars DRA team lead by Brent Drake
  - Habitation team lead by Larry Toups
- Mission planning for missions using highly efficient space propulsion
  - Ellen Braden for interactions leading to understanding of mission plans then performing calculations of the mass of major elements of the SHM mission

Backup Information



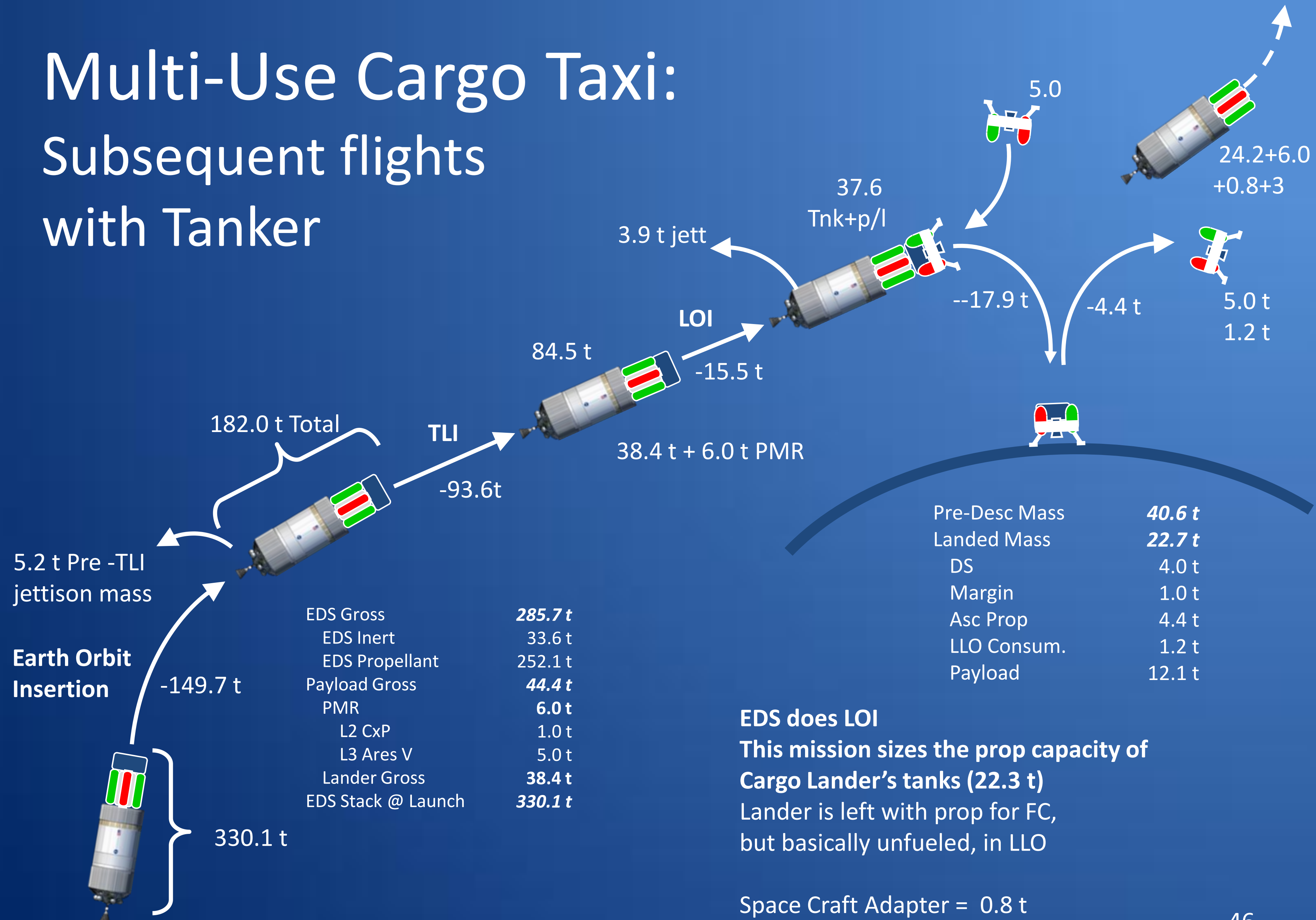
Ways to Implement the SHM Concept

- Inflatable habitat structure to reduce structural mass
- ISS as an assembly site (for all except the nuclear powerplant)
- Consider advanced ECLSS technologies to save more than 1000 kg
- Use Orion instead of the MMSEV for contingency and to provide direct return of the crew
  - Provides contingency capabilities and shortens crew return time.
  - Eliminates the roving capability at the destination.
- Segment ISP prop tanks and discard tanks when empty (Mars DRA)
  - Refueling required in any scenario
- Leave the MMSEV on the surface
  - Compromises contingency capabilities during return
- Develop and fuel in LEO then transport to beyond the radiation belts of Earth before crew ingress
  - Maximizes Earth launch mass to space, minimizes crew radiation exposure

LSS Scenario 10
Evolvable LOX/CH4 Crew and Cargo Taxi with Tanker with In-Flight Refuel

- Started with LCCR architecture and implemented the capability to refuel both cargo and crew missions to reuse the surface delivery systems
  - Eliminated nearly all the graveyard of used vehicles
  - Much more efficient Lunar scenario when plan is to establish lunar base of operations
  - LCCR infrastructure with as few changes as practical to enable reuse of elements
    - Added a refueling module capable of delivering fuel and providing a pressurized module with resupplies of consumables
    - Added an abort capability to crew landers
    - Altair, SEVs and Habitats based on other Cx designs
      - LCCR = Lunar Capability Concept Review

Multi-Use Cargo Taxi:
Subsequent flights with Tanker



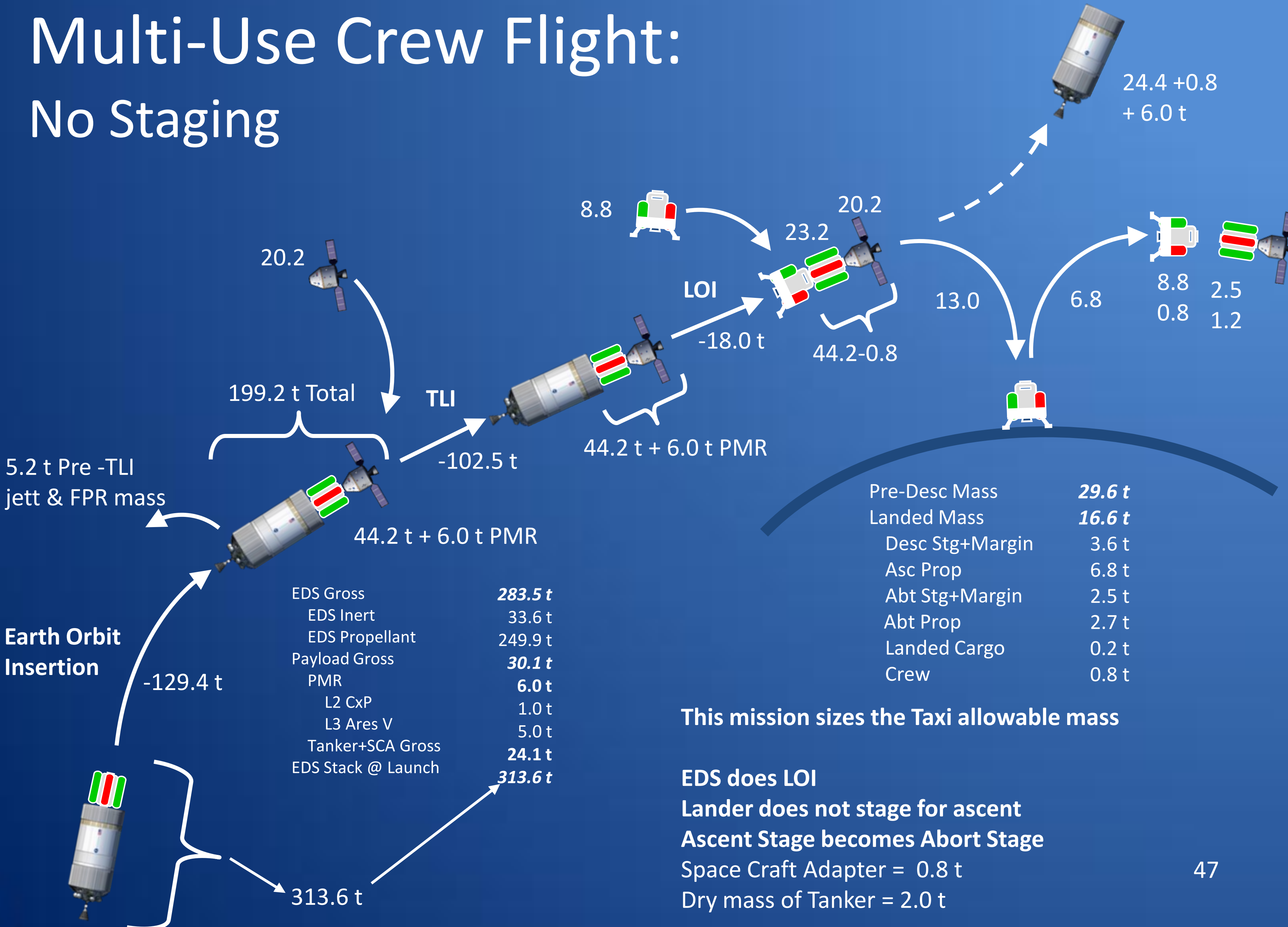
EDS Gross	***285.7 t***
EDS Inert	33.6 t
EDS Propellant	252.1 t
Payload Gross	***44.4 t***
PMR	**6.0 t**
L2 CxP	1.0 t
L3 Ares V	5.0 t
Lander Gross	**38.4 t**
EDS Stack @ Launch	***330.1 t***

Pre-Desc Mass	***40.6 t***
Landed Mass	***22.7 t***
DS	4.0 t
Margin	1.0 t
Asc Prop	4.4 t
LLO Consum.	1.2 t
Payload	12.1 t

EDS does LOI
This mission sizes the prop capacity of Cargo Lander's tanks (22.3 t)
Lander is left with prop for FC, but basically unfueled, in LLO

Space Craft Adapter = 0.8 t
Dry mass of Tanker = 2.0 t

Multi-Use Crew Flight:
No Staging



EDS Gross	***283.5 t***
EDS Inert	33.6 t
EDS Propellant	249.9 t
Payload Gross	***30.1 t***
PMR	**6.0 t**
L2 CxP	1.0 t
L3 Ares V	5.0 t
Tanker+SCA Gross	**24.1 t**
EDS Stack @ Launch	***313.6 t***

Pre-Desc Mass	***29.6 t***
Landed Mass	***16.6 t***
Desc Stg+Margin	3.6 t
Asc Prop	6.8 t
Abt Stg+Margin	2.5 t
Abt Prop	2.7 t
Landed Cargo	0.2 t
Crew	0.8 t

This mission sizes the Taxi allowable mass

EDS does LOI
Lander does not stage for ascent
Ascent Stage becomes Abort Stage
Space Craft Adapter = 0.8 t
Dry mass of Tanker = 2.0 t