



# Austere Human Missions to Mars

Hoppy Price

*Jet Propulsion Laboratory, California Institute of Technology*

Alisa Hawkins, Torrey Radcliffe

*The Aerospace Corporation*

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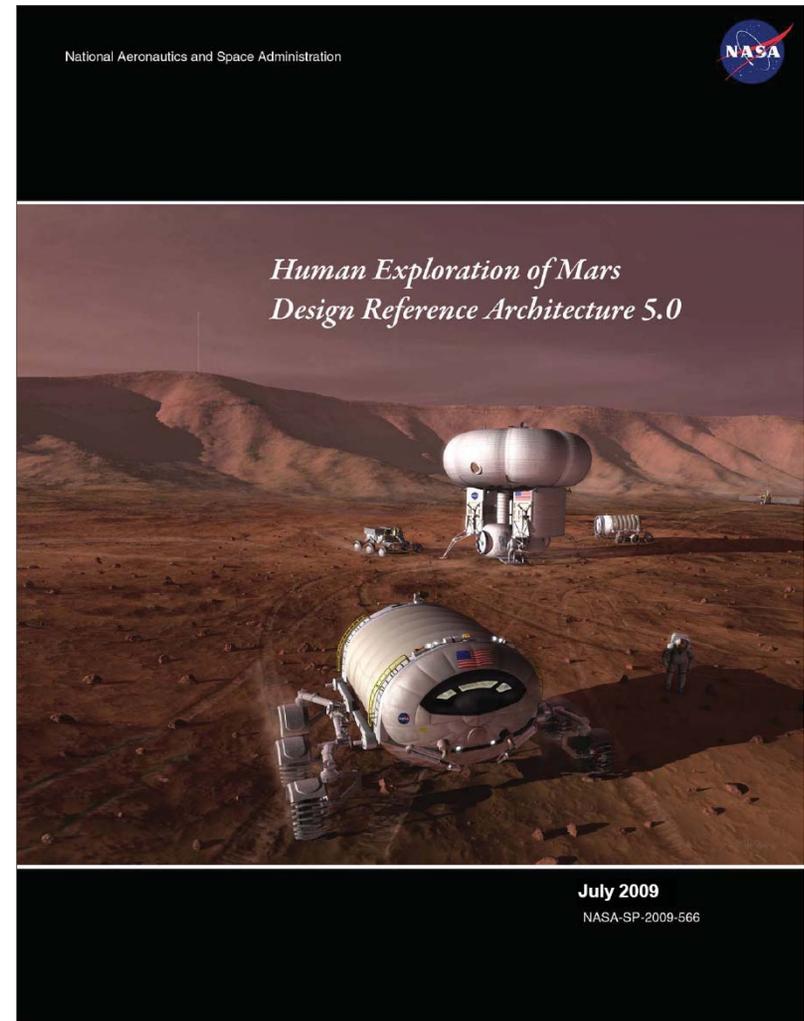




## Background



- Design Reference Architecture 5 (DRA 5) is the most recent concept developed by NASA to send humans to Mars in the 2030 time frame. DRA 5 is optimized to provide a robust program that could deliver a new 6-person crew at each biennial Mars opportunity and provide for power and infrastructure to maintain a continuing human presence on Mars.
- “Austere” architecture is scaled back from DRA 5 and might offer lower development cost, lower flight cost, and lower development risk. This approach will not meet all the DRA 5 mission requirements.
  - This approach exercises many of the descope options described in DRA 5 Addendum Table 7-15, “Example Contingencies, Fallbacks, and Descope Options” (see “Additional Material”)
  - This may represent a minimum mission set that would be acceptable from a science and exploration standpoint







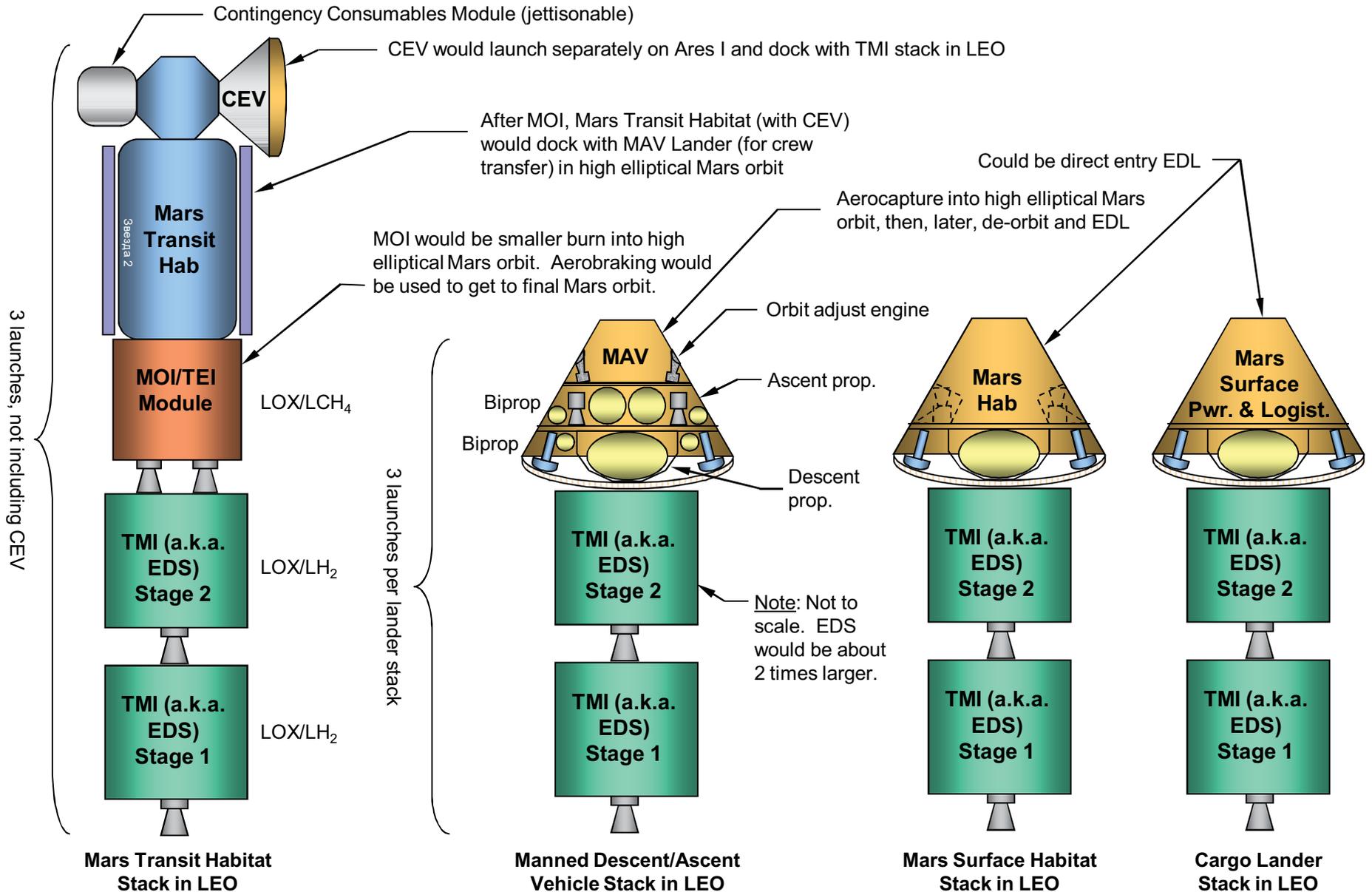
## Ground Rules for Notional “Austere” Approach



- Meet basic science goals of DRA 5, but with reduced crew size and mission frequency
  - Crew of 4 launched every 4 years
- Implemented as a flat-funded, sustainable program
  - Ideally with no greater annual cost or total cost than ISS (thru 1<sup>ST</sup> Mars mission)
- Design the program to be implementable on the earliest possible schedule
  - Reduce total cost
  - Maintain public interest
- Driven by philosophy of minimizing development risk and cost, and in-flight mission risk
- Conservative approach, minimizing high risk or high cost technology development (i.e. avoid developing new technology, if you don't absolutely need it).
- Maximize development commonality and production commonality, e.g. common lander designs, common Earth Departure Stages (EDS's)

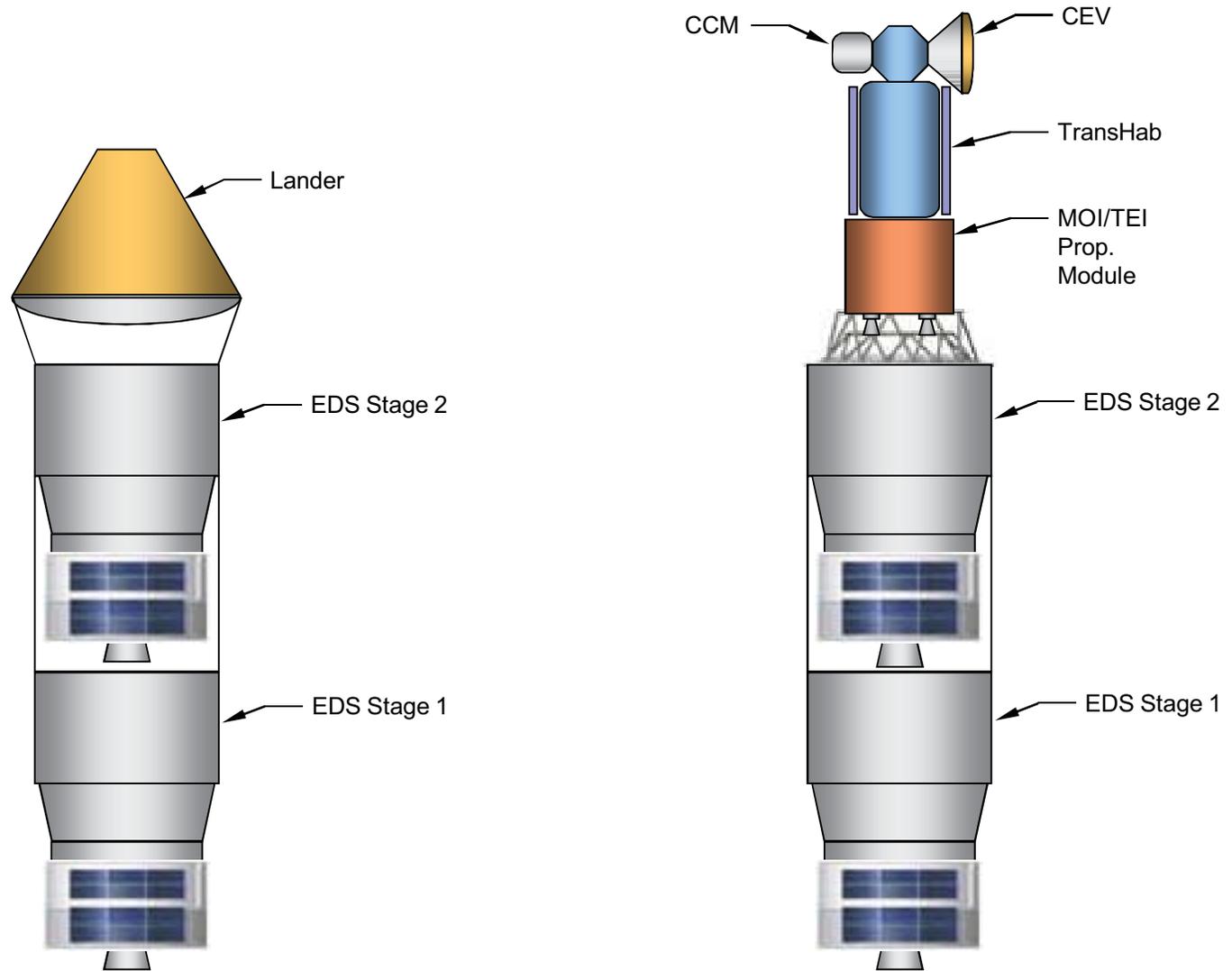


# Mission Elements for Notional "Austere" Approach





# Earth Departure Configurations Approximately to Scale

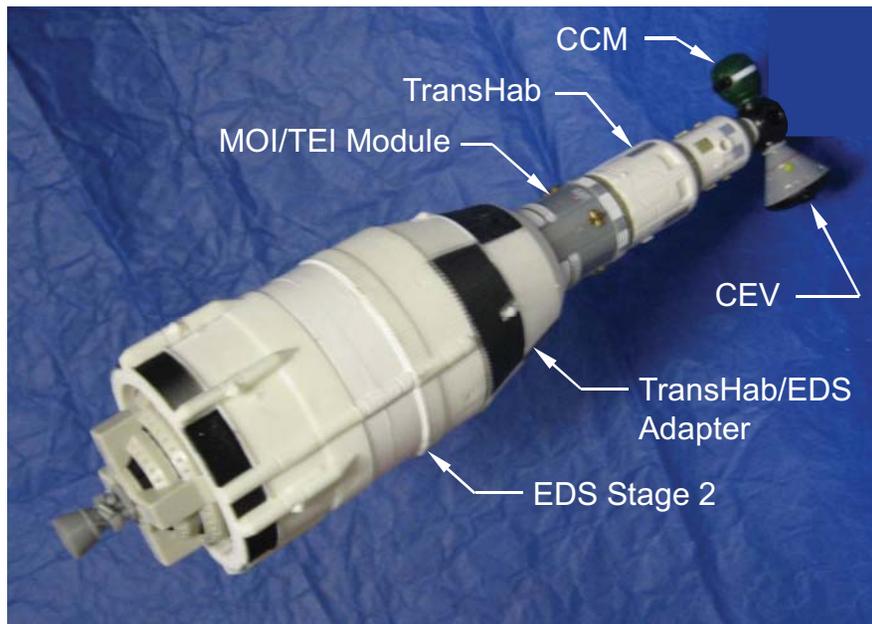




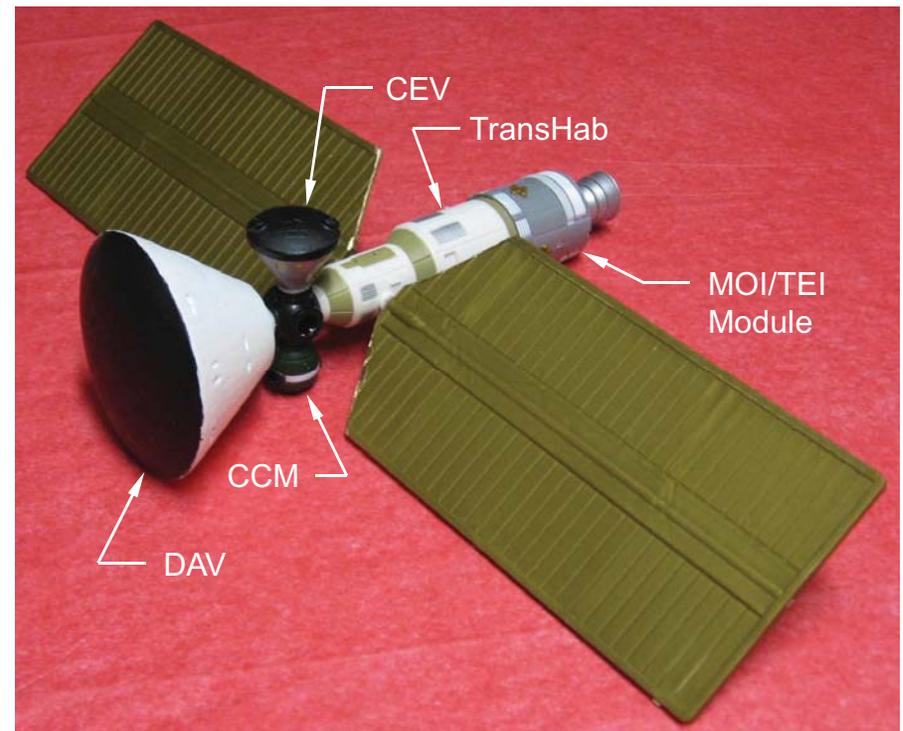
## Photos of Scale Models (1/144 scale)



TransHab TMI with EDS Stage 2 attached

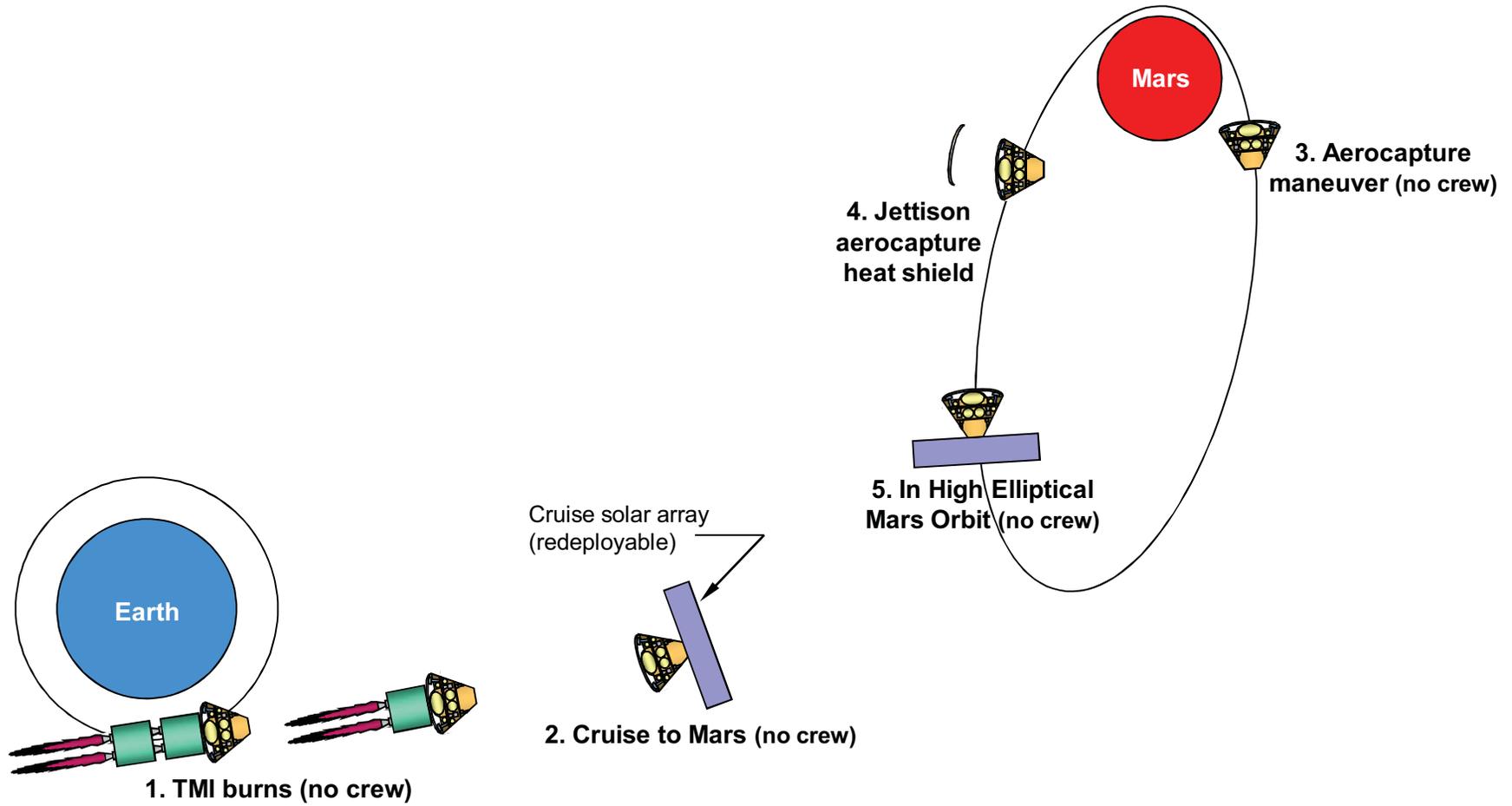


TransHab and DAV docked in Mars orbit



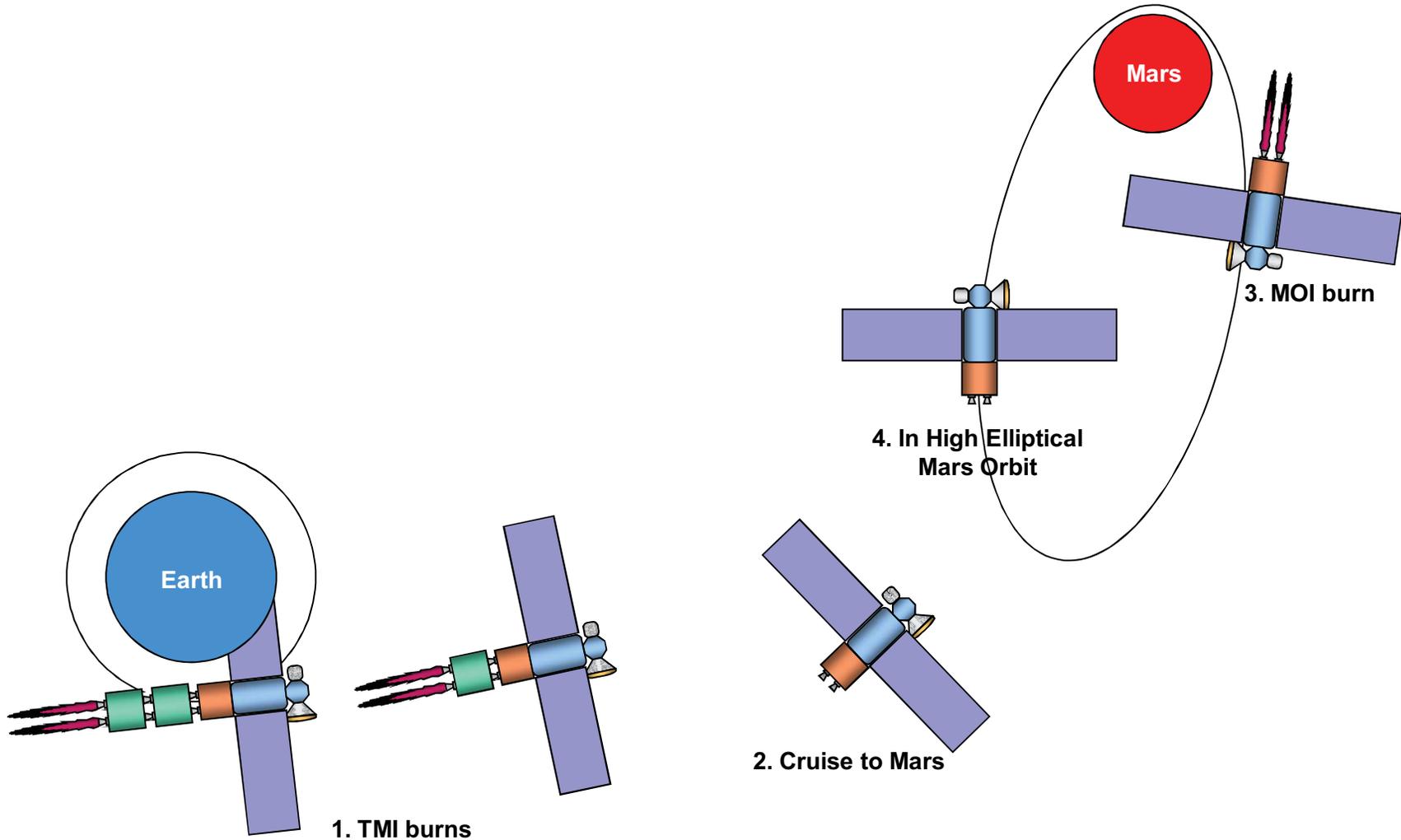


# Descent/Ascent Vehicle TMI, Cruise, and MOI



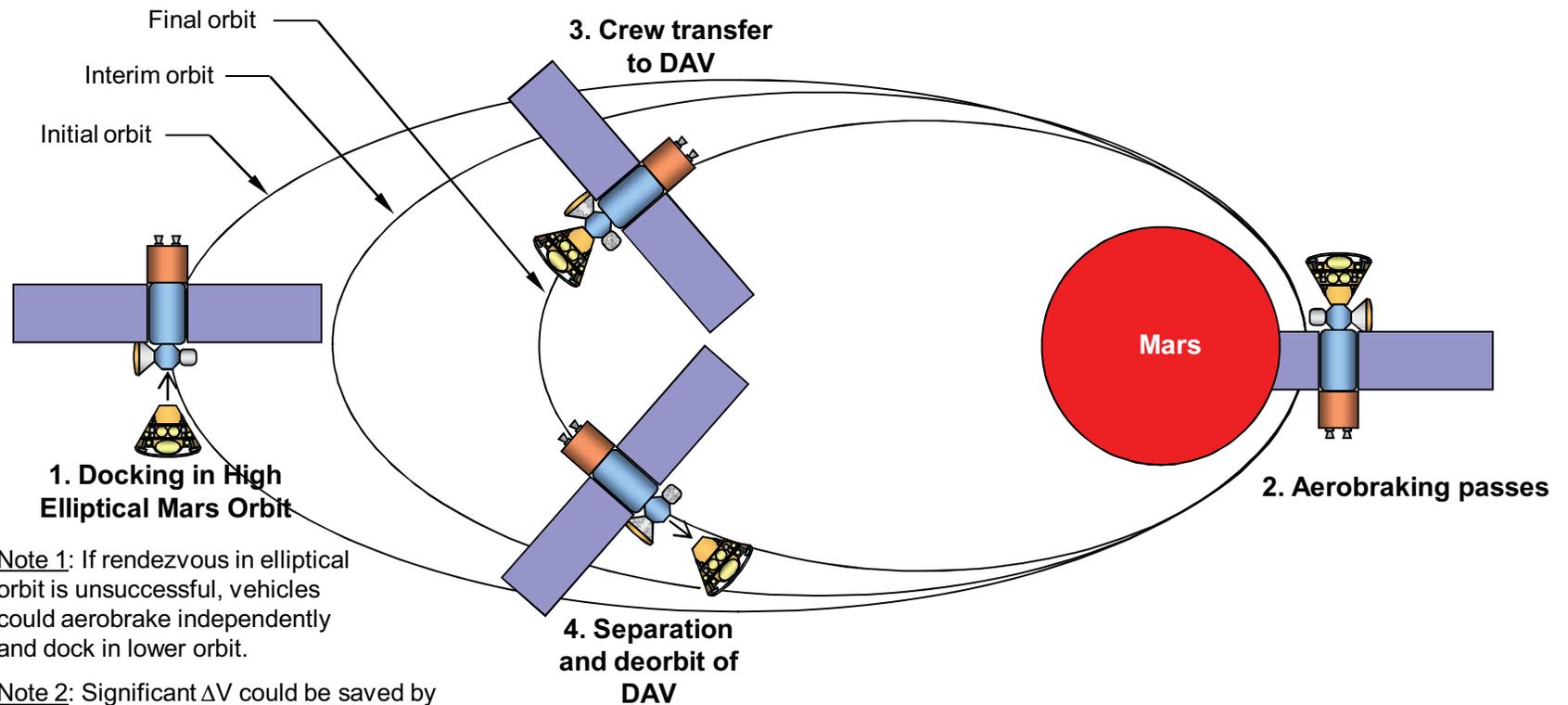


# Transit Habitat TMI, Cruise, and MOI





# DAV and TransHab Docking and Aerobraking

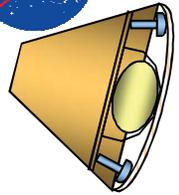


Note 1: If rendezvous in elliptical orbit is unsuccessful, vehicles could aerobrake independently and dock in lower orbit.

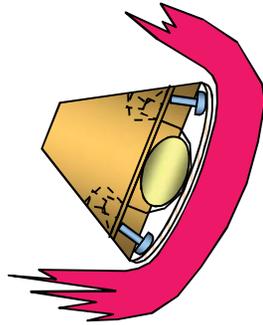
Note 2: Significant  $\Delta V$  could be saved by de-orbiting Lander from high elliptical Mars orbit. Disadvantage is that for abort-to-orbit, MAV would have to loiter for 1-3 months for TransHab to aerobrake.



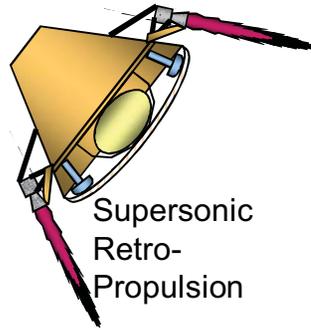
# EDL Concept



Pre-entry

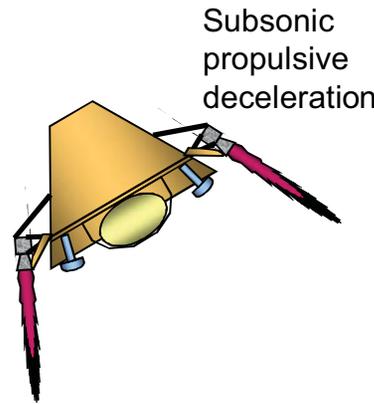


Entry and atmospheric deceleration



Supersonic Retro-Propulsion

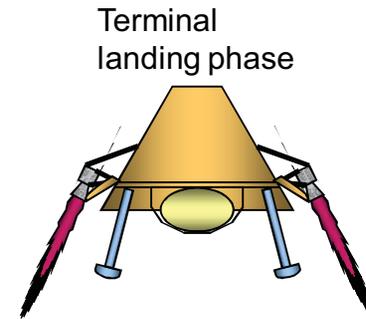
Note: There are no parachutes or inflatable decelerators



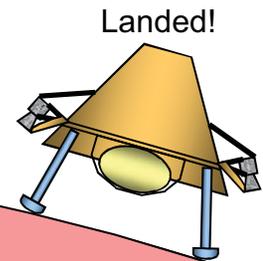
Subsonic propulsive deceleration



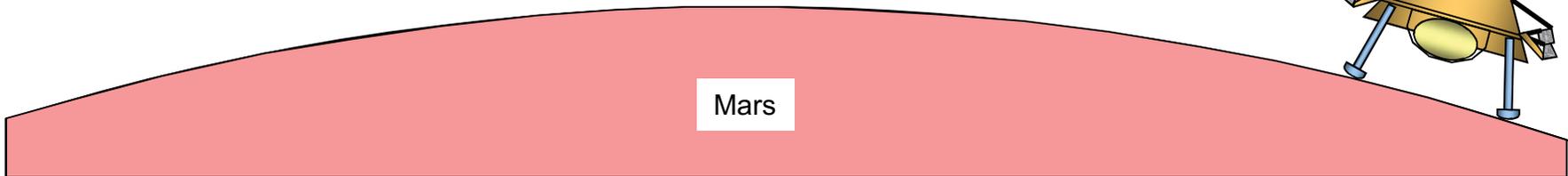
Jettison heat shield



Terminal landing phase



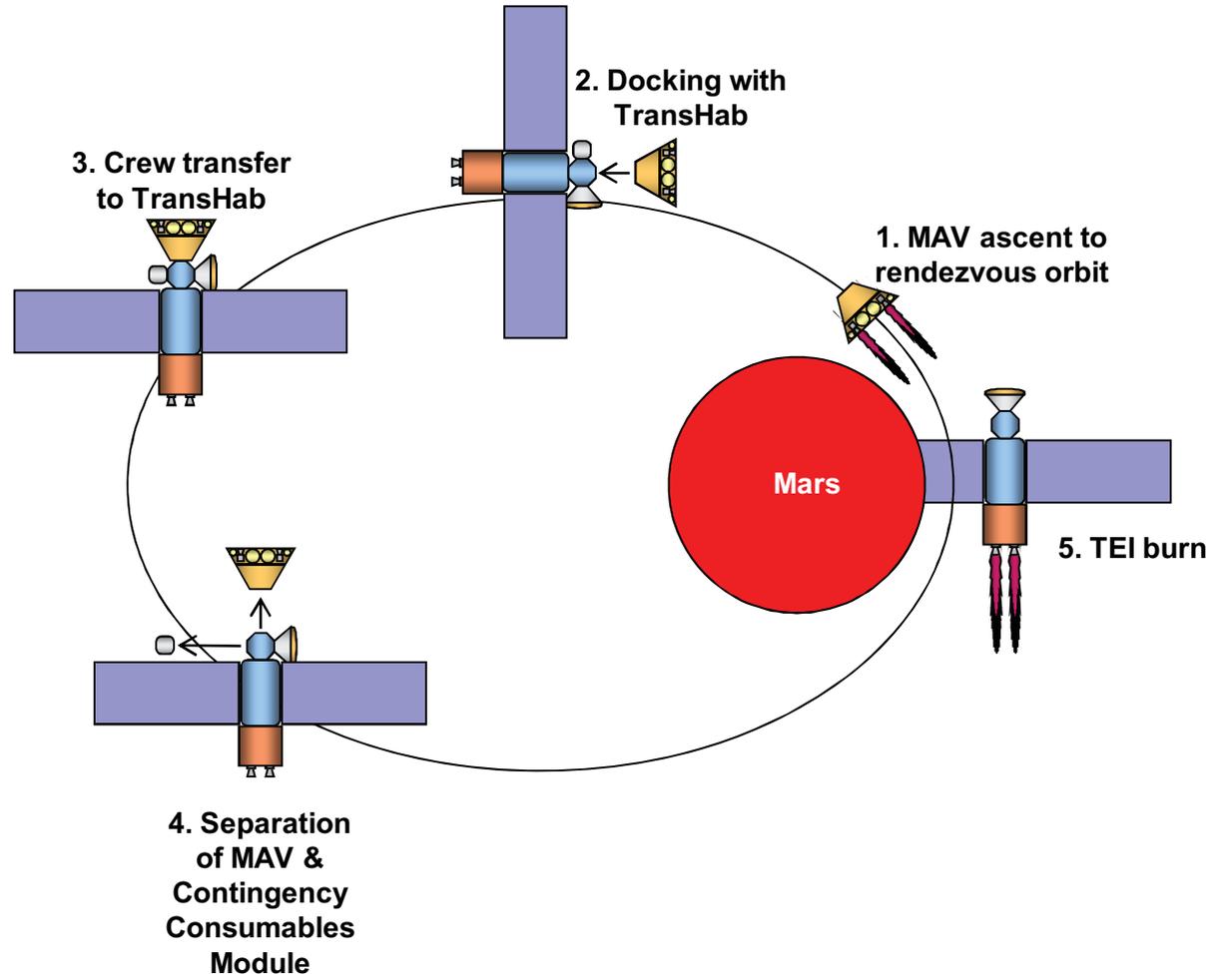
Landed!



Mars



# MAV Ascent, TransHab Docking, and TEI





## Key Features of Transit Habitat (TransHab)



- Similar to Zvezda module on ISS
  - Expanded to support crew of 4
  - Larger solar arrays for operation in Mars orbit
- Zvezda type multiple docking node
  - Would support CEV, Mars Lander, and Contingency Consumables Module (CCM)
  - Could serve as airlock for EVAs to correct anomalies or perform repairs
- Would contain an MOI/TEI propulsion module with LOX/LCH<sub>4</sub> propellant to avoid more difficult cryo storage and volume problems with LH<sub>2</sub>
- TransHab would launch to LEO on Ares V with CCM. CEV would launch separately on Ares I and dock with TransHab.
- Two EDSs stages would launch to LEO separately, each on an Ares V
- The TransHab with docked CEV would launch as a single stack to Mars, and could safely return the astronauts to Earth in the event that it fails meets up with any other mission elements
- Transit Habitat would use low  $\Delta V$  MOI into high elliptical orbit, dock with DAV, and then aerobrake as a stack into Low Mars Orbit (LMO)
  - Aerobraking estimated to take 1-3 months
- TransHab would return crew and CEV to Earth at conclusion of Mars mission
- TransHab design could support other interplanetary missions (e.g. asteroids)



## Key Features of Earth Departure Stage



- A common LOX/LH<sub>2</sub> Earth Departure Stage (EDS) would be utilized for all vehicle stacks launched to Mars
  - Would include rendezvous and docking equipment, possibly similar to ATV
  - Two EDSs would be used as a two-stage vehicle for each launch to Mars
- A possible design would be to scale down the Ares V 2<sup>ND</sup> stage in height to ~60% propellant capacity, use interstage structures based on Ares V, and utilize as much commonality and/or tooling as possible
- EDS would need power and cooling equipment to loiter in LEO, possibly for several months, to facilitate docking with other mission elements in the stack for launch to Mars



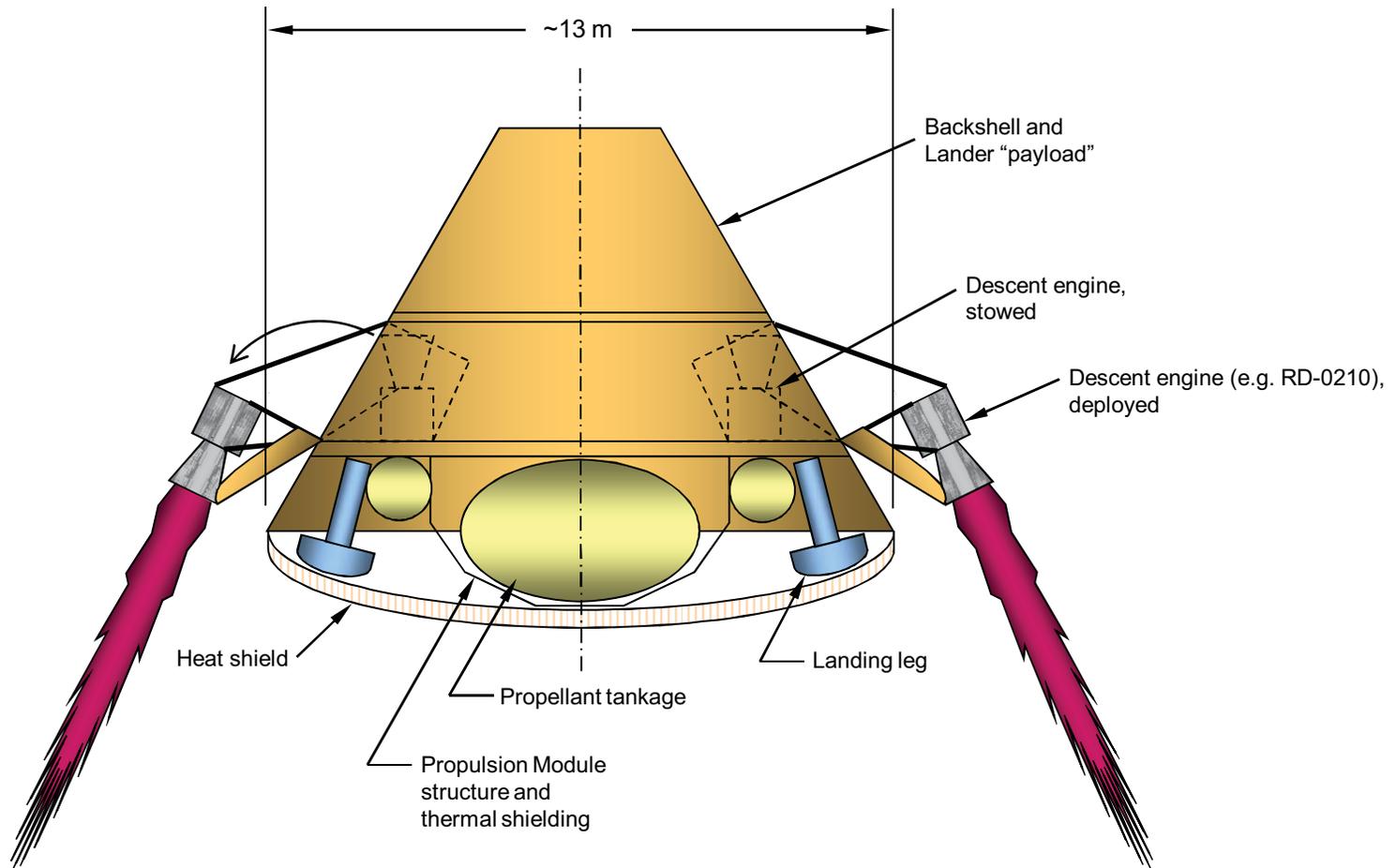
## Key Features of Landers



- All landed elements would use identical Mars Entry, Descent, and Landing (EDL) system, platform/moldline, and Earth departure configuration. This would allow for design verification with a single unmanned flight. It would also facilitate efficiencies in design and production.
- Landed elements would include:
  - Descent Ascent Vehicle (DAV) to transport crew to and from Martian surface
  - Mars Surface Habitat (SurfHab)
  - Mars Surface Power and Logistics Module
    - Probably required as a separate module on a volume basis, if not a mass basis
    - Would notionally have ~20 kW of Radioisotope Stirling power
    - Would also include two small pressurized 2-man rovers
  - Specialized cargo landers (e.g. deep drilling platform, large ISRU unit)
- The DAV would aerocapture into high elliptical Mars orbit (unmanned at the time) and later dock with the TransHab for crew transfer to the DAV
  - After aerocapture, the first heat shield is jettisoned like a skin over a second heat shield. The second heat shield is later used for Mars EDL.
- The DAV could perform abort-to-orbit in the very last seconds of the landing profile in the event of bad terrain, landing gear failure, or descent propulsion failure
- Cargo landers would probably use direct entry rather than aerocapture
- Propulsion on Landers and MAV would be traditional biprop (NTO/MMH)
  - Low risk and volumetrically compact

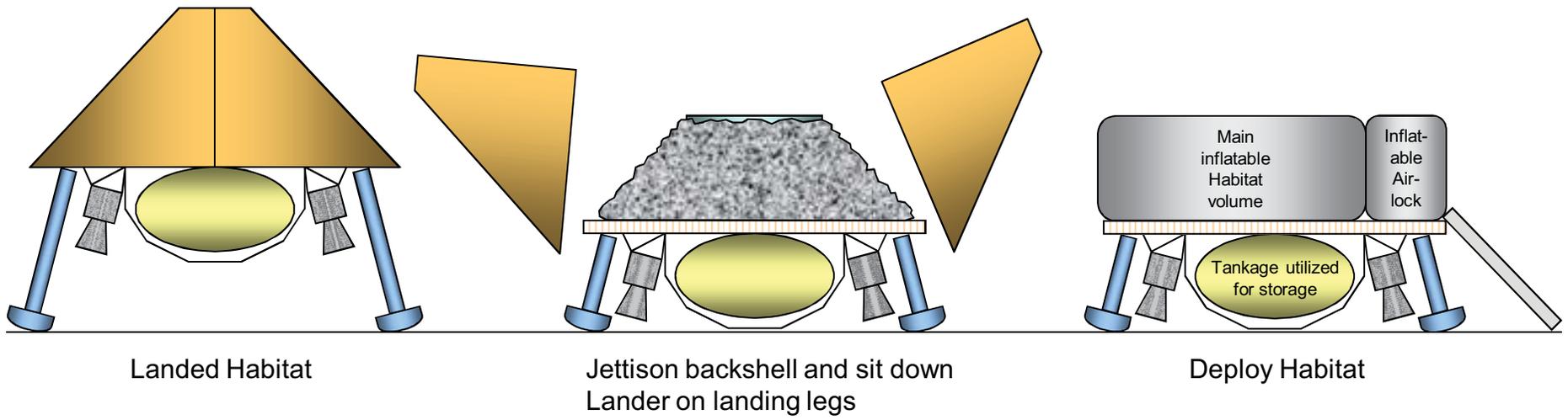


# Deployable Supersonic Retro-Propulsion Concept





# Concept for Mars Surface Habitat Deployment



Note: Solar panels and antennas not shown



# Conceptual Types of Mars Landers



	Payload Mass (T)
<b>Descent/Ascent Vehicle</b>	<b>46</b>
Crew cabin	6
Ascent Stage with propellant	40
<b>Surface Habitat</b>	<b>52</b>
Pressurized Habitat with all required consumables	35
Airlock with EVA suits	5
Two 5 kWe radioisotope Stirling generators	1
Small atmospheric ISRU oxygen generator	1
Science equipment	10
<b>Power/Logistics Module</b>	<b>52</b>
Two 2-man Small Pressurized Rovers, each with one 5 kWe radioisotope Stirling generator	20
Two relocatable 5 kWe radioisotope Stirling generators (in addition to the rover units)	1
Additional consumables	10
Science equipment	21



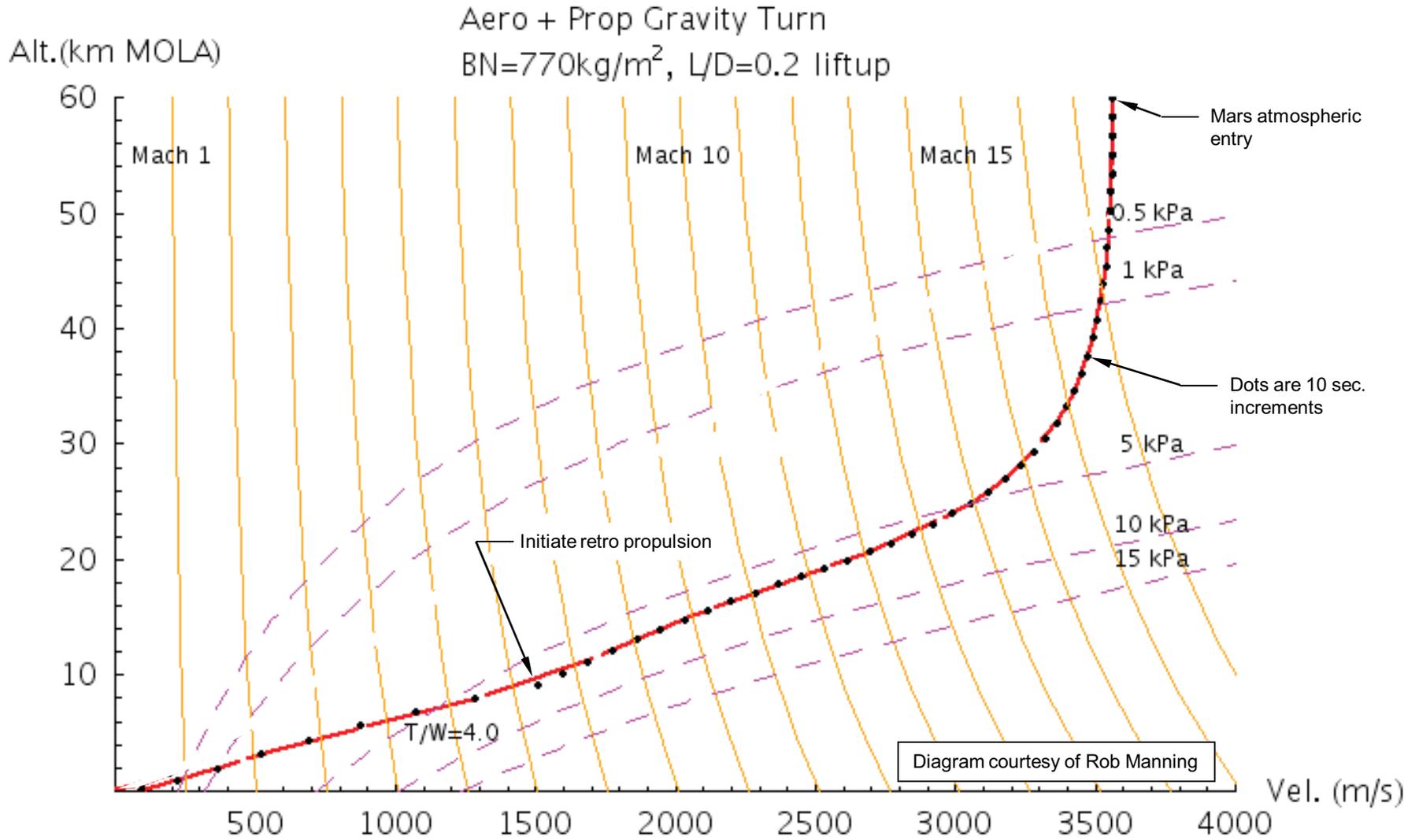
## EDL Concept



- Blunt body entry vehicle
  - Good design heritage and flight history
  - Efficient load paths
  - No complex extraction of the lander
- No deployable parachutes or inflatable decelerators
  - Flight regime cannot utilize foreseeable parachute designs
  - Development and test costs of advanced decelerators (e.g. inflatables) avoided
  - Complexity and possible in-flight risks avoided
- Supersonic Retropropulsion (SRP) used for deceleration to subsonic regime
- Same SRP rockets utilized for subsonic deceleration and landing
- EDL profile:
  - Atmospheric entry ranging from ~3.3 – 4.5 km/s
  - Initiate SRP ~6 min. after entry at ~10 km alt. and ~1.5 km/s
    - Thrust/weight ratio of ~ 4/1 (Martian weight)
  - Becomes subsonic ~70 sec. later
    - Jettison heatshield and deploy landing gear
  - Landing is ~20 sec. later



# EDL Phase Diagram for Common Lander

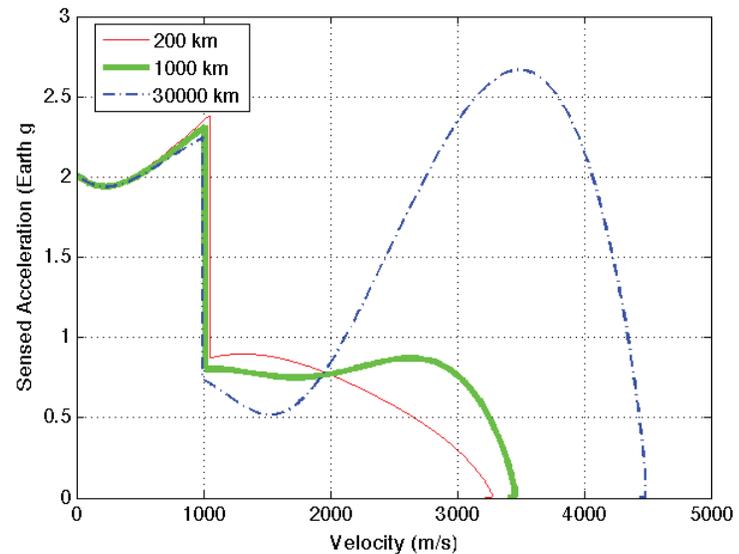
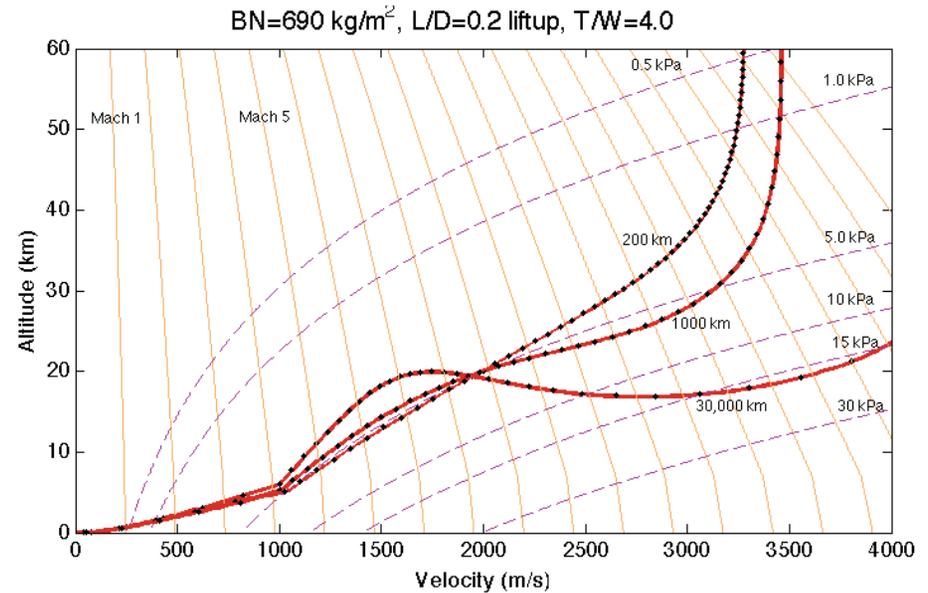




# EDL Analyses with TOP



- Aerospace Corporation used Trajectory Optimization Program (TOP) to perform independent assessments of austere architecture EDL
- Results were similar to JPL analysis
- Different entry profiles all ended up in the same velocity/altitude/dynamic pressure regime for SRP initiation, therefore the propulsive profiles were almost identical





# Notional Mass Allocations for Major Elements



Element	Mass (T)	"Gear Ratio"	Prop. type	Ares V	Ares I	Comments
MAV Cabin	6.2					2.8 times Apollo Ascent Module dry mass
MAV Total	45.9	7.4	NTO/MMH			Includes ascent propulsion and structure
Lander Descent Stage	119.3	3.6	NTO/MMH			Includes separate aerocapture heat shield
Lander/MAV Total	<b>165.2</b>			<b>1</b>		
MAV EDS's	<b>330.3</b>	3.0	LOX/LH <sub>2</sub>	<b>2</b>		Two stage assembly requiring two Ares V launches
Cargo Lander payload	52.0					Can be Habitat, or Surface Power and Logistics Module
Cargo Descent Stage	114.4	3.2	NTO/MMH			
Cargo Total	<b>166.4</b>			<b>1</b>		
Cargo EDS's	<b>332.8</b>	3.0	LOX/LH <sub>2</sub>	<b>2</b>		Two stage assembly requiring two Ares V launches
CEV	<b>10.0</b>				<b>1</b>	Current Orion CM mass
Transit Habitat	35.0					For comparison, Mir Core Module mass = 21 T
Contingency Module	7.0					Emergency supplies for Mars abort to orbit (jettisonable)
Subtotal	52.0					
MOI/TEI Module	114.4	3.2	LOX/LCH <sub>4</sub>			Assumes 1.2 km/s MOI followed by aerobraking
Subtotal (w/o CEV)	<b>156.4</b>			<b>1</b>		A single Ares V launches MOI/TEI module plus Habitat
EDS Stages	<b>332.8</b>	3.0	LOX/LH <sub>2</sub>	<b>2</b>		Two stage assembly requiring two Ares V launches
<b>Grand Total</b>	1,983.1			12	1	Incl. 2 Cargo Landers (Surf. Hab., Power & Logistics)

- "Gear Ratios" were checked by JPL Mass Tracker tool analyses.
- Ares V is assumed to deliver **~167 T to LEO** to provide adequate mass capability.



## New Technology Development



- New technologies were considered only where needed to enable the mission, reduce cost, or reduce development or mission risk
  - Supersonic Retropropulsion (SRP) for Lander EDL
    - Probably needed by any crewed Mars mission architecture
  - 5 kWe Stirling Dynamic Isotope Power System (DIPS) for surface power
    - Judged to be lower risk, lower mass, and lower cost than fission or solar
      - No deployable elements
      - No placement issues
      - Insensitive to dust storms
      - No SCRAM issues or non-recoverable events
      - Possibilities exist for mechanical repairs (very low radiation environment)
    - Each 4-yr. mission cycle would need 4-6 times the amount of Pu<sup>238</sup> used on Cassini
  - LOX/CH<sub>4</sub> propulsion for TransHab
    - LOX/kerosene could be an alternate propellant choice (might even be better choice)
    - NTO/MMH biprop might be a possible fallback (see “Additional Material” in back)
- Some optional technologies could greatly enhance the mission
  - Small ISRU unit for generating breathing oxygen from Martian atmosphere
    - Would enable more EVA time
  - Inflatable surface habitat to provide larger living quarters



## Notional Flight Test Program for Lander



- Unmanned DAV test flight would use full-up system with two EDS modules to launch the stack to Mars
  - Would require three Ares V launches
  - Would validate all phases of the DAV mission:
    - LEO assembly
    - TMI
    - Cruise to Mars
    - Aerocapture into high Mars orbit
    - Aerobraking to low Mars orbit
    - EDL
    - Would remain on the surface for the duration required by a crewed mission; then the MAV would be launched into Mars orbit
  - The MAV in the test flight could deliver a Mars sample container to Mars orbit as part of a robotic Mars Sample Return mission
- DAV test flight would also validate EDL design for the cargo landers, since they utilize an identical mold line and identical EDL subsystem design
  - Cargo landers might employ direct entry rather than entry from low Mars orbit, so that difference would have to be validated by analysis



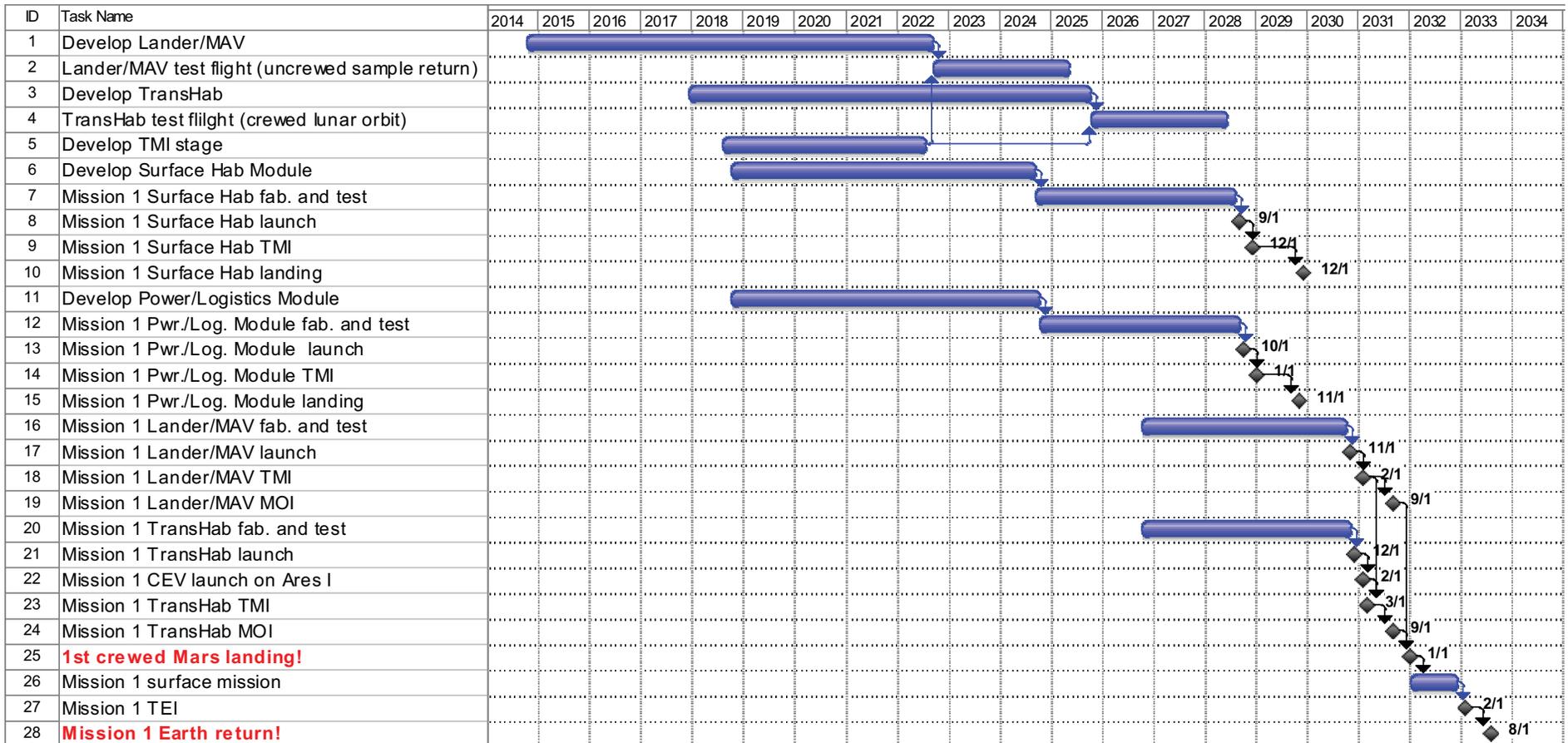
## Notional Flight Test Program for Transit Habitat



- TransHab design could be validated in a relevant environment without having to travel to Mars
- Could be achieved by a test flight in near-Earth space that could be crewed with abort-to-Earth capability in the event of problems
- A three-year flight would fully validate the TransHab, and this could be conducted in LEO, Lunar orbit, near-Earth space such as  $L_2$ , or some combination of those regions
- Could be fully crewed for the duration, crewed for only certain intervals in the test flight, or staffed by rotating crew teams
  - Nominal Mars mission would have crew in TransHab for no more than ~10 months at a stretch
- One EDS would be desirable for the test flight to validate interfaces and performance, so two Ares V launches would be needed to support the test flight



# Notional Development and Flight Schedule



Note: This schedule would require three Ares V rockets to be available to launch the DAV test flight in 2022



## Estimated Cost Profile (All-U.S. Program)



		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	Total		
Descent/Ascent Vehicle (DAV)	dvmt.	500	1,000	1,500	2,200	2,500	2,000	500													10,200	
Earth Departure Stage (EDS)	dvmt.	200	300	400	600	500	400	200														2,600
Ares V upgrade	dvmt.	300	400	600	600	600	300	200														3,000
DAV test flight	test						500	1,500	1,390													3,390
TransHab Development	dvmt.				200	400	600	600	700	500	400	300										3,700
MOI/TEI Stage	dvmt.					200	300	400	600	600	400	200										2,700
CEV upgrade	dvmt.							200	200	200	200	200										1,000
TransHab test flight	test									504	1,008	504										2,015
SurfHab Development	dvmt.					300	300	700	750	800	750	750	350									4,700
Power/Logistics Module	dvmt.					200	400	500	700	750	550	400	300									3,800
SurfHab	Flt. 1												851	1,703	851							3,405
Power/Logistics Module	Flt. 1												920	1,840	920							3,680
DAV	Flt. 1														848	1,695	848				3,390	
TransHab/Crew	Flt. 1														633	1,265	633				2,530	
SurfHab	Flt. 2																851	1,703	851			
Power/Logistics Module	Flt. 2																920	1,840	920			
DAV	Flt. 2																				848	
TransHab/Crew	Flt. 2																				633	
Reserves/margin (50%)		500	850	1,250	1,800	2,350	2,400	2,400	2,170	1,677	1,654	1,177	1,211	1,771	1,626	1,480	1,626	1,771	1,626			25,055
<b>Total (\$M)</b>		<b>1,500</b>	<b>2,550</b>	<b>3,750</b>	<b>5,400</b>	<b>7,050</b>	<b>7,200</b>	<b>7,200</b>	<b>6,510</b>	<b>5,031</b>	<b>4,961</b>	<b>3,531</b>	<b>3,632</b>	<b>5,314</b>	<b>4,877</b>	<b>4,440</b>	<b>4,877</b>	<b>5,314</b>	<b>4,877</b>			<b>75,165</b>

- Cost estimates are notional and draw heavily upon the cost estimates performed for DRA 5
- Based upon NAFCOM models, top-level historical analogies, and results from previous Mars mission studies
- Costs for test flights & operational flights include Ares V launches, Ares I launches, and Orion crewed spacecraft
- Estimates do not contain sustaining costs for the Constellation Program nor mission operations costs



# Estimated Cost Profile (International Program)



		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	Total		
Descent/Ascent Vehicle (DAV)	dvmt.	500	1,000	1,500	2,200	2,500	2,000	500													10,200	
Earth Departure Stage (EDS)	dvmt.	200	300	400	600	500	400	200														2,600
Ares V upgrade	dvmt.	300	400	600	600	600	300	200														3,000
DAV test flight	test						500	1,500	1,390													3,390
TransHab Development	dvmt.																					0
MOI/TEI Stage	dvmt.																					0
CEV upgrade	dvmt.							200	200	200	200	200										1,000
TransHab test flight	test									335	500	335										1,170
SurfHab Development	dvmt.					300	300	700	750	800	750	750	350									4,700
Power/Logistics Module	dvmt.					200	400	500	700	750	550	400	300									3,800
SurfHab	Flt. 1												851	1,703	851							3,405
Power/Logisitics Module	Flt. 1												920	1,840	920							3,680
DAV	Flt. 1														848	1,695	848					3,390
TransHab/Crew	Flt. 1														440	805	440					1,685
SurfHab	Flt. 2																851	1,703	851			
Power/Logisitics Module	Flt. 2																920	1,840	920			
DAV	Flt. 2																					848
TransHab/Crew	Flt. 2																					440
Reserves/margin (50%)		500	850	1,250	1,700	2,050	1,950	1,900	1,520	1,043	1,000	843	1,211	1,771	1,529	1,250	1,529	1,771	1,529			21,010
<b>Total (\$M)</b>		<b>1,500</b>	<b>2,550</b>	<b>3,750</b>	<b>5,100</b>	<b>6,150</b>	<b>5,850</b>	<b>5,700</b>	<b>4,560</b>	<b>3,128</b>	<b>3,000</b>	<b>2,528</b>	<b>3,632</b>	<b>5,314</b>	<b>4,588</b>	<b>3,750</b>	<b>4,588</b>	<b>5,314</b>	<b>4,588</b>			<b>63,030</b>



## Notional Development Costs (included in previous cost charts)



Development Item	Comments	Cost Basis or Analogy	Cost ('09 \$B)
Earth Departure Stage (EDS)	Incl. rend. & docking system (ATV heritage)	Ares V EDS	3.9
Descent/Ascent Vehicle dvmnt.	Incl. Supersonic Retro-Propulsion (SRP) dvmnt.	Orion development	15.3
Test flight: DAV, unmanned	Might be part of an MSR mission		5.1
Mars Surface Habitat	Leverages off of earlier lunar surface habitiat	ISS module	7.1
Surface Power/Logistics Module	Assuming Stirling RTG's		5.7
CEV Block Upgrade for Mars			1.5
Mars Transit Habitat	Incl. MOI/TEI prop. module	ISS module	9.6
Test flight: TransHab & CEV	Manned flight in LEO or circumlunar		3.0
	<b>Total</b>		51.2
<b>Notes:</b>	Cost bogeys do not include mission or ground operations or facilities.		
	Costs include 50% margin over DRA 5/Aerospace Corp. estimates.		
	Lander/MAV test flight doesn't incl. any costs for an MSR mission.		
	This table doesn't include any Ares V upgrade costs.		



## Hypothetical Launch Timeline



Time	KSC Launch	LEO Launch	Vehicle	Comments
M-875 days	Mars Surface Habitat		Ares V	
M-870 days	Power/Logistics Module		Ares V	Isotope Stirling pwr.; small pressurized rovers
M-825 days	Habitat EDS 1		Ares V	
M-820 days	Habitat EDS 2		Ares V	
M-815 days		Habitat TMI	EDS 1&2	Habitat is launched to Mars
M-790 days	Power EDS 1		Ares V	
M-785 days	Power EDS 2		Ares V	
M-780 days		Power TMI	EDS 1&2	Surface Power/Logistics Module launched to Mars
M-95 days	Descent/Ascent Vehicle		Ares V	
M-90 days	Mars Transit Habitat		Ares V	Based on Zvezda-type module
M-45 days	Lander EDS 1		Ares V	
M-40 days	Lander EDS 2		Ares V	
M-35 days		Lander TMI	EDS 1&2	DAV is launched (uncrewed) to Mars
M-15 days	CEV		Ares I	
M-10 days	TransHab EDS 1		Ares V	
M-5 days	TransHab EDS 2		Ares V	
M		TransHab TMI	EDS 1&2	Crew is launched to Mars
<b>Notes:</b> M = TMI time for crewed Mars Transit Habitat with CEV				
This is not necessarily the best timeline. It's just a representative example of one that might work.				



# Conceptual Ares V (51.00.48) Launch Configurations

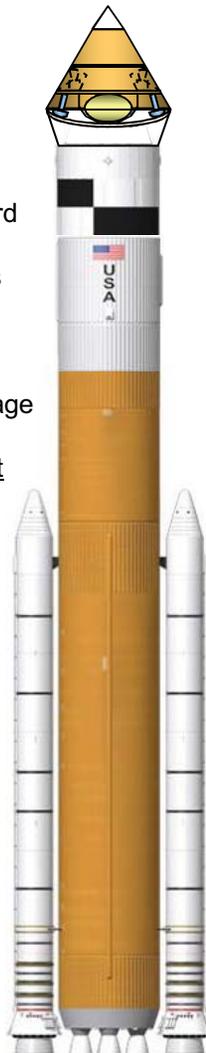
## Lander Configuration

Would require non-standard fairing ~13 m diameter, or lander backshell serves as fairing

### Cargo Lander Types:

1. Surface Habitat
2. Power/Logistics Package
3. Deep Drilling Package

DAV includes Mars Ascent Vehicle (MAV)



3

Number of launches per 4-year campaign cycle:

## TransHab Configuration

- Standard 10m fairing
- Includes MOI/TEI propulsion module
- Contingency Consumables Module could be launched separately, if needed, to reduce launch mass on Ares V



1

## Earth Departure Stage (EDS) Configuration

- EDS could be derived from Ares V stage 2 (40% reduction)
- Top of standard 10m fairing used for nose cone on EDS.
- Large production rate might lend to COTS
- Program might provide one spare EDS/Ares V on standby to cover a launch failure



8



## Conclusions



- This is conceptually a low risk approach with very little new technology development
  - Supersonic Retro-Propulsion (SRP) for EDL
  - Space storable LOX/LCH<sub>4</sub> propulsion for Transit Habitat
  - 5 kWe Dynamic Isotope Power System (DIPS)
  - Bulk of dvmt. work would be straightforward engineering design, fab, and testing
- Development risk could be low, with a program cost and schedule similar to that of the ISS – about 18 years and \$100 B
- **This architecture would require a ~170 T to LEO Ares V**
- 2/3 of the Ares V launches would be identical build-to-print EDS stages
  - Economy of scale in production
  - COTS provider might be a possibility
  - Mission reliability could be significantly increased by holding an extra Ares V with EDS Stage in reserve, ready to launch on short notice
- This is just a notional concept for a crewed Mars mission architecture. Validating this concept would require developing Phase A designs for each of the mission elements and performing simulation runs with higher fidelity mission modeling tools.
- Cost estimates are notional, based on NAFCOM modeling and comparisons to past developments. Coming up with validated cost estimates would require considerable analysis.



## Additional Material



# DRA 5 Contingencies, Fallbacks, and Descope Options Table

	Benefits	Impacts	Comments
<b>Contingencies</b>			
LOX/kerosine propulsion for landers and MAV	Lower development cost and risk. Heritage for pump-fed engines. Lower in-flight risk for long-term cryo fuel storage, esp. for pre-deploy. Easier thermal design.	Slightly lower $I_{sp}$	
Aerobraking used to lower Mars apoapsis for Mars Transit Vehicle (MTV)	Much lower propulsive MOI $\Delta V$	2-3 months for aerobraking taken from surface mission. Probably some moderate impacts to spacecraft configuration.	Aerobraking might be possible in <2 months
<b>Fallbacks</b>			
Surface power is solar with RPS emergency power	Lower development cost and risk	Lower overall power available. ISRU for propellant may be problematic. Only have emergency survival power during severe duststorms.	
Blunt-body entry vehicle for landers	Probably lower development cost and risk. Better structural load paths. Probably simpler implementation in jettisoning heatshield and backshell.	Lower internal volume. Less configuration flexibility. Possibly less heritage from Lunar Lander.	Might use inflatable hypercone or other deployable aerobrake
Chemical in-space propulsion (TMI, MOI, and TEI)	Lower development cost and risk	Higher launch mass	LOX/LH <sub>2</sub> or LOX/LCH <sub>4</sub>
<b>Descopes</b>			
Reduced crew size (e.g. 4)	Lower mass and cost	Reduced crew capability and redundancy	
Launch opportunities alternate between cargo and crew	1/2 the launch rate. Significantly lower sustaining cost.	Crews sent to Mars only at every other Mars opportunity. Lose benefits of overlapping redundant elements.	Uses pre-deploy architecture



## Possible Mission Contingencies



- If DAV were to fail prior to descent, crew would remain in TransHab and return to Earth at the designated time in the mission plan.
- If the Power/Logistics module were to fail, the crew could still perform a full-duration surface mission, but would be limited in resources and ability to travel very far from the SurfHab.
- If the SurfHab were to fail, the crew could still perform a significant surface mission living in the two small pressurized rovers and utilizing other resources on the Power/Logistics module. Limitations in resources and living volume would probably necessitate a less than full-duration surface mission.
- If both the SurfHab and Power/Logistics modules were to fail, and there was no common-cause lander failure, then the crew could perform a landing in the DAV and conduct a brief surface mission similar to the Apollo lunar missions.



## Concept for Transit Habitat NTO/MMH Option



- Based on Mass Tracker runs, the architecture conceptually closes using NTO/MMH propellants for the TransHab under the following conditions:
  - Separate NTO/MMH stages for MOI and for TEI
  - Ares V must be capable of lifting ~180 T to LEO, or an additional launch is required to deliver all the TransHab elements to LEO
    - Current Ares V (51.00.48) has been assessed as delivering 187.7 T to LEO
- This could potentially be a lower risk and lower development cost implementation or could provide a fallback option in the event that LOX/LCH<sub>4</sub> or LOX/kerosene propulsion were not used for the TransHab



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## Terminology



- CCM – Contingency Consumables Module
- CEV – Crew Exploration Vehicle (Orion)
- COTS – Commercial Orbital Transportation Services
- DAV – Descent/Ascent Vehicle
- DIPS – Dynamic Isotope Power System
- DRA – Design Reference Architecture
- DRM – Design Reference Mission
- EDL – Entry, Descent, and Landing
- EDS – Earth Departure Stage
- EVA – Extra Vehicular Activity
- $I_{SP}$  – Specific Impulse
- ISS – International Space Station
- ISRU – In-situ Resource Utilization
- JPL – Jet Propulsion Laboratory
- $L_2$  – Earth Lagrangian point 2
- LEO – Low Earth Orbit
- $LCH_4$  – Liquid Methane
- $LH_2$  – Liquid Hydrogen
- LOX – Liquid Oxygen
- MAV – Mars Ascent Vehicle
- MAWG – Mars Architecture Working Group
- MOI – Mars Orbit Insertion
- MSL – Mars Science Laboratory
- NTR – Nuclear Thermal Rocket
- $Pu^{238}$  – Plutonium 238
- SCRAM – Safety Control Rod Axe Man (jargon for emergency reactor shutdown)
- SPLM – Surface Power and Logistics Module
- SRP – Supersonic Retropropulsion
- SurfHab – Mars Surface Habitat
- T – Metric ton (1,000 kg)
- TEI – Trans-Earth Injection
- TMI – Trans-Mars Injection
- TOP – Trajectory Optimization Program
- TransHab – Mars Transit Habitat



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