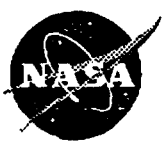


1N-20  
532  
L-15

# "Fast Track" Lunar NTR Systems Assessment for NASA's First Lunar Outpost and its Evolvability to Mars

Stanley K. Borowski and Stephen W. Alexander  
*Lewis Research Center  
Cleveland, Ohio*

Prepared for the  
10th Symposium on Space Nuclear Power and Propulsion  
cosponsored by the American Nuclear Society and  
the American Institute of Aeronautics and Astronautics  
Albuquerque, New Mexico, January 10-14, 1993



National Aeronautics and  
Space Administration

(NASA-TM-107092) FAST TRACK LUNAR  
NTR SYSTEMS ASSESSMENT FOR NASA'S  
FIRST LUNAR OUTPOST AND ITS  
EVOLVABILITY TO MARS (NASA, Lewis  
Research Center) 15 p

N96-1257

Unclass

G3/20 0072072

**“FAST TRACK” LUNAR NTR SYSTEMS ASSESSMENT  
FOR NASA’S FIRST LUNAR OUTPOST  
AND ITS EVOLVABILITY TO MARS**

Stanley K. Borowski  
Nuclear Propulsion Office  
NASA Lewis Research Center  
21000 Brookpark Road  
Cleveland, OH 44135  
(216) 977-7091

Stephen W. Alexander  
Advanced Space Analysis Office  
NASA Lewis Research Center  
21000 Brookpark Road  
Cleveland, OH 44135  
(216) 977-7127

**Abstract**

Integrated systems and missions studies are presented for an evolutionary lunar-to-Mars space transportation system (STS) based on nuclear thermal rocket (NTR) technology. A “standardized” set of engine and stage components are identified and used in a “building block” fashion to configure a variety of piloted and cargo, lunar and Mars vehicles. The reference NTR characteristics include a thrust of 50 thousand pounds force (klbf), specific impulse ( $I_{sp}$ ) of 900 seconds, and an engine thrust-to-weight ratio of 4.3. For the National Aeronautics and Space Administration’s (NASA) First Lunar Outpost (FLO) mission, an expendable NTR stage powered by two such engines can deliver ~96 metric tonnes (t) to trans-lunar injection (TLI) conditions for an initial mass in low Earth orbit (IMLEO) of ~198 t compared to 250 t for a cryogenic chemical system. The stage liquid hydrogen (LH<sub>2</sub>) tank has a diameter, length, and capacity of 10 m, 14.5 m and 66 t, respectively. By extending the stage length and LH<sub>2</sub> capacity to ~20 m and 96 t, a single launch Mars cargo vehicle could deliver to an elliptical Mars parking orbit a 63 t Mars excursion vehicle (MEV) with a 45 t surface payload. Three 50 klbf engines and the two standardized LH<sub>2</sub> tanks developed for the lunar and Mars cargo vehicles are used to configure the vehicles supporting piloted Mars missions as early as 2010. The “modular” NTR vehicle approach forms the basis for an efficient STS able to handle the needs of a wide spectrum of lunar and Mars missions.

**INTRODUCTION**

On July 20, 1989, the 20th anniversary of the Apollo 11 Moon landing, President Bush tasked NASA to undertake a Space Exploration Initiative (SEI) aimed at returning humans to the Moon “to stay” in the next century, followed by a journey to Mars using systems “space tested” in the lunar environment. Initial assessments of the space transportation system elements and infrastructures required to move humans and support equipment (for example, habitats, supplies, and science and exploration equipment) from Earth to the surfaces of the Moon and Mars were outlined in the “90 Day Study Report” (NASA 1989). In a more recent report (Synthesis Group 1991) entitled “America at the Threshold: America’s Space Exploration Initiative”, the Synthesis Group outlined several different approaches to accomplish the SEI missions.

The Synthesis Group also recommended important technical strategies that affect space transportation systems design. These included use of: (1) a heavy lift launch vehicle (HLLV) to limit on-orbit assembly; (2) a split mission strategy (where cargo and crew fly on separate missions); (3) pre-deployed and verified “turn-key” habitats; (4) chemical and nuclear thermal propulsion for lunar and Mars missions, respectively; (5) direct entry of returning crews to Earth’s surface; (6) lunar missions as a “test bed” for Mars, and (7) to the extent possible, common systems for the lunar and Mars missions.

At present, NASA’s Exploration Program Office (ExPO) is considering chemical propulsion for an “early return to the Moon”, and NTR propulsion for the more demanding Mars missions to follow. Because the time and cost to develop two separate transportation systems could be substantial, the NASA Lewis Research Center (LeRC) has been examining the rationale and benefits of developing a NTR-based lunar STS (Borowski 1991) and then evolving it to Mars mission applications (Borowski et al. 1992) through the use of modular engine and stage components. In

addition to enhancing performance, the use of NTR propulsion for lunar missions could provide valuable operational experience while also allowing NASA to make a significant down payment during its initial lunar program on key components of the modular STS needed for the subsequent Mars mission. A modular approach can also enhance mission flexibility and safety, simplify vehicle design and assembly, and reduce development/procurement costs through standardization of the fewest number of components. An accelerated, reduced cost approach to overall lunar/Mars exploration is therefore expected.

### NTR PERFORMANCE CHARACTERISTICS

The nuclear thermal rocket represents the next major evolutionary step in propulsion technology. By using a fission reactor, rather than chemical reactants, to provide the heat source, the NTR can use low molecular weight LH<sub>2</sub> as both the reactor coolant and propellant to achieve I<sub>sp</sub> values nearly twice that of cryogenic chemical rockets at comparable exhaust temperatures.

The feasibility of a hydrogen-cooled, graphite-moderated NTR was demonstrated in the Rover nuclear rocket program (Koenig 1986) begun at Los Alamos in 1955. The promising early results from this effort led to the formation in 1960 of a joint program between NASA and the Atomic Energy Commission (AEC) to develop a Nuclear Engine for Rocket Vehicle Application (NERVA). From 1955 until the program was terminated in 1973, a total of twenty reactors were designed, built and tested at a cost of ~\$1.4 billion. Escalated to 1992 dollars, the Rover/NERVA technology represents an investment of ~\$10 billion.

Performance projections for modern day NERVA-derivative engine systems utilizing both coated particle "graphite" and "composite" fuel forms, and "state-of-the-art" nozzle and turbopump technologies indicate substantial improvements in both I<sub>sp</sub> and engine thrust-to-weight ratio over the 1972 NERVA reference engine design (see Table 1). Modest increases in chamber temperature, pressure and individual fuel element power output (from ~0.9 megawatts of thermal power (MW<sub>t</sub>) to ~1.2 MW<sub>t</sub>) have been assumed along with a nozzle area expansion ratio of 200 to 1 and a 110% length optimum contour Rao nozzle. An expander cycle is also baselined with turbine drive gas provided by the propellant that cools the reactor tie-tube support elements. Finally, dual centrifugal turbopumps and an internal radiation shield (comprised of boron-carbide aluminum-titanium hydride (BATH) and lead) are included in the engine weight estimates to provide redundancy, and improve engine reliability and safety.

TABLE 1. Characteristics of NERVA-Type Engines.

Parameters	72 NERVA*	"State-of-the-art" NERVA Derivatives*					
	Hot Bleed/Expander	Expander					
Fuel Form	Graphite	Graphite			Composite		
Thrust (klbf)	75	25	50	75	25	50	75
Chamber Temperature (K)	2350	← 2550 →			← 2700 →		
Chamber Pressure (psia)	450	← 785 →			← 785 →		
Nozzle Expansion Ratio	100:1	← 200:1 →			← 200:1 →		
Specific Impulse (sec)	825/845	← 870 →			← 900 →		
Engine Mass (kg)**	11250	3727	4762	6205	3883	5237	6823
Engine Thrust/Weight **	3.0	3.0	4.8	5.5	2.9	4.3	5.0

\* Engine masses contain dual turbopump capability for redundancy.  
 \*\* Includes internal shield but no external disk shield mass.

## FIRST LUNAR OUTPOST MISSION/STAGE DESCRIPTION

NASA has spent considerable effort assessing the requirements for returning humans to the Moon. For the FLO, a split mission "lunar campsite" scenario has been adopted (ExPO 1992a). On the initial cargo mission, a pre-integrated, reusable habitat module is delivered intact on a common lander vehicle which performs both lunar orbit insertion and descent. The habitat provides facilities to support a crew of four for 45 Earth days (a lunar day, night, day cycle). Once the operational functions of the outpost have been verified the crew begins their journey to the Moon. On the piloted mission, the habitat module is replaced by a lunar ascent/Earth return stage with the crew module used at mission end for direct Earth entry. Both the cargo and piloted missions are launched separately on a single 250 t-class HLLV.

The main elements of the FLO transportation system are shown in Figure 1. The common lander and its payload are placed on their four day trajectory to the Moon using an expendable TLI stage. The current "reference" TLI stage contains ~133.5 t of liquid oxygen/liquid hydrogen (LOX/LH<sub>2</sub>) propellant and uses a single J-2S engine operating at thrust and I<sub>sp</sub> levels of ~265 kbf and 436 seconds, respectively. The "alternative" NTR stage contains ~66 t of LH<sub>2</sub> propellant and is propelled by two 50 kbf thrust engines operating with a I<sub>sp</sub> of 900 seconds. After TLI, the spent NTR stage is delivered to a long-lived (~100,000 year) heliocentric orbit via a "trailing edge" lunar gravity assist maneuver.

Key ground rules and assumptions used in determining the characteristics of the lunar NTR TLI stage are summarized in Table 2 which provides details on payload mass, velocity change ( $\Delta V$ ) requirements, primary and auxiliary propulsion, tankage and contingency factors. Figure 2 compares the IMLEO requirements for the FLO mission using both NTR and chemical propulsion systems. Individual data points shown on the single and multi-engine NTR curves indicate representative stage configurations which satisfy a "30 minute limit" on burn time specified in this study to provide additional safety margin. All of the NTR stages considered have lower IMLEO than their chemical engine counterparts. In addition to the single J-2S reference system, a clustered engine

TABLE 2. FLO Mission Ground Rules and Assumptions.

<u>"One Burn" Lunar Scenario</u>		
• <u>TLI Payload</u>	96 t (piloted vehicle & TLI stage adaptor)	
• <u>TLI Maneuver</u>	$\Delta V$	= 3200 m/s + gravity losses
	Initial orbit	= 100 n. mi. circular LEO (185 km)
• <u>NTR System</u>	Propellant	= Cryogenic hydrogen
	Isp	= 900 sec (composite) / 870 sec (graphite)
	External Shield Mass	≈ 60 kg/ kbf thrust
	Burn Duration	≤ 30 minutes
	Flight Performance Reserve	= 1% of usable propellant
	Cooldown (effective)	= 3% of usable propellant
	Residual	= 1.5% of total tank capacity
• <u>RCS System</u>	Propellant	= Hydrazine
	Isp	= 237 sec
	TLI burnout $\Delta V$	= 60 m/s (30 m/s for trailing edge lunar flyby)
• <u>Tankage</u>	Material	= 2219-T87 Al
	Geometry	= 10 m diameter cylindrical tank with $\sqrt{2}/2$ domes
	Insulation	= 2 inch MLI + micrometeoroid shield (3.97 kg/m <sup>2</sup> )
	Boiloff	= 12.40 kg / day
• <u>Contingency</u>	Engine & external shields	= 15%
	All other dry masses	= 10%

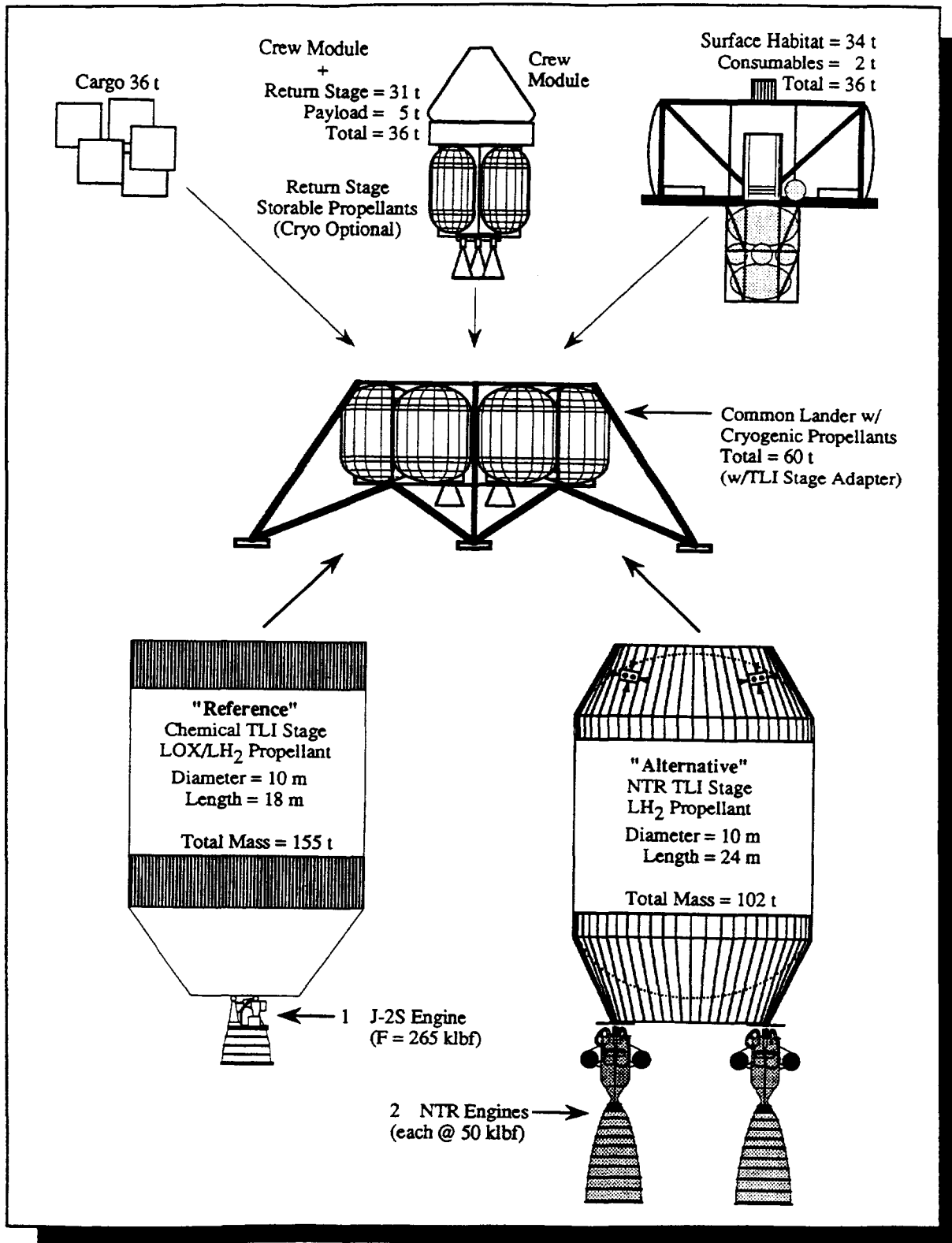


FIGURE 1. FLO Transportation System Elements.

configuration using five RL-10 A-4 engines (but delivering only 80 t of payload) is also shown for comparison. Figure 2 shows quite dramatically that NTR propulsion can enhance the performance capability for the FLO mission. Dimensions and mass characteristics for a reference NTR TLI stage are shown in Figure 3.

**MARS MISSION SCENARIOS/VEHICLE DESCRIPTIONS**

The ExPO, in conjunction with the NASA centers, is presently assessing the requirements for supporting a piloted mission to Mars as early as 2010 using a split “fast conjunction”-class mission profile (Joosten 1991). With this strategy, cargo would first be transported to Mars by a cargo vehicle(s) taking a slow, minimum energy trajectory to Mars. The piloted vehicle would travel to Mars on a faster, higher energy direct trajectory after receiving confirmation that the cargo vehicle(s) had arrived safely in Mars orbit. By employing a “fast transit time” strategy, it is thought that crew health hazards resulting from long term exposure to weightlessness and space radiation can be minimized. The “fast conjunction” option also maximizes the exploration time at Mars.

Three basic split/sprint mission modes are available for consideration (ExPO 1992b). In the “All-Up” mode, the piloted transfer vehicle (PTV) carries its own Mars excursion vehicle (MEV) and all of the propellant required for the fast-return transit to Earth. The corresponding cargo transfer vehicle (CTV) carries only an autonomous lander outfitted with the necessary supplies to support the surface mission. In the “No MEV” mode, the PTV carries only its return propellant and lands on Mars with a MEV carried on the CTV. A rendezvous in Mars orbit is therefore

***UC<sub>2</sub> Particles in Graphite with ZrH Moderator Augmentation***  
***1.2 MWth per Fuel Element, T<sub>c</sub>=2550 K, Isp=870 sec***

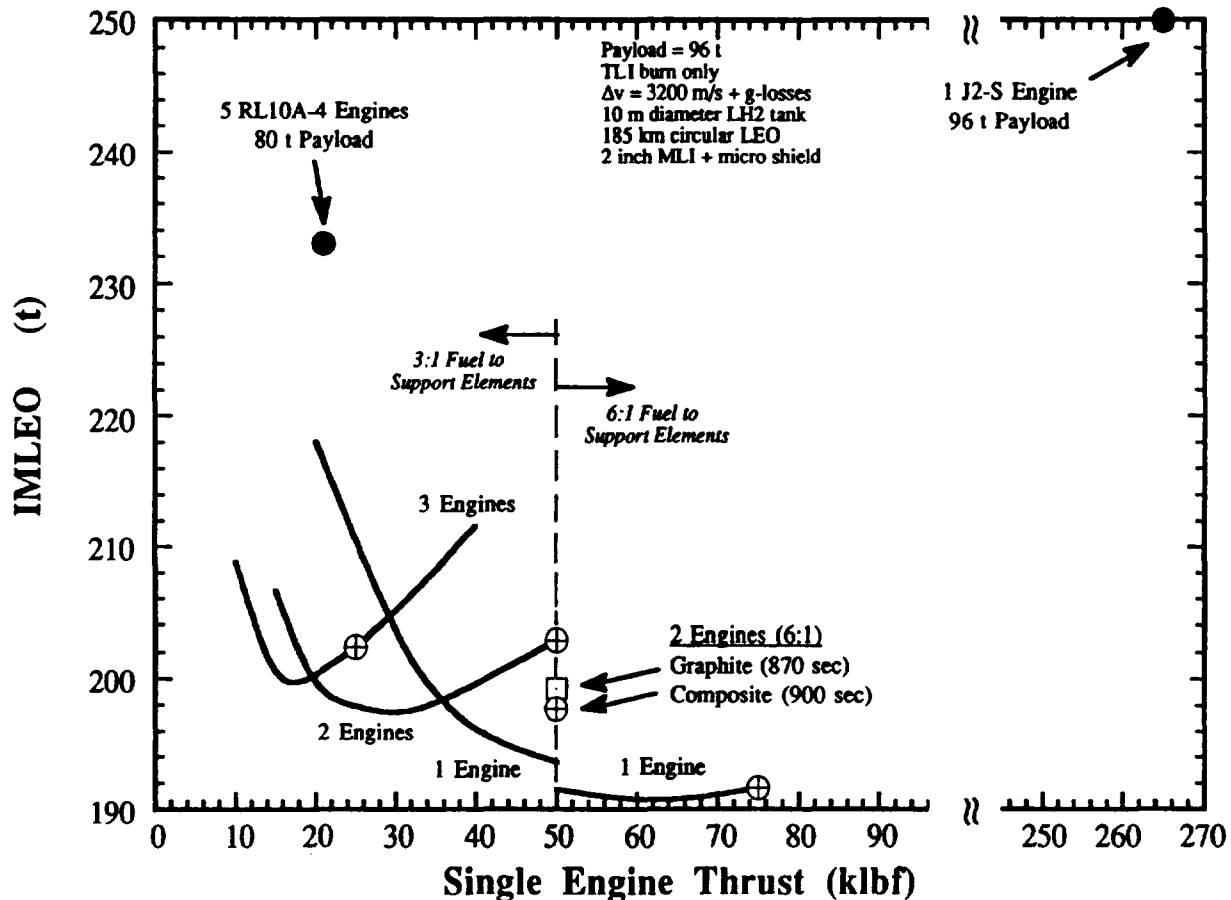
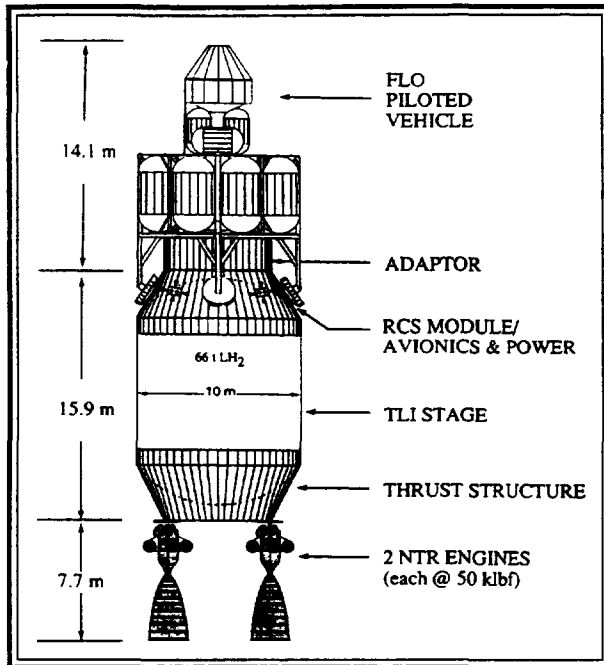


FIGURE 2. Benefits of NTR Propulsion for “First Lunar Outpost”.



### Expendable FLO TLI Vehicle

<u>Element</u>	<u>Mass (t)</u>
• TLI Stage	13.30
• Avionics and Power	1.00
• Reaction Control	0.46
• NTR Assemblies	
Engines (2)	10.47
External Shields (2)	6.00
• Contingency	3.95
• <u>Dry Mass</u>	<u>35.17</u>
• LH <sub>2</sub> Propellant	65.48
• RCS Propellant	1.06
• <u>Stage Mass</u>	<u>101.73</u>
• FLO Piloted Vehicle	93.00
• FLO/Stage Adaptor	3.00
• <u>IMLEO</u>	<u>197.73</u>

FIGURE 3. Vehicle Configuration and Mass Properties for FLO.

required between the PTV and CTV. The third option, the “No MEV/No trans-Earth Injection (TEI) Propellant” mode (also referred to as the “Minimum Piloted Mass” option), uses CTVs to pre-deploy at Mars all cargo including Earth return propellant. The TEI propellant can be transported either in a “tanker” CTV or in a separate “return stage”. Both techniques still require a Mars orbit rendezvous between the PTV and CTV, but the latter option would eliminate the need for propellant transfer. NTR vehicle designs have been developed for each of the split/sprint mission modes. The Mars mission ground rules, assumptions, and  $\Delta V$  budgets used in this study are summarized in Tables 3 and 4, respectively.

### Mars Cargo Vehicle

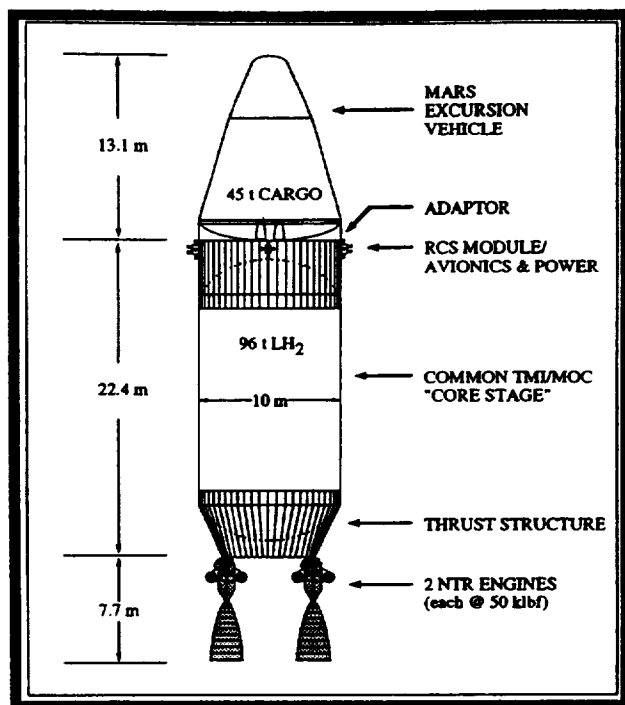
By extending the length of the FLO NTR stage (to ~20 m), upgrading avionics, and increasing fuel cell reactants and reaction control system (RCS) propellants, a single launch Mars cargo vehicle is possible. In the cargo mission scenario, a single trans-Mars injection (TMI) burn lasting ~24.5 minutes is used for Earth departure. Upon reaching Mars, the cargo vehicle performs a 3.5 minute Mars orbit capture (MOC) burn to achieve a 250 x 33,840 km (~24 hour period) elliptical parking orbit. At the appropriate time, the Mars cargo lander performs a de-orbit maneuver and uses a combination of aerobraking, parachutes and terminal descent propulsion to land ~45 t of payload on the Mars surface. Three cargo vehicles would precede the piloted vehicle in the “All-Up” mission mode with a fourth cargo mission (carrying the piloted MEV) required in the “No MEV” mission option. In the “No MEV/No TEI propellant” mode, a “tanker” CTV (functioning as a separate Earth “return stage”) is added to support the piloted mission.

The overall configuration and mass properties for the Mars cargo vehicle are shown in Figure 4. The IMLEO is under 201 t and the overall vehicle height is ~43.2 m. The length available for the Mars cargo vehicle is ~44.8 m. This is set by the length of the Saturn V-derived HLLV’s first and second stages (~80.2 m) and the height of the Vertical Assembly Building doors (~125 m).

TABLE 3. Mars Mission Ground Rules and Assumptions.

<b>Mission</b>				
	Cargo	Tanker	Piloted	
• Payload Outbound	4 x 63.0 t	-	-	MEV
	-	50.3 t	-	TEI Propellant
	-	-	55.8 t	Crew Habitat
• Payload Return	-	55.8 t	-	Crew Habitat
	-	6.8 t	-	MEV Crew Cab
	-	1.0 t	-	Mars Return Samples
• Parking Orbits	407 km	407 km	407 km	Earth Departure (circular)
		250 km x 1 sol		Mars Arrival/Departure
• Perigee Burns	1	1	1-3	Earth Departure
• Crew Size	-	-	6	
<b>Propulsion</b>				
• NTR System				
Propellant				Cryogenic Hydrogen
Isp				900 sec (composite)/ 870 sec (graphite)
External Shield Mass				≈ 60 kg/klbf thrust
Burn Duration				≤ 30 minutes
Flight Performance Reserve				1% of usable propellant
Cool down (effective)				3% of usable propellant
Residual				1.5% of total tank capacity
• RCS System				
Propellant				N <sub>2</sub> O <sub>4</sub> /MMH
Isp				320 sec
<b>Structure</b>				
• Tankage				
Material				2219-T87 Al
Diameter				10 m
Geometry				Cylindrical tank with √2/2 domes
• Insulation				
Cargo				2" MLI + micro shield (3.97 kg/m <sup>2</sup> )
Piloted & Tanker				
"Core Stage" & "In-line" tanks				4" MLI + micro shield+VCS (7.53 kg/m <sup>2</sup> )
TMI "Drop" Tanks				2" MLI + micro shield (3.97 kg/m <sup>2</sup> )
• Contingency				
Engine & External Shield				15%
All other dry masses				10%
<b>Boiloff</b>				
• Cargo Vehicle				0.769 kg/m <sup>2</sup> /month
• Piloted & Tanker Vehicle				
"Core Stage" & "In-line" tanks				0.375 kg/m <sup>2</sup> /month
TMI "Drop" Tanks				0.769 kg/m <sup>2</sup> /month
<b>Miscellaneous</b>				
• Gravity losses modelled for Earth departure only				





### 2007 Mars Cargo Vehicle

Element	Mass (t)
• Common TMI/MOC "Core Stage"	18.81
• Stage Avionics & Power	2.00
• Reaction Control	0.48
• NTR Assemblies	
Engines (2)	10.47
External Shields	-
• Contingency	3.70
• <u>Dry Mass</u>	<u>35.46</u>
• LH <sub>2</sub> Propellant	95.33
• RCS Propellant	5.35
• <u>Stage Mass</u>	<u>136.14</u>
• Mars Excursion Vehicle	63.00
• MEV/Stage Adaptor	1.70
• <u>IMLEO</u>	<u>200.85</u>
<b>Total IMLEO (3 vehicles)</b>	<b><u>602.55</u></b>

FIGURE 4. Mars Cargo Vehicle and Mass Properties.

TABLE 4. Mars Cargo and Piloted Mission  $\Delta V$  Budgets.

Vehicle Mission Mode	Launch Date	Outbound Transit Time (days)	Inbound Transit Time (days)	Total Mission Time (days)	TMI $\Delta V$ (km/s)	MOC $\Delta V$ (km/s)	TEI $\Delta V$ (km/s)	Total $\Delta V$ (km/s)
Cargo	2007	343.2	N/A	343.2	3.882	0.831	N/A	4.713
Piloted Outbound	2009	191.4	N/A	721.7	4.431	2.188	N/A	6.619
Tanker Outbound/ Piloted Inbound	2009	320	158.7	915	3.740	0.814	2.601	7.155

**Note:**

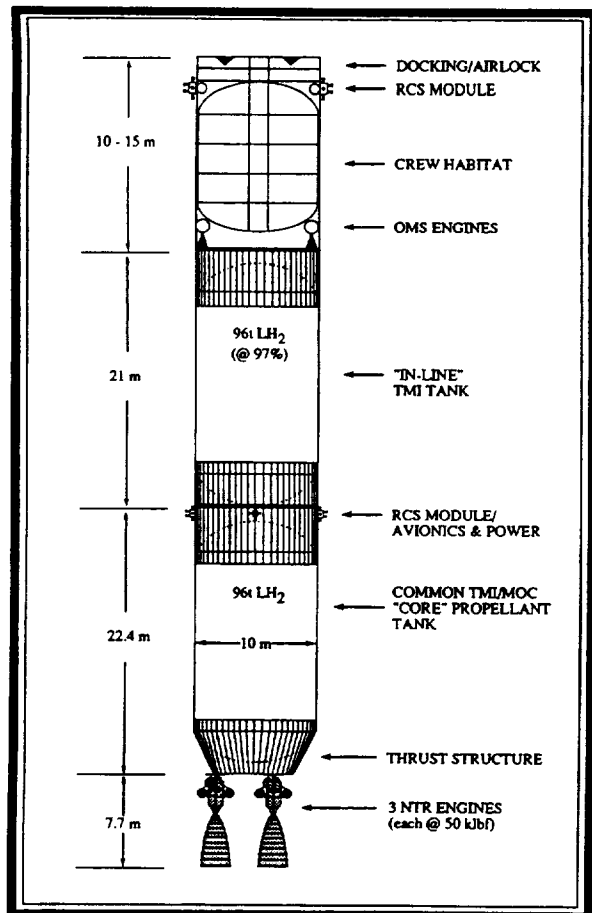
$\Delta V$  based on 407 km circular orbit at Earth and 250 x 33840 km elliptical Mars parking orbit.

TMI  $\Delta V$  includes 100 m/s for plane change

TEI  $\Delta V$  includes 150 m/s for apsidal alignment

### Mars Piloted Vehicle

The 2010 Mars landing mission is one of the most demanding mission opportunities over the ~15 year synodic cycle. Preliminary estimates by LeRC for the "All-Up" mission mode indicate IMLEO requirements approaching 1000 t for a 300 day total transit time (880 day total mission time) "fast-conjunction"-class mission with an ~24 hour elliptical Mars parking orbit. For the present study a total mission transit time (outbound and back) of ~350 days was chosen as the reference (see Table 4). Engine and total thrust levels ranging from 25 to 125 klbf, and



## 2010 Mars Piloted Vehicle “No MEV/No TEI Propellant Mission”

<u>Element</u>	<u>Mass (t)</u>
• Crew Habitat System	55.75
• Common TMI / MOC “Core Stage”	22.09
• TMI “In-Line” Tank	22.70
• Stage Avionics & Power	2.00
• Reaction Control System	1.04
• NTR Assemblies	
Engines (3)	15.71
External Shields (3)	9.00
• Contingency	8.49
• <u>Vehicle Dry Mass</u>	<u>136.78</u>
• LH <sub>2</sub> Propellant	189.52
• RCS Propellant	7.63
• <u>IMLEO</u>	<u>333.93</u>

FIGURE 5. “Outbound” Mars Piloted Vehicle and Mass Properties.

from 100 to 250 kJbf, respectively, were also examined. The optimum total thrust level for the more difficult “All-Up” and “No MEV” mission modes was found to be ~150 kJbf with two 75 kJbf-class engines providing the lowest IMLEO. Three 50 kJbf-class engines were chosen as the reference configuration, however, because of the commonality with the FLO lunar transfer stage and the Mars cargo vehicle (both of which use 50 kJbf-class engines). The three engine configuration also allows for the possibility of successful mission completion even with the loss of one engine, an option that does not exist with two engines.

Figure 5 shows the overall configuration and mass properties for the outbound Mars piloted vehicle operating in the “No MEV/No TEI propellant” mission mode. The vehicle consists of a “core stage” and “in-line” LH<sub>2</sub> propellant tank (each 10 m in diameter and 20 m in length), and a crew habitat module. The piloted vehicle is assembled at a 407 km circular Earth orbit altitude using two 230 t-class HLLVs. Autonomous rendezvous and docking is assumed between the “core” stage and the combined “in-line” LH<sub>2</sub> tank/crew habitat payloads. A “single burn” Earth departure scenario is baselined with gravity losses on the order of 315 m/s. A “triple perigee” burn scenario reduces gravity losses to ~80 m/s and the piloted vehicle IMLEO by approximately 9 t (from ~334 to 325 t). The “in-line” propellant tank provides ~67% of the usable propellant required for TMI with the remaining 33% being provided by the “core” stage propellant tank. The “single burn” TMI maneuver requires a total burn time by the three 50 kJbf NTRs of ~31 minutes.

After an outbound transfer time of ~191 days, the piloted vehicle initiates the MOC burn which lasts for ~9 minutes. Following rendezvous and docking maneuvers between the piloted vehicle and the cargo vehicle transporting the piloted MEV (Figure 6a), the crew descends to the Martian surface to begin a 530 day stay. During this surface exploration period, the “tanker” CTV arrives at Mars and docks with the habitat module on the outbound piloted vehicle (Figure 6b). In the scenario assumed here, the tanker functions as the Earth return stage for the

inbound portion of the piloted mission (Figure 6c) with the “spent” outbound piloted stage being jettisoned after hab module transfer. This approach eliminates the need for propellant transfer between the “tanker” CTV and the PTV. When the surface mission is completed, the crew returns to the “reconfigured” piloted vehicle in the ascent portion of the piloted MEV (Figure 6d). Prior to TEI, the MEV ascent stage is jettisoned. The MEV crew cab, however, is retained for later use during Earth entry (Figure 6e). The total “round trip” burn time on the “tanker” CTV’s three 50 kbf engines is ~32.5 minutes. Figure 7 shows the overall configuration and mass characteristics for the 2009 “tanker/return stage” Mars cargo vehicle.

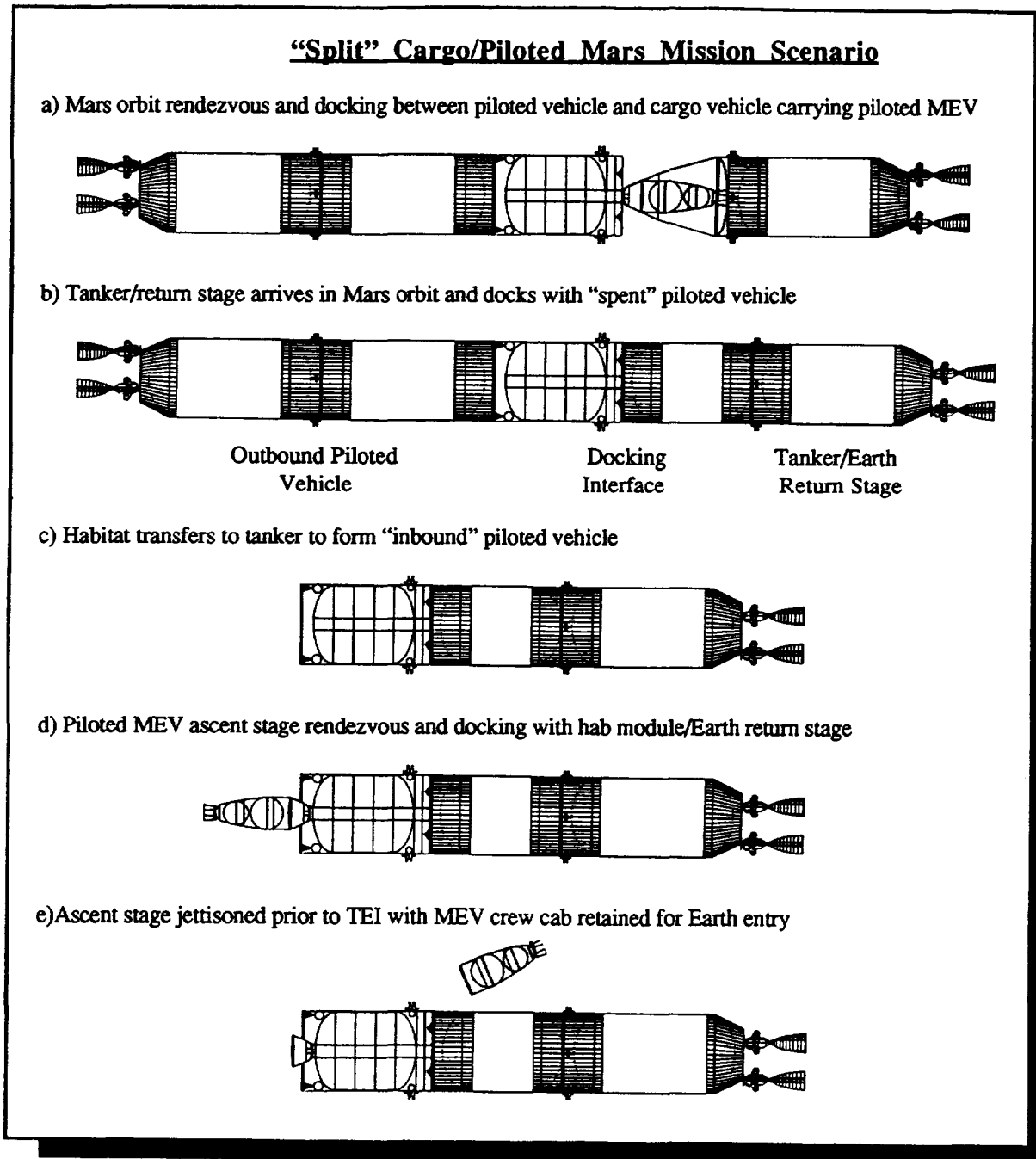
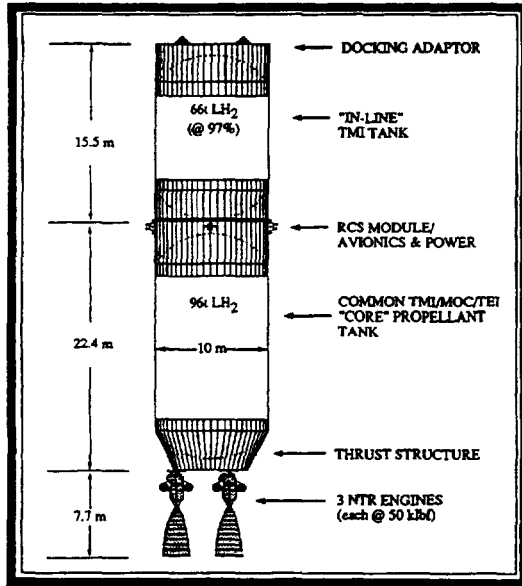


FIGURE 6. Mars Orbital Maneuvers between Cargo, Piloted and Tanker Vehicles.



### 2009 Mars Tanker Vehicle

Element	Mass (t)
• Common TMI/MOC/TEI "Core Stage"	22.09
• TMI "In-Line" Tank	18.30
• Stage Avionics & Power	2.00
• Reaction Control	1.04
• NTR Assemblies	
Engines (3)	15.71
External Shields	9.00
• Contingency	8.05
• <u>Dry Mass</u>	<u>76.19</u>
• LH <sub>2</sub> Propellant	160.34
• RCS Propellant	6.72
• <u>IMLEO</u>	<u>243.25</u>

FIGURE 7. Mars "Tanker" Vehicle and Mass Properties

The relative size of the cargo and piloted vehicles supporting the 2010 Mars mission are shown in Figure 8 along with the FLO NTR TLI stage for comparison. The piloted vehicle for the "All-Up" split mission mode has the largest IMLEO at ~760 t and is the most demanding in terms of the number of HLLVs and time required for orbital assembly (5 launches over ~10 months assuming 60 day launch centers). The three TMI "drop" tanks are attached to a pre-integrated truss/LH<sub>2</sub> feed system which also connects the basic spacecraft to the crew habitat module and MEV.

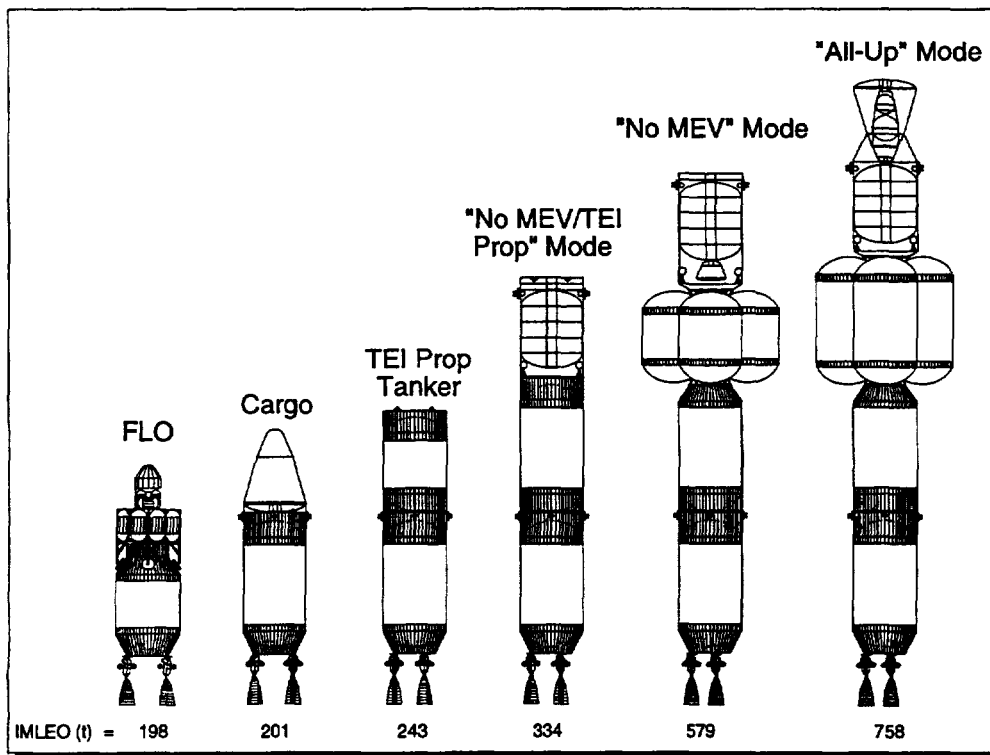


FIGURE 8. Relative Size of Lunar/Mars Vehicle Configurational Options.

With the "No MEV" mission mode, the IMLEO can be reduced by ~180 t. The greatest reduction in piloted vehicle mass occurs, however, with the "No MEV/No TEI Propellant" mission mode. With this scenario piloted vehicles on the order of 300 to 350 t can be assembled in LEO with two launches of a 150 to 200 t- class HLLV. Figure 9 summarizes the key components of the modular NTR approach discussed in this paper.

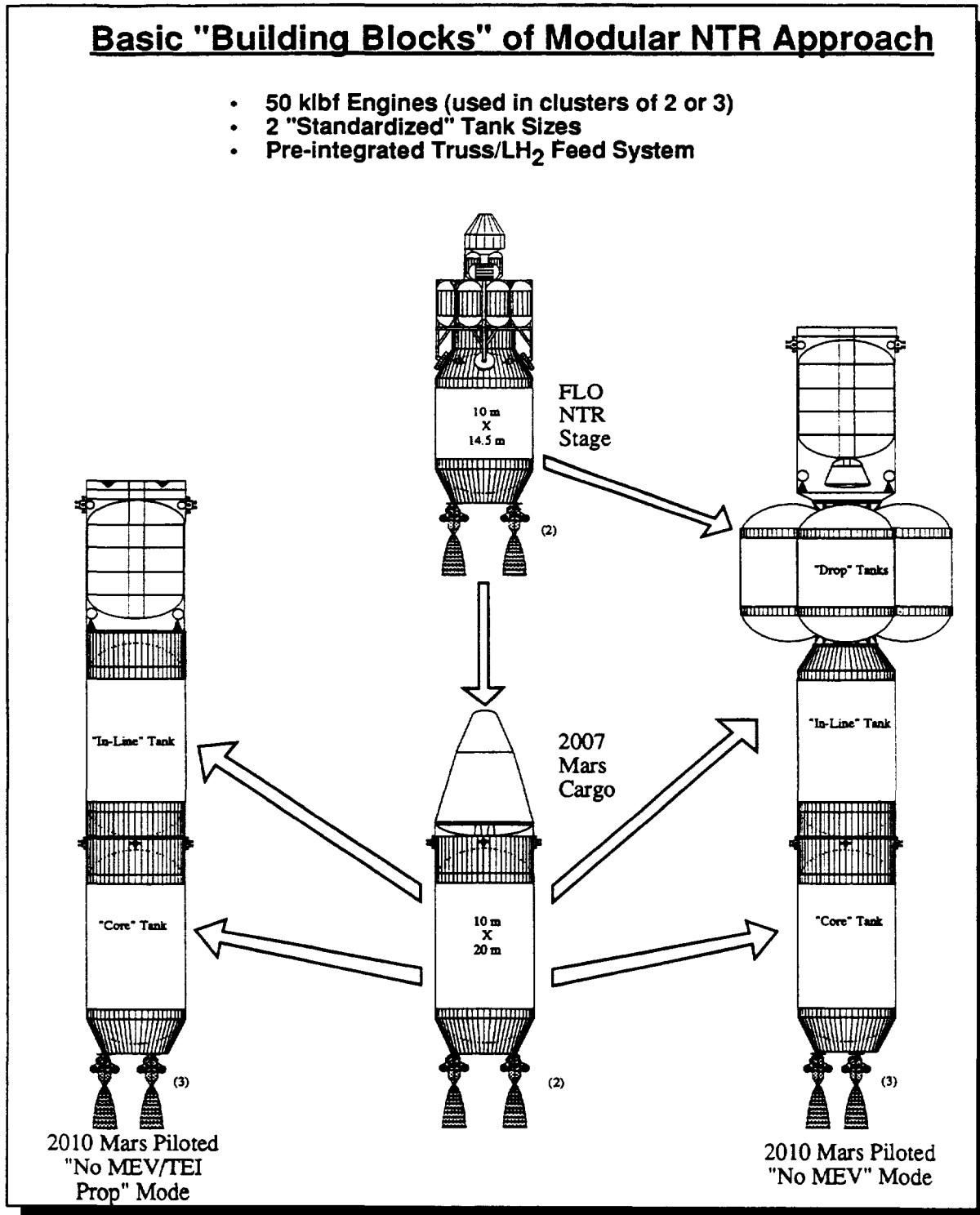


FIGURE 9. Key Components of Modular, NTR-Based Lunar/Mars Transportation System.

## SUMMARY AND CONCLUSIONS

The rationale and benefits of developing and implementing an evolutionary lunar-to-Mars STS based on modular NTR engine and stage components are presented. Key components of this modular approach are described and consist of (1) a 50 klbf NERVA-derived engine used in clusters of 2 or 3; (2) two "standardized" tank sizes developed for the First Lunar Outpost and Mars cargo vehicle applications; and (3) for larger piloted vehicle configurations, a pre-integrated truss/propellant feed system used for transferring LH<sub>2</sub> from the TMI drop tanks into the "in-line" tank. By using these components in a "building block" fashion a variety of single and multi-engine lunar and Mars vehicles can be configured to satisfy particular mission requirements.

With its factor of two advantage in I<sub>sp</sub> over chemical propulsion and its high thrust-to-weight ratio, the NTR is ideally suited to performing both piloted and cargo, lunar and Mars missions. The modular NTR approach can form the basis for an efficient space transportation system, satisfying the needs of all these options. What will be required for its realization is a "new design philosophy" -- away from customized and mission specific transportation system concepts to a "faster, better, cheaper" concept utilizing a single, common system design able to handle the needs of a wide spectrum of lunar and Mars missions.

## Acknowledgements

The work was performed within the Nuclear Propulsion Office (NPO) and Advanced Space Analysis Office (ASAO) at NASA's Lewis Research Center. The authors gratefully acknowledge the programmatic support of Dr. Gary Bennett (NASA Headquarters), and the contributions to this paper by Mr. David Plachta (LeRC/ASAO), Mr. David Weaver (NASA ExPO), and Mr. Robert Corban (LeRC/NPO).

## References

- Borowski, S. K. (1991) "The Rationale/Benefits of Nuclear Thermal Rocket Propulsion for NASA's Lunar Space Transportation System," AIAA-91-2052, presented at 27th Joint Propulsion Conference, Sacramento, CA, 24-26 June 1991.
- Borowski, S. K., J. S. Clark, R. J. Sefcik, R. R. Corban and S. W. Alexander (1992) "An Accelerated Development, Reduced Cost Approach to Lunar/Mars Exploration Using a Modular NTR-Based Space Transportation System," IAF-92-0574, presented at 43rd Congress of the International Astronautical Federation, Washington, DC, August 28 - September 5, 1992.
- EXPO (1992a) *Analysis of the Synthesis Group Architectures: Summary & Recommendations*, XE-92-004, NASA Exploration Program Office, Houston, TX.
- EXPO (1992b) *Analysis of the Synthesis Group's "Moon to Stay & Mars Exploration" Architecture*, XE-92-001, NASA Exploration Program Office, Houston, TX.
- Joosten, B. K., B. G. Drake, D. B. Weaver, and J. K. Soldner (1991) "Mission Design Strategies for the Human Exploration of Mars," IAF-91-336, presented at 42nd Congress of the International Astronautical Federation, Montreal, Canada, 5-11 October 1991.
- Koenig, D. R. (1986) *Experience Gained from the Space Nuclear Rocket Program (Rover)*, LA-10062-H, Los Alamos National Laboratory, Los Alamos, NM.
- NASA (1989) *Report of the 90-Day Study on Human Exploration of the Moon and Mars*, National Aeronautics and Space Administration, Washington, DC.
- Synthesis Group (1991) *America at the Threshold - America's Space Exploration Initiative*, Report of the Synthesis Group, U.S. Government Printing Office, Washington, DC.

# REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE October 1995	3. REPORT TYPE AND DATES COVERED Technical Memorandum	
4. TITLE AND SUBTITLE  "Fast Track" Lunar NTR Systems Assessment for NASA's First Lunar Outpost and its Evolvability to Mars		5. FUNDING NUMBERS  WU-242-10-01	
6. AUTHOR(S)  Stanley K. Borowski and Stephen W. Alexander		8. PERFORMING ORGANIZATION REPORT NUMBER  E-9970	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135-3191		10. SPONSORING/MONITORING AGENCY REPORT NUMBER  NASA TM-107092	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)  National Aeronautics and Space Administration Washington, D.C. 20546-0001		11. SUPPLEMENTARY NOTES  Prepared for the 10th Symposium on Space Nuclear Power and Propulsion cosponsored by the American Nuclear Society and the American Institute of Aeronautics and Astronautics, Albuquerque, New Mexico, January 10-14, 1993. Responsible person, Stanley K. Borowski, organization code 6850, (216) 977-7091.	
12a. DISTRIBUTION/AVAILABILITY STATEMENT  Unclassified - Unlimited Subject Categories 16 and 20  This publication is available from the NASA Center for Aerospace Information, (301) 621-0390.		12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  Integrated systems and missions studies are presented for an evolutionary lunar-to-Mars space transportation system (STS) based on nuclear thermal rocket (NTR) technology. A "standardized" set of engine and stage components are identified and used in a "building block" fashion to configure a variety of piloted and cargo, lunar and Mars vehicles. The reference NTR characteristics include a thrust of 50 thousand pounds force (klbf), specific impulse ( $I_{sp}$ ) of 900 seconds, and an engine thrust-to-weight ratio of 4.3. For the National Aeronautics and Space Administration's (NASA) First Lunar Outpost (FLO) mission, and expendable NTR stage powered by two such engines can deliver ~96 metric tonnes (t) to trans-lunar injection (TLI) conditions for an initial mass in low Earth orbit (IMLEO) of ~198 t compared to 250 t for a cryogenic chemical system. The stage liquid hydrogen (LH <sub>2</sub> ) tank has a diameter, length, and capacity of 10 m, 14.5 m and 66 t, respectively. By extending the stage length and LH <sub>2</sub> capacity to ~20 m and 96 t, a single launch Mars cargo vehicle could deliver to an elliptical Mars parking orbit a 63 t Mars excursion vehicle (MEV) with a 45 t surface payload. Three 50 klbf engines and the two standardized LH <sub>2</sub> tanks developed for the lunar and Mars cargo vehicles are used to configure the vehicles supporting piloted Mars missions as early as 2010. The "modular" NTR vehicle approach forms the basis for an efficient STS able to handle the needs of a wide spectrum of lunar and Mars missions.			
14. SUBJECT TERMS  Nuclear thermal rocket; NTR; First lunar outpost; FLO; Rover, NERVA; Modular; Space transportation; Moon; Mars			15. NUMBER OF PAGES 15
17. SECURITY CLASSIFICATION OF REPORT Unclassified			16. PRICE CODE A03
18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT	