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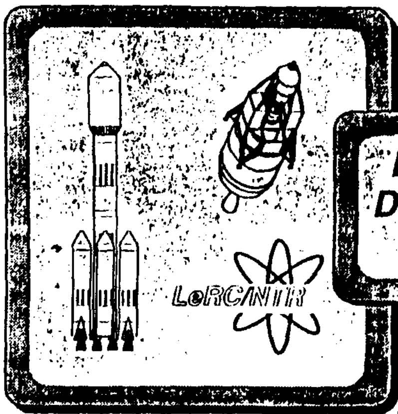

Lunar NTR Vehicle Design & Operations Study

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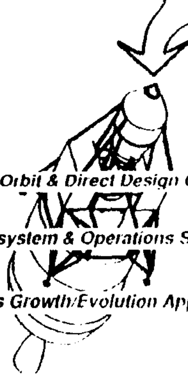
LTS/NTR Design & Operations Study

Objectives

Perform an Evaluation of the Potential Applications of a Specific Nuclear Thermal Rocket (NTR) Design to Past and Current (First Lunar Outpost) Mission Profile(s) for Piloted and Cargo Lunar Missions, and to Assess the Applicability of Utilizing Lunar Vehicle Design Concepts for Mars Missions

- Assess NTR Propulsion For Lunar Vehicle Concepts Based on Existing Mission Profiles
- Define and Size the Stage/Transfer Vehicles for Lunar NTR Applications
- Perform an Operational and Programmatic Assessment
- Perform a Chemical/NTR Lunar Concept Comparison

Products



Lunar Orbit & Direct Design Concepts

Key Subsystem & Operations Sensitivities

Mars Growth/Evolution Approach

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Reqts Provide Basis for NTR Vehicles

Mission Statement

- Support Exploration & Habitation of Lunar Surface with consideration for evolvability to Mars
- Lunar IOC 2000-2005
- Mars IOC: 2005 Cargo 2007 Piloted

Functional Reqts	System Reqts: Lunar Direct	System Reqts: Lunar Orbit Rendezvous
1.0 Prelaunch Proc		
2.0 Launch Ops	NLS & Saturn V derived launch systems	66t & 135 t launch system Only 2 HLLV Flts per mission 2nd HLLV Flt within 3 days
3.0 Transfer to Lunar Surface	4 Day Transit Cargo Mission- 33 t Manned Mission-5 t LOI Ops Altitude = 300 km Post TLI Disposal ΔV = 30 m/s Post LOI Disposal ΔV = 860 m/s	3 Day Transit LOI Ops Altitude = 300 km Post TLI Disposal ΔV = 30 m/s Post LOI Disposal ΔV = 860 m/s Deliver at least 5 t cargo & crew of 4 on piloted mission
4.0 Surface Ops	Surface Stay = 45 Days	Surface Stay = 180 Days
5.0 Earth Return	NTR reuse altitude = 500 km Return 200 kg to earth Post TEI disposal ΔV = 194 m/s	NTR reuse altitude = 500 km Return 500 kg to earth Post TEI disposal ΔV = 194 m/s

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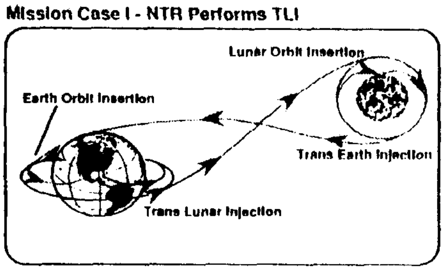
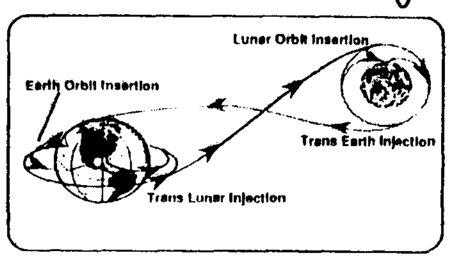
Lunar Mission Options

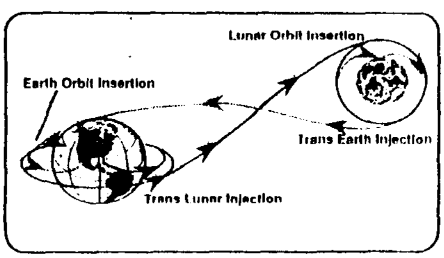
Mission Case I - NTR Performs TLI



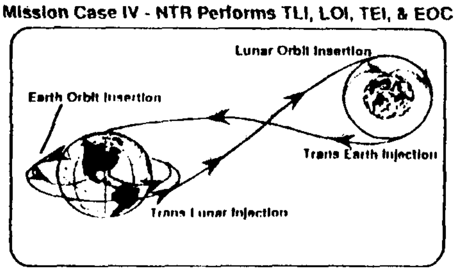


Mission Case II - NTR Performs TLI & LOI

Mission Case IV - NTR Performs TLI, LOI, TEI, & EOC



Mission Case III - NTR Performs TLI, LOI, & TEI



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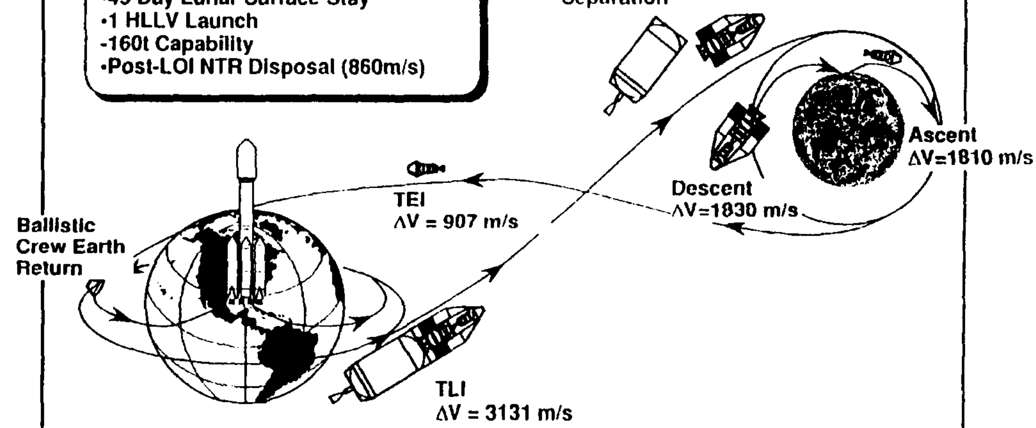
LD Space Operations Overview

Key Features:
- NTR Performs TLI, LOI
- Longest single burn time 30 min
- 45 Day Lunar Surface Stay
- 1 HLLV Launch
- 160t Capability
- Post-LOI NTR Disposal (860m/s)



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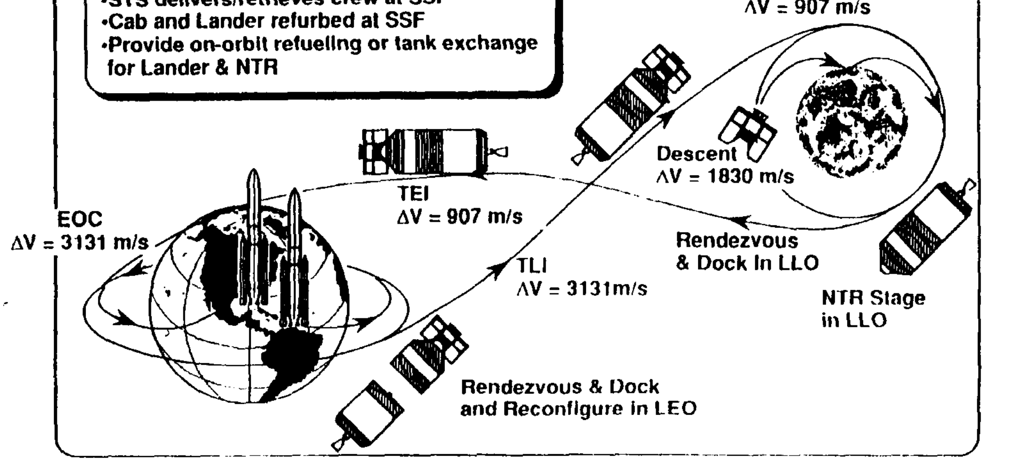
LR921009-LD Ops

LOR Space Based Operations Overview

Key Features:
- NTR Performs TLI, LOI, TEI, and EOC

Infrastructure Requirements:
- STS delivers/retrieves crew at SSF
- Cab and Lander refurbed at SSF
- Provide on-orbit refueling or tank exchange for Lander & NTR



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LR921009 LOR Reuse Ops

System Design Considerations

- Expendable vs. Reusable
  - Operations Complexity Too High For Reusability
  - Performance Maximization Achieved With Expendable Mission
  - Safety Concerns Lessened With Expendable Mission
- Shielding Considerations
  - NERVA Disk Shield
  - Modified Disk Shield Optimizes Design and Use of Propellant
  - Propellant and Tankage
  - Lander Propellant and Structure
- Launch Vehicle Considerations
  - Lunar Direct Mission
    - Smallest Launch Vehicle Necessary to Complete FLO Mission
  - Lunar Orbit Rendezvous
    - Complete Reasonable Lunar Architecture Using Medium Sized Launch Vehicle
- Thermal Protection Considerations
  - Active Refrigeration Too Heavy For Benefit & Abort Mission If Failed MLI & SOFI
- Lander Considerations
  - Lunar Direct Mission
    - 2 Stage Cryo/Storable Removes Long Term Hydrogen Storage on Orbit
  - Lunar Orbit Rendezvous
    - 1 1/2 Stage Cryo/Cryo Out-performs 2 Stage Lander Consistently in Past STV Studies
- Material and Construction Considerations
  - Aluminum Lithium Technology On Schedule For Flight Use By 2005
  - Isogrid Construction Promising For Structural Considerations
- Engine Configuration
  - Single vs Cluster
  - 25k vs 50k vs 75k

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Lunar Orbit Rendezvous Configurations

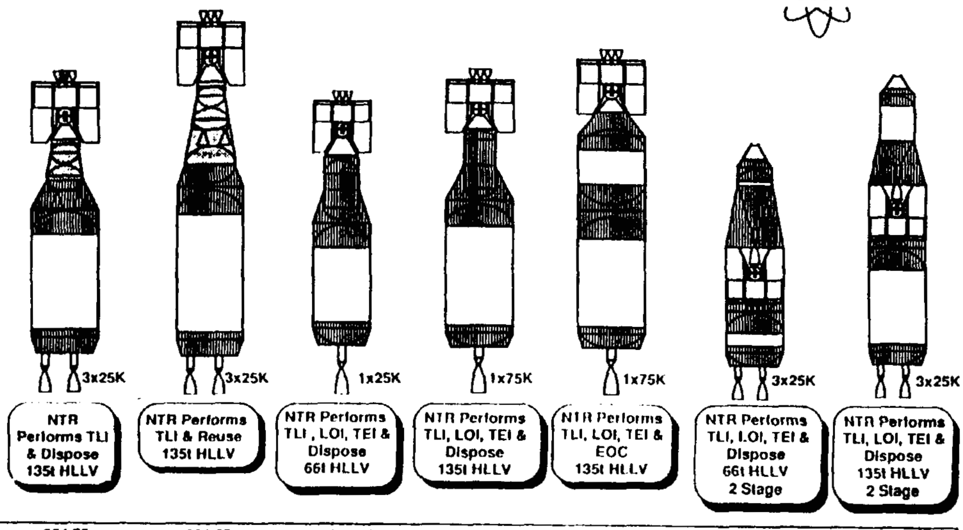
The chart below shows the top seven candidates of the Lunar Orbit Rendezvous configurations. We started with eighteen possible configurations in this category, and through performance runs, design constraints and operational issues, that eighteen was narrowed to the following seven. The missions that utilized a cryogenic liquid oxygen and liquid hydrogen TEI stage were extremely close in performance to those missions using NTR to perform the TEI burn. Therefore, it was beneficial to show the elimination of an entire technology, use of a LOX/LH$_2$ stage, and to show that a lunar mission can be supported solely by NTR technology. Another criteria that eliminated candidates was performance at least 5.00 tonnes to the lunar surface on a piloted mission. Also eliminated in the earlier phases of the study were two HLLV candidates. We started with four HLLV candidates: 66t, 105t, 132t, and 135t launch capacities. We narrowed that field to two candidates based on past STV analysis showing the 132t and 135t vehicles virtually even on performance. Of the three that were left, 66t, 105t, 135t, we eliminated the 105t because of study complexity and to demonstrate that NTR can be utilized on the two extreme launch vehicles and, therefore, everything in between.

Three of the configurations shown below started with a cluster of three 25Klb$_f$ NTR engines, but with further analysis their performance was greatly enhanced by going to a single engine configuration. Also, two of the configurations are two stage NTR configurations. The first NTR stage performs the TLI burn and is then staged off to perform a lunar assist disposal burn into heliocentric space. The second NTR stage then performs the rest of the mission and is also disposed of after the TEI burn.

LH920803 LPLOR Configs

Lunar Orbit Rendezvous Configurations

NTR



Stack Mass	254.75	263.25	128.56	265.45	267.83	131.73	261.68
Perfomance							
Piloted	26.55	19.55	7.21	38.68	19.35	5.88	38.53
Cargo	47.55	39.62	25.66	61.52	44.93	23.69	60.39

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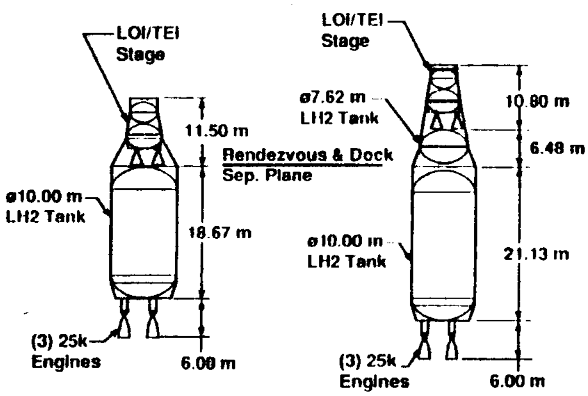
Lunar Orbit Rendezvous Configurations

NTR Performs TLI and Disposed
NTR Performs TLI and Reused



LOI/TEI Stage

Component	TLI & Dispose t	TLI & Reuse t
Structure	2.46	2.39
Tankage	0.99	0.93
Subsystems	2.83	2.83
Engine Structure	0.51	0.51
Engines	0.80	0.80
Contingency (15%)	1.14	1.12
Total Dry	8.73	8.58
Propellant	41.18	35.71
Total Wet	49.91	44.29

NTR Stage

Component	TLI & Dispose t	TLI & Reuse t
Structure	0.87	1.83
Tankage	5.10	7.20
Subsystems	2.11	2.64
Engine Structure	0.75	0.86
Engines	11.18	11.18
Shield	0.00	0.00
Contingency (15%)	3.00	3.56
Total Dry	23.01	27.27
Propellant	91.88	116.13
Total Wet	114.89	143.40

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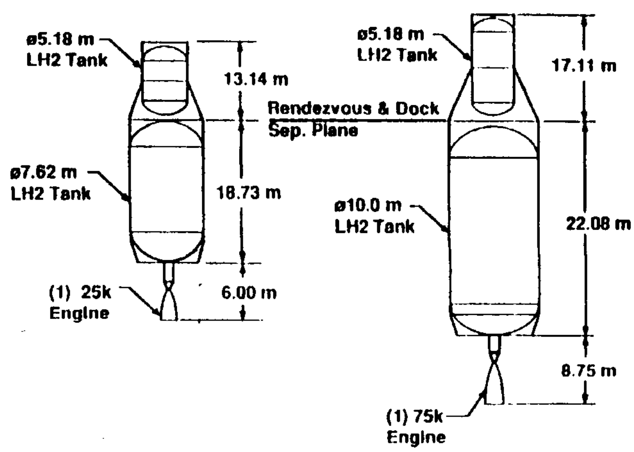
Lunar Orbit Rendezvous Configurations

NTR Performs TLI, LOI, TEI and Disposed - 66t HLLV & 135t HLLV



NTR Stage

Component	66t t	135t t
Structure	1.37	1.95
Tankage	3.71	6.80
Subsystems	1.98	2.87
Engine Structure	0.41	0.96
Engine	3.73	6.83
Shield	1.50	4.50
Contingency (15%)	1.91	3.59
Total Dry	14.61	27.50
Propellant	63.73	123.09
Total Wet	78.34	150.59

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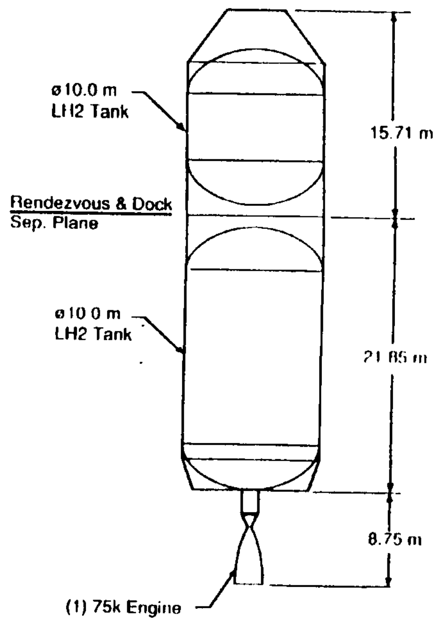
Lunar Orbit Rendezvous Configurations

NTR Performs TLI, LOI, TEI and EOC - 135t HLLV



NTR Stage

Component	t
Structure	2.91
Tankage	9.70
Subsystems	3.45
Engine Structure	0.96
Engine	6.83
Shield	4.50
Contingency (15%)	4.25
Total Dry	32.60
Propellant	160.08
Total Wet	192.68

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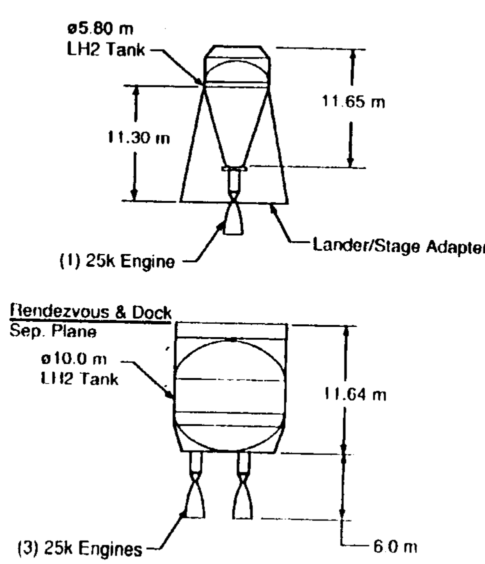
Lunar Orbit Rendezvous Configurations

2 Stage NTR Performs TLI, LOI, TEI and Dispose - 66t HLLV



NTR Stage 1 & 2

Component	t
Sturcture	2.59
Tankage	4.50
Subsystems	1.69
Engine Structure	0.76
Engine	14.91
Shield	1.50
Contingency (15%)	3.89
Total Dry	29.84
Propellant	54.42
Total Wet	84.26

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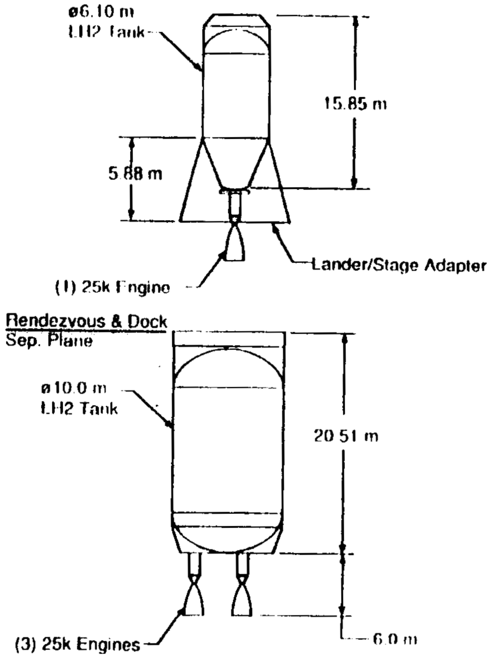
Lunar Orbit Rendezvous Configurations

2 Stage NTR Performs TLI, LOI, TEI and Dispose - 135t HLLV



NTR Stage 1 & 2

Component	t
Structure	1.79
Tankage	6.60
Subsystems	2.73
Engine Structure	0.81
Engine	14.91
Shield	1.50
Contingency (15%)	4.25
Total Dry	32.59
Propellant	114.55
Total Wet	147.14

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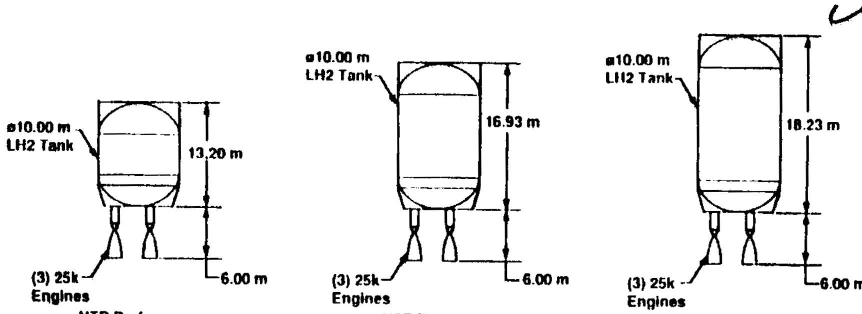
Preliminary LD NTR/TLI Configurations



NTR Stage

Component	TLI & Dispose t	TLI & Reuse t	TLI, LOI & Dispose t
Lander/TLI Adapter	1.49	1.49	1.49
Tankage	4.40	5.20	5.50
Subsystems	.81	.93	.97
Engine Structure	2.01	2.29	2.38
Engines	11.18	11.18	11.18
Shield	0.00	0.00	0.00
Contingency (20%)	3.98	4.22	4.30
Total Dry	23.87	25.31	25.82
Propellant	59.60	80.64	87.96
Total Wet	83.47	105.95	113.78

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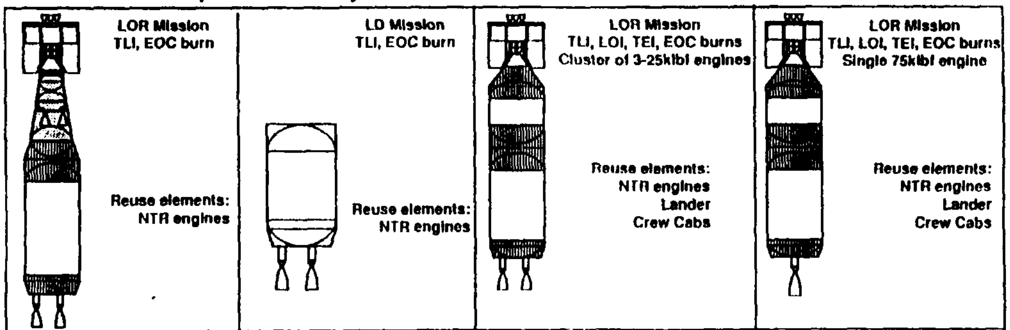
NTR Reuse Examined in Study

•Developed vehicle mass properties, payload capabilities, space operations
—2 cases consider reuse for NTR only
—2 cases consider space based fully reusable vehicles



Notes: Reusable Hardware elements designed for 5 mission
NTR returns to 500 km circular orbit between missions

•Identified infrastructure needs (assumed existing)*
—STS for crew delivery/retrieval
—SSF for refurb
—Capability for on-orbit refueling or tank exchange

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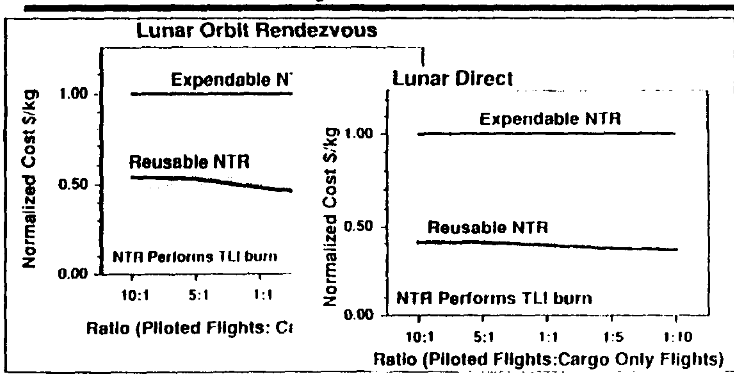
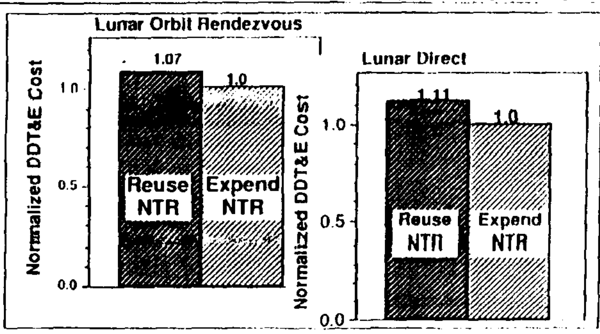
*Infrastructure costs (elements & associated operations) were not included in cost analysis

LR920819 REUSE GRD RULES2

Reuse Cost Analysis



Reuse Reduces Vehicle Recurring Cost approximately 50%



Reuse Increases Vehicle DDT&E approximately 10%

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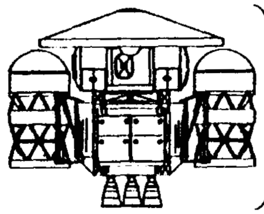
LR920818 Reuse$

NTR/Cryo Reusable System Comparison

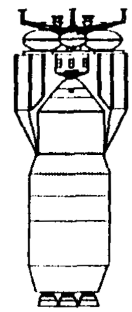
LeRC/NNTR



Space Based 90-Day Study Derived LTS

Reusable Rendezvous & Docked NTR/Cryo LTS

		MASS PROPERTIES (T)	
27.58	27.58	Dry Mass	42.90
		(NTR/TLI Stage) (Lander)	(32.60) (12.30)
251.0	174.0	Total Propellant	185.0
5.0	15.26	Piloted Cargo	14.8
283.6	217.50	TOTAL SYSTEM	242.78



Rendezvous & Docked LTS (2 135 t HLLVs)

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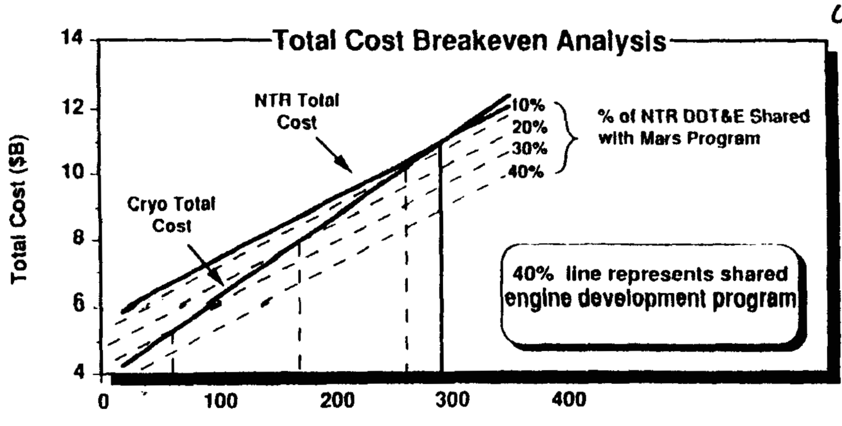
Mars Evolution Key to Affordability

LeRC/NNTR



Sharing Development Cost of Common Elements with Mars Program Lowers Total Cost of Lunar Missions

Example: Splitting the engine development cost between the lunar and Mars programs shifts breakeven point from 300 t to less than 50t

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HH921012 Mars evolution

Conclusions

- **Near term NTR Provides Feasible Alternative to Cryo system for Lunar Missions**

  -Performance
  NTR LD concept offers smaller IMLEO for same payload capability as cryo system
  NTR LOR offer greater payload delivery capability for same IMLEO
  -Cost
  NTR more cost efficient ($/kg) than cryo system
  NTR Development cost greater than cryo systems
  -Ops
  LOR option requires on-orbit cryo transfer (technology risk)

  -Schedule
  1st cargo launch capability in 2002

- **Near term NTR enable efficient evolution to Mars**

  -Cost
  Shared development cost of common elements enhances affordability
  Hardware commonality
  -Mission
  Lunar NTR adaptable to wide range of mission architectures (Direct, MOR)

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LR921009-Conclusion