TRANSPORTATION: DESTINATION MARS

Bill Eoff
NASA Marshall Space Flight Center
Exploration Transportation Office

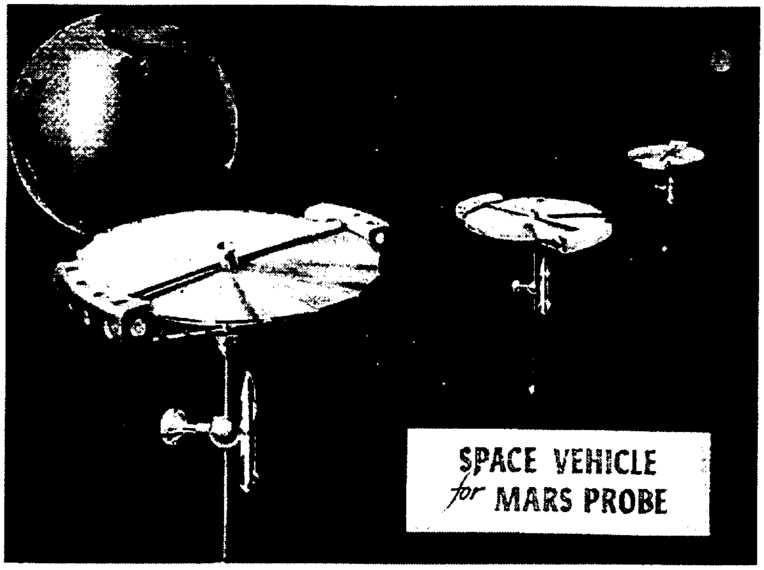
58-91
C16737

As the agency space transportation lead center, Marshall Space Flight Center has been conducting transportation assessments for future robotic and human Mars missions to identify critical technologies. Five human Mars options are currently under assessment with each option including all transportation requirements from Earth to Mars and return. The primary difference for each option is the propulsion source from Earth to Mars. In case any of the options require heavy launch capability that is not currently projected as available, an in-house study has been initiated to determine the most cost effective means of providing such launch capability. This assessment is only considering launch architectures that support the overall human Mars mission cost goal of $25B. The guidelines for the launch capability study included delivery of 80 metric ton (176 KLB) payloads, 25 feet diameter x 92 feet long, to 220 nmi orbits at 28.5 degrees. The launch vehicle concept of the study was designated "Magnum" to differentiate from prior heavy launch vehicle assessments. This assessment along with the assessment of options for all transportation phases of a Mars mission are on-going.

The Marshall Exploration Transportation Office (RA50), under Mr. Bill Eoff, is responsible for managing the Mars Transportation Study (MTS) in response to the Integrated Mars Mission Study co-chaired by Mr. Doug Cooke, Johnson Space Center and Mr. Norm Haynes, Jet Propulsion Laboratory. Ames Research Center, Kennedy Space Center, Langley Research Center, Lewis Research Center and Stennis Space Center also participant in the study.

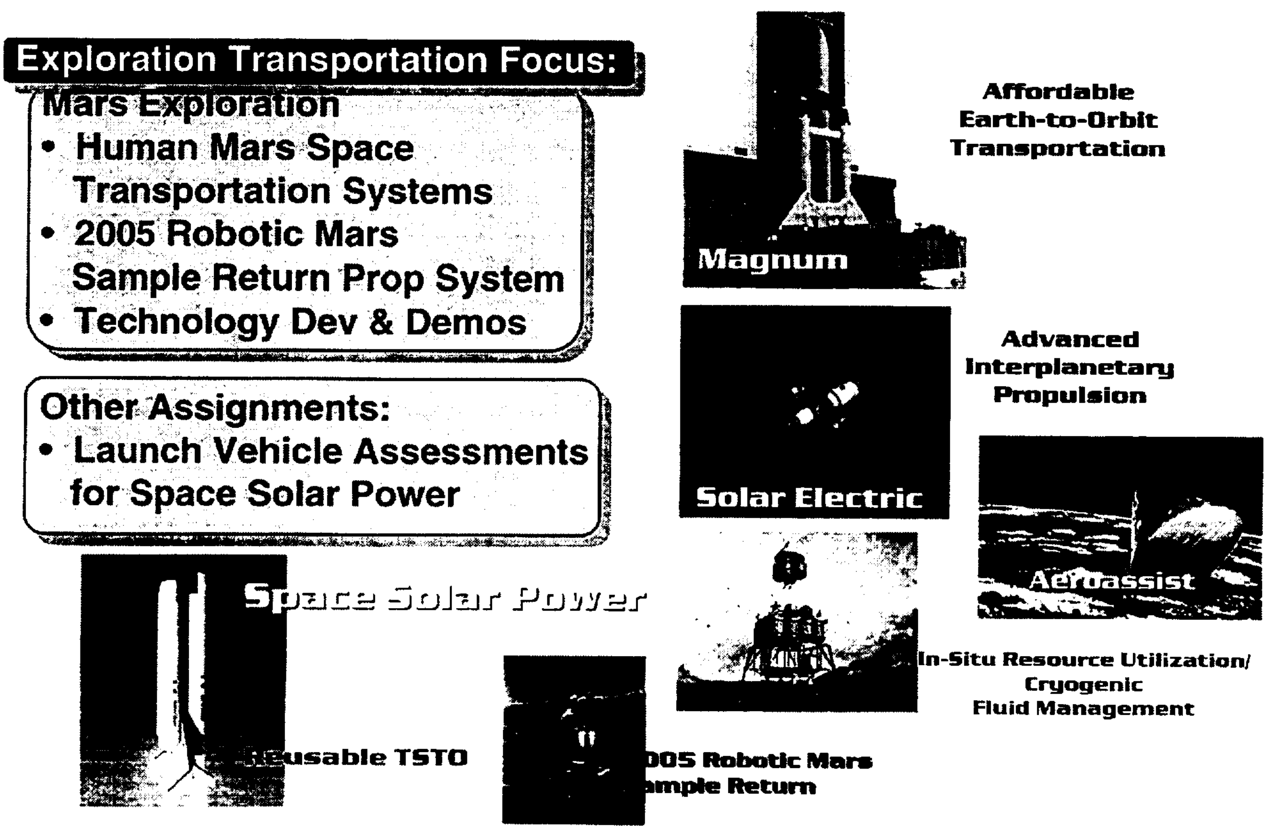
Acronyms

AGS	Advanced Grid Stiffened (Composite) Shroud
AR&C	Automatic Rendezvous & Capture
ASTP	Advanced Space Transportation Program
DDT&E	Design, Development, Test & Evaluation
DRM	(Human Mars) Design Reference Mission
EELV	(USAF) Evolved Expendable Launch Vehicle
ETO	Exploration Transportation Office
ETO	Earth to Orbit
ETP	Exploration Transportation Program
HEELV	(TRW) Highly Evolved Expendable Launch Vehicle
HLV	Heavy Lift Vehicle
HMM	Human Mars Mission
IMLEO	Initial Mass to Low Earth Orbit
ISPP	In-Situ Propellant Production
LCE	(TRW) Low Cost Engine
LFBB	(Shuttle) Liquid Fly Back Boosters
MLV	Magnum Launch Vehicle
MT	Metric Tons
RLV	Reusable Launch Vehicle
SDV	Shuttle Derived Vehicle
SPS	Solar Power Satellite
SSP	Space Solar Power Program
STP	Space Transportation Programs
TBCC	Turbine Based Combined Cycle
TMI	Trans-Mars Insertion
TSTO	Two Stage To Orbit

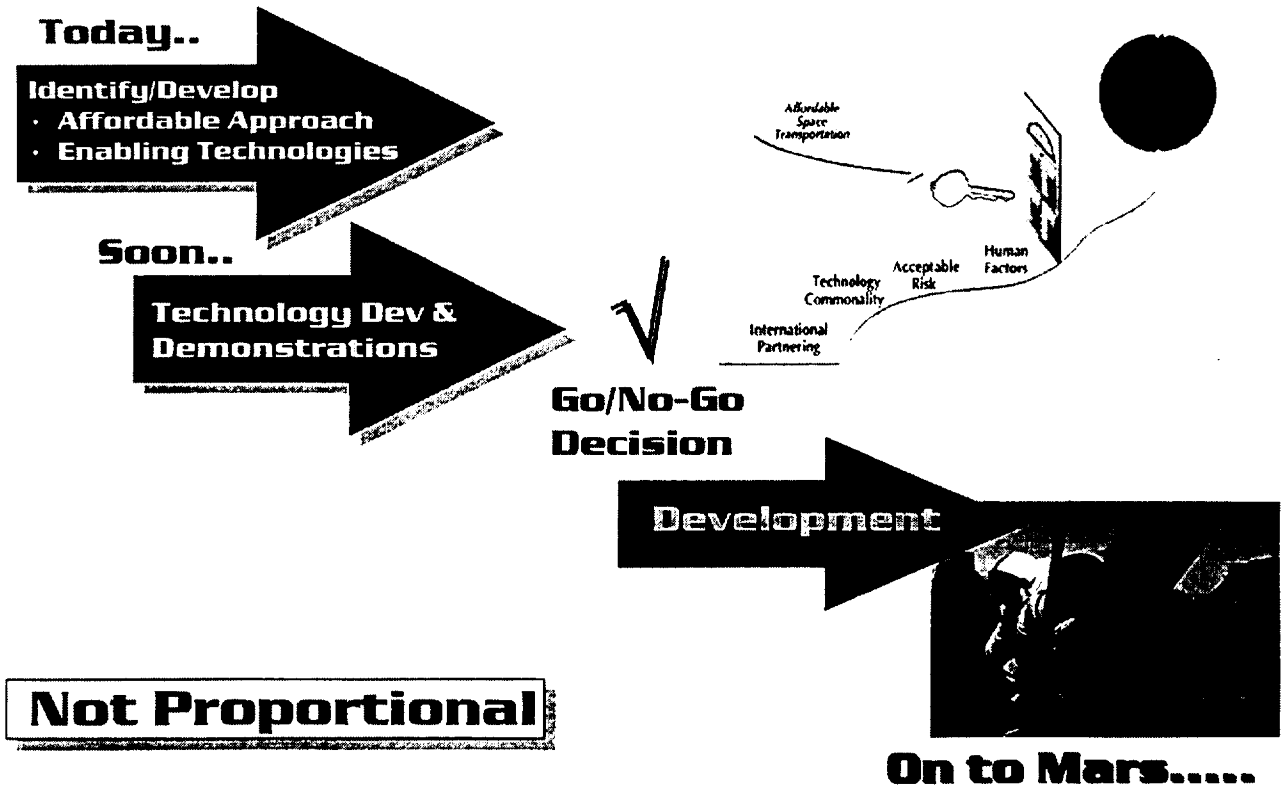


Von Braun proposed a human Mars mission in his 1953 book, the "Mars Project," with ten ships, a crew of seventy and 5.3 million metric tons of fuel.

Exploration Transportation

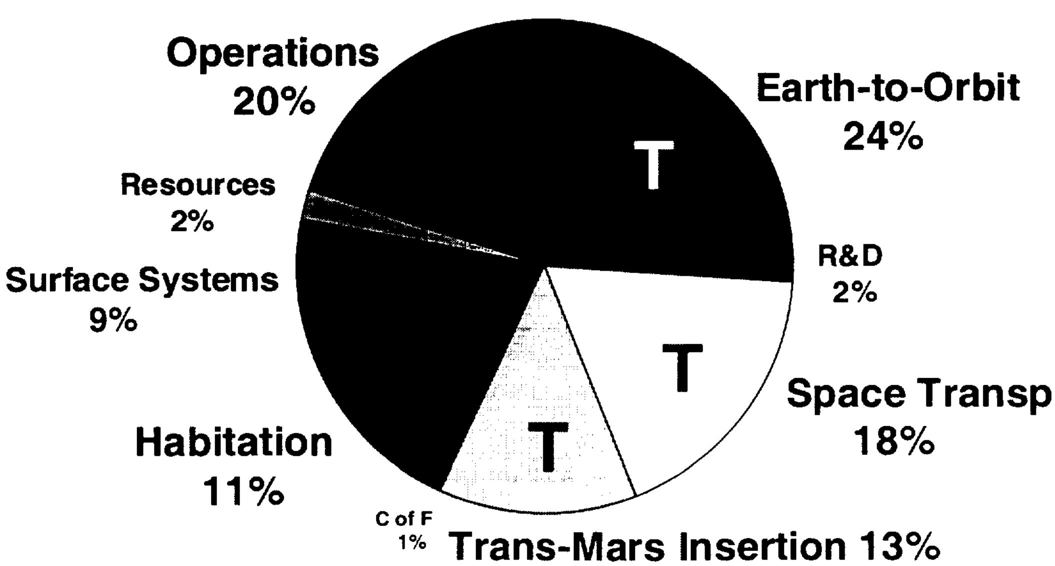


Exploration Transportation



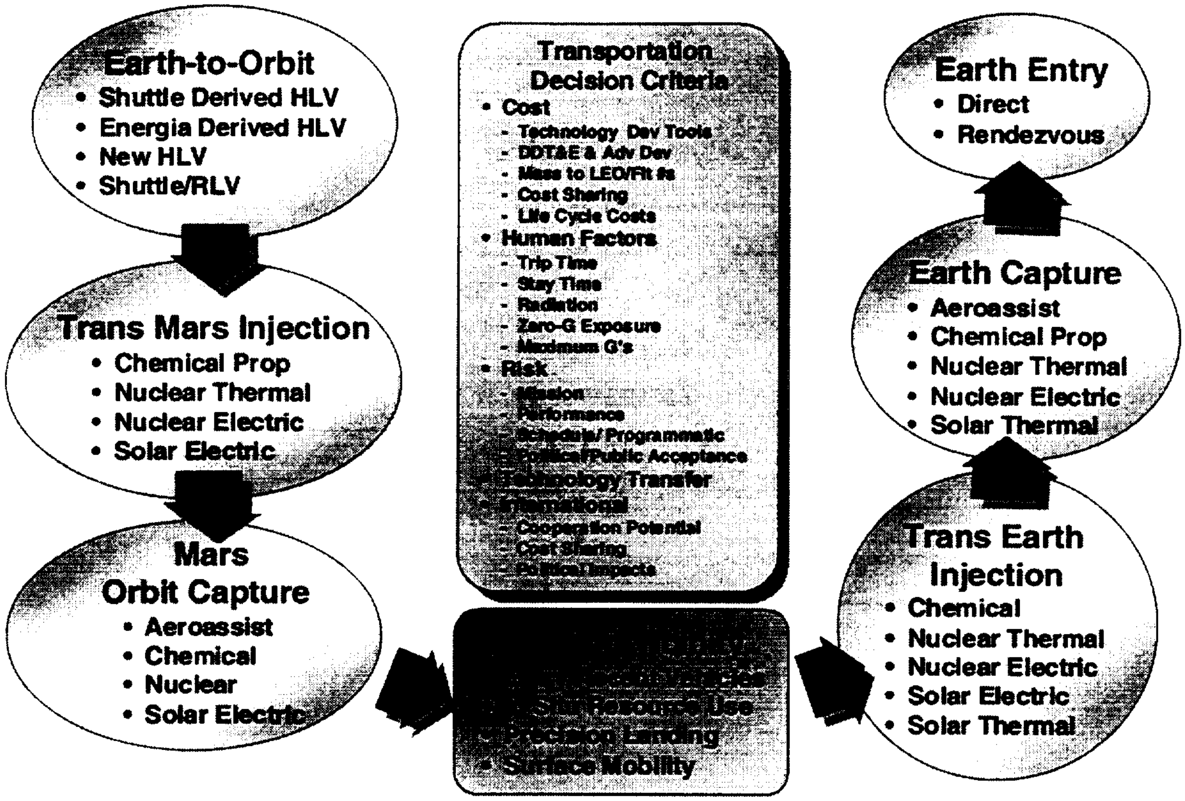
Why Invest in Transportation Technologies?

- Transportation Historically Accounts for >50% Of Exploration Mission Costs.
- Space Transportation Costs Must Be Reduced to Make Exploration Affordable.
- Transportation Technology Investments Are Required to Reduce Costs.



Human Mars Exploration Costs- DRM

Human Mars Mission
Transportation Architecture Options

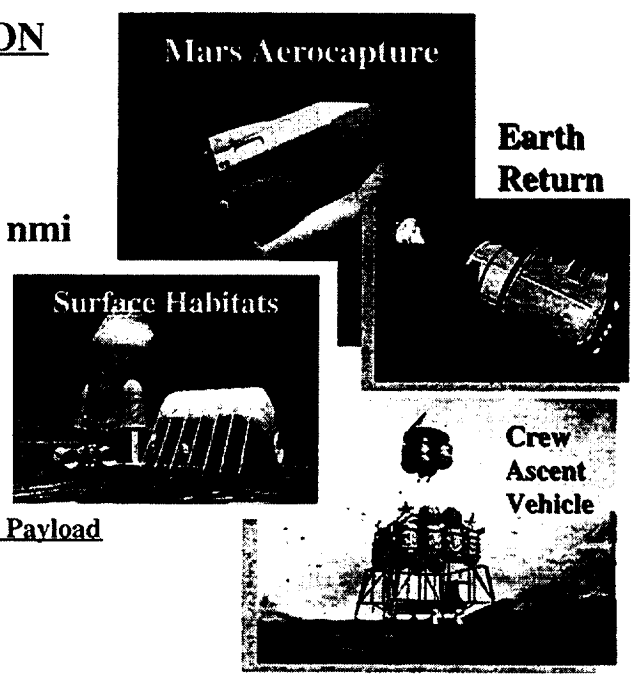


Human Mars Payload Requirements

<u>DESIGN REFERENCE MISSION</u>

- P/L Diameter: 7.5 m/ 24.8 ft
- P/L Length: 27.7 m/ 91.4 ft
- P/L weight: 80 MT/ 176 Klb
- Assembly Orbit: 407 km/ 220 nmi
  28.5 degrees
- Launch Rate: 6/ year

HMM ETO Costs Driven by:
- Mass Required in Earth Orbit
- Launch Costs



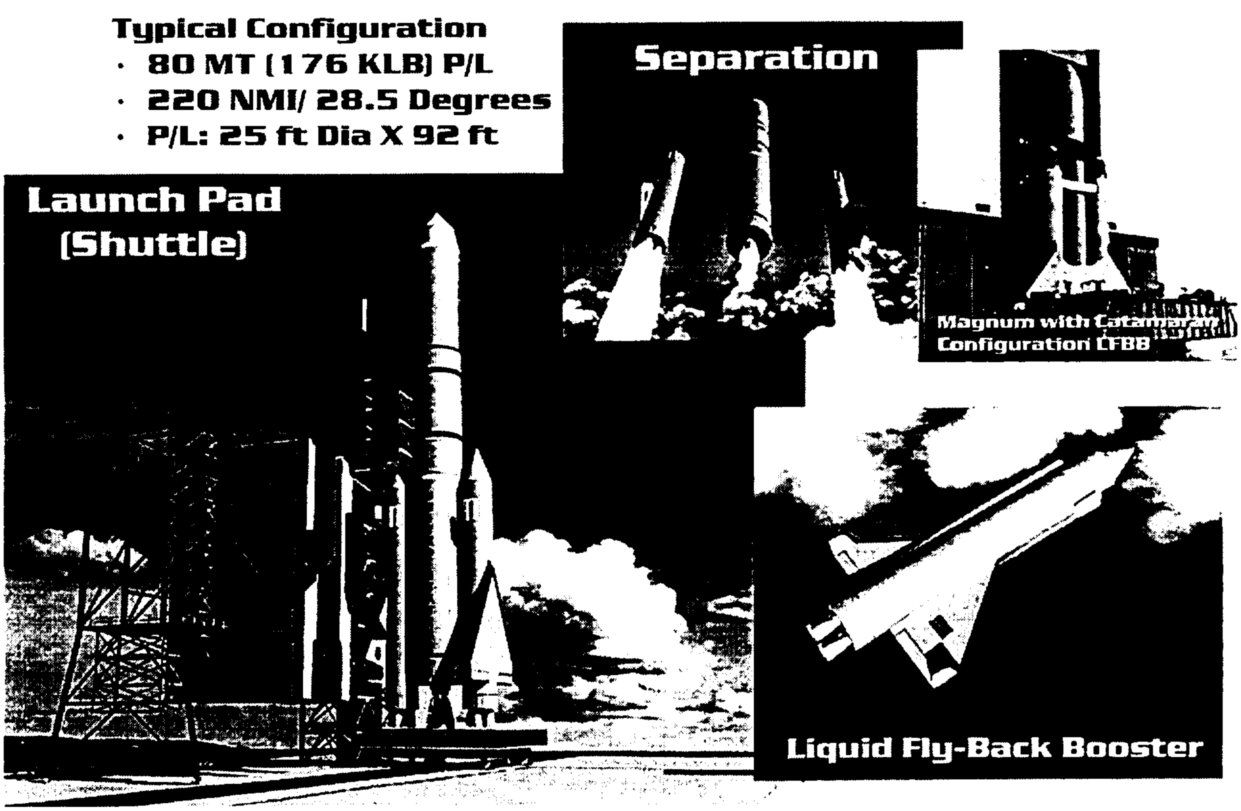
IMLEO (Initial Mass to LEO)		Launch Vehicle Payload
89' 90-Day Study	850 MT	250 MT
93'/94' DRM	850 MT	217 MT
96' DRM	660 MT	100 MT
97' DRM	431 MT	80 MT

200-300 MT → **Affordable Launch Costs**

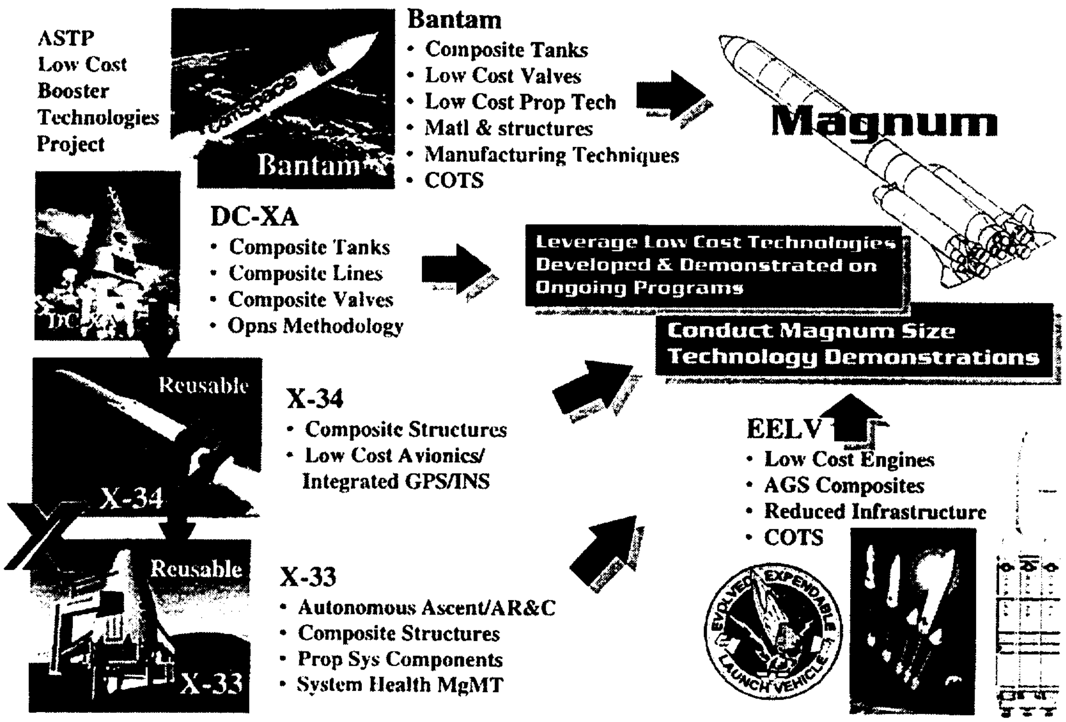
Affordable Earth-to-Orbit Transportation

- Need: Minimize Total Transportation Costs Including In-Space Assembly and Checkout.
- Exploration ETO Could Be Accomplished With RLV/Shuttle; However, Costs of Launch/In-Space Assembly and Checkout Would Be Prohibitive (30+ Launches and Associated Assembly/Checkout Per Human Landing).
- Approach: Each Mars Payload Launched in Two 80 Metric Ton Pieces.
  - Pieces Automatically Assembled On-Orbit.
  - Design Reference Mission Requires 6 to 7 Launches of 80 MT Vehicle for First Humans to Mars.
    - Two Payloads (4 ETO Launches) Required During the First Opportunity (Human Support Cargo/ ISRU).
    - One Payload (2 ETO Launches) Required During the Second Opportunity (Humans).
- Cost Bogey for ETO: $3B to $6B for First Human Landing
  - Technology Investment
  - DDT&E
  - Flight Hardware and Integration
  - Launch Facilities and Operations

Magnum Concept

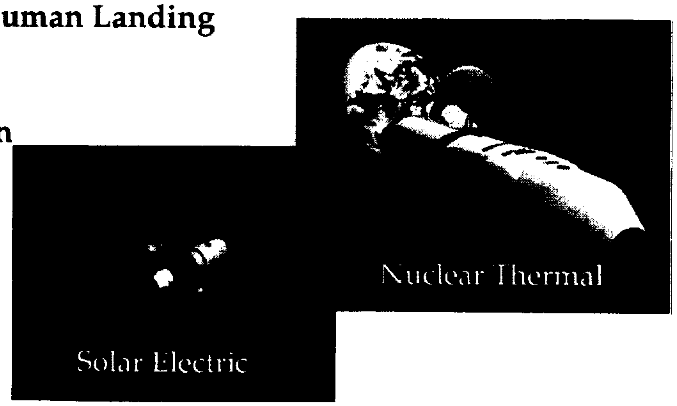


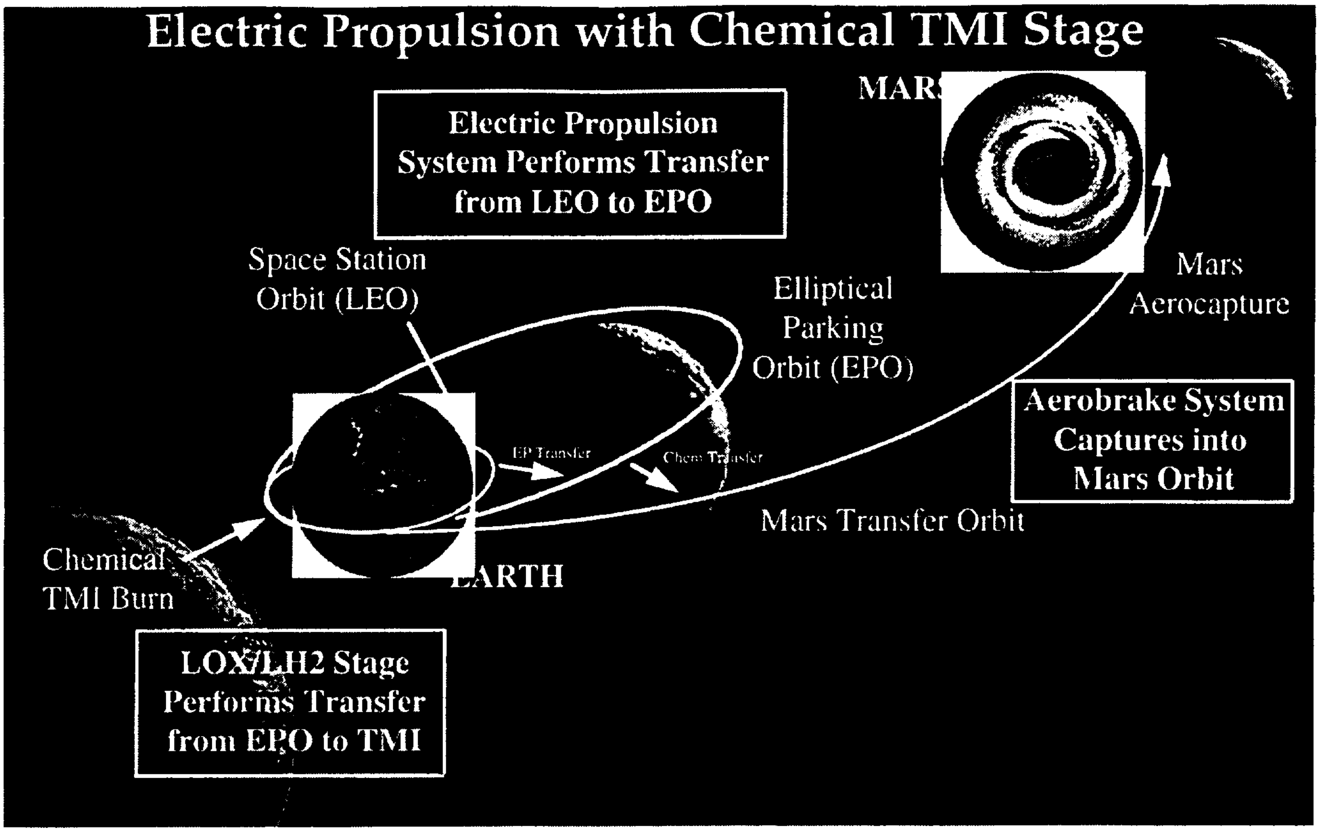
Magnum Applied Technologies



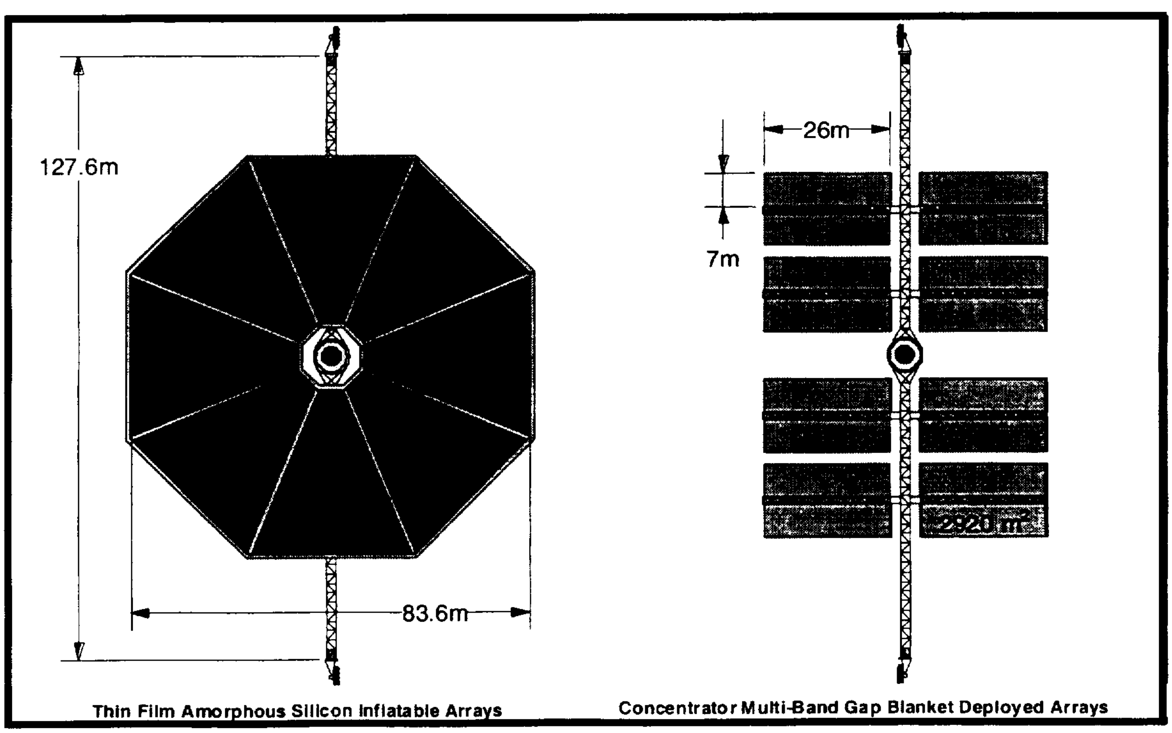
Advanced Interplanetary Propulsion

- Needs:
  - Minimize Total Transportation Costs
  - Develop Affordable Option for Non-Nuclear In-Space Transportation
- Approach:
  - Parallel Nuclear Thermal and Solar Electric Technologies for Trans-Mars Injection (TMI).
    - Downselect by End of 2001
    - Nuclear Thermal Focused on Fuels Improvements, Components, and Test Capability.
    - Solar Electric Focused on High Power Thruster, Components, and Test Capability.
  - Decent/Ascent Focused on Research to Support Use of In-Situ Resource Products.
- Cost Bogey for TIM: <$3B for First Human Landing
  - Technology Investment
  - DDT&E
  - Flight Hardware and Integration
  - Launch Processing



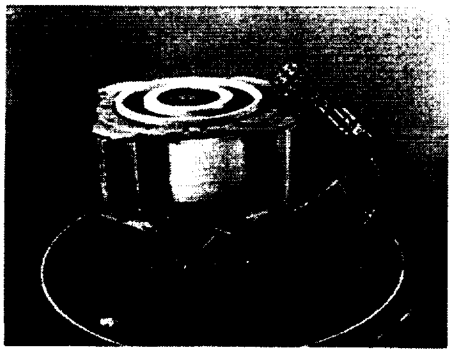


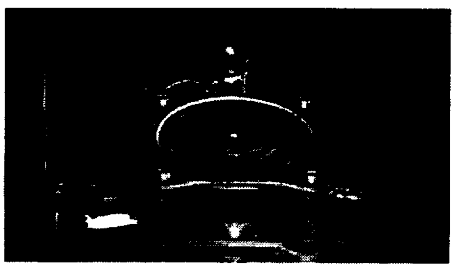
Solar Electric Transfer Vehicle Concepts



Electric Propulsion Technology for TMI

Small Russian Hall Thrusters
(1.5 to 4.5 Kw)





High Power Electric Propulsion for Exploration
(50 to 100 Kw)

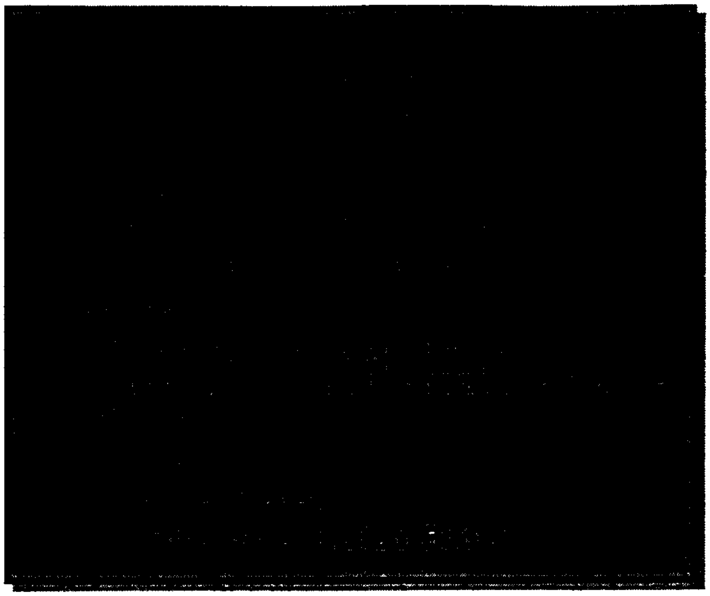
- High Power Hall Thrusters
  - 25 Kw Russian Thruster Tested and Evaluated
  - 50 Kw Breadboard Using American Technologies
  - 100 Kw Prototype unit
- Power Processing Technologies
  - Light Weight
  - Efficient
- Tankage and Feed System Technologies

Trans-Mars Insertion Option

Nuclear Thermal Propulsion Technology

- Fuel Development, Test and Validation for High Performance Bimodal Operation
- Effluent Treatment for Environmentally Acceptable Ground Test Capability
- Low Cost Component Technologies
- Materials Technologies
- Health Management and Instrumentation Technologies

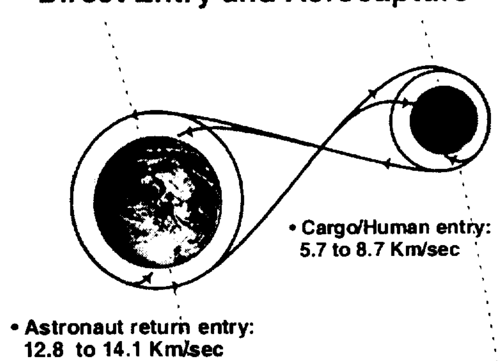
Aeroassist



Mars Exploration Program
Aeroassist Benefits & Requirements

Direct Entry and Aerocapture

DRM Requirements & Goals
- Fast human transit drives entry speeds
- 15% mass fractions
- Minimal EVA Assy
- L/D for precision landing
- Biconic/"new" shape



- Aeroassist significantly reduces system complexity and mass of propulsion systems.
- Reductions in mass of vehicles -> Reduced launch requirements or direct increase in payload e.g.., 40 % reductions in IMLEO for Human mission assuming chemical propulsion.
- Aerocapture at Mars gives options for precision landing with reduced entry errors, entry in daylight conditions, or entry after an unexpected dust storm.

Aeroassist Technology
Investment Returns

Aerothermodynamics: Prediction of flowfield surrounding entry vehicle to determine aerodynamic forces and surface heating conditions.

Impact: Reduce uncertainties -> smaller safety factors -> mass & cost decrease

TPS: Protective material system surrounding entry vehicle, designed to maintain specified spacecraft structure and payload temperatures.

Impact: Lightweight TPS -> Smaller launch vehicle & useful payload mass increase

GN&C: Actively control vehicle attitude and trajectory during entry

Impact: Enables precision landing and aerocapture missions

Vehicle Design: Optimized integration of entry vehicle systems to meet mission requirements

Impact: Drives technology focus & assures project goals are met. Allows design problems to surface before Phase C/D

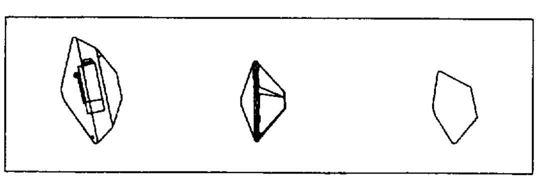
Investment in Aeroassist Technology will enable exciting planetary missions, allow for larger payloads, and use smaller launch vehicles. It will enable HEDS exploration of of Planetary Bodies with Atmosphere.

"Better, Faster Cheaper"

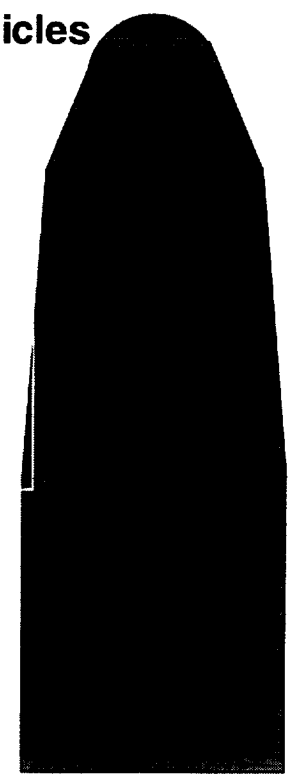
Comparison of Mars Entry Vehicles

	Viking	Pathfinder	Mars 2001	HEDS Biconic
$V_{e,rel}$ (km/s)	4.5	7.65	6.52	5.7 - 8.4
Diameter (m)	3.5	2.65	2.4	8.6
m_e (kg)	981	603	450	65000
Q_o (J/cm²)*	~1000	~4000	~7000	50000 (est)
q_{max} (W/cm²) *	25	100	60	1000 (est)

* non-ablating conditions



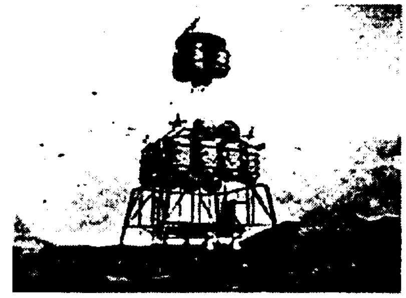
Viking Mars Pathfinder Mars 2001



HEDS Biconic

Concerned NASA technologist

In-Situ Resource Utilization



- Needs:
  - Minimize Total Transportation Costs
  - Develop Affordable Options for In-Situ Propellant Production (ISPP) from Mars Resources
- HEDS Approach:
  - Integrated Technology Program Addressing Needs of Human Missions
  - Phased Precursor Demonstrations of ISPP on Robotic Missions (Under Review)
    - 2001: Component Experiments
    - 2003: Small Oxygen Production Capability
    - 2005: BYOP Mars Sample Return Using Cryogenic Oxygen (Fuel is TBD)
    - 2007: Mars Sample Return Using ISPP to Provide Ascent Stage Propellants

Cryogenic Fluid Management

- Needs:
  - Minimize Total Transportation Costs
  - Cryogenic Fluid Storage for Long Periods In-Space and on the Martian Surface
  - ISPP Product Liquification, Transfer, and Storage
  - Minimum Propellant Boiloff Losses (Goal is Zero Boiloff)
- HEDS Approach:
  - Integrated Technology Program Addressing Needs of Human Missions as Part of ASTP CFM Program (STT Project)
  - Phased Precursor Demonstrations of Mars Surface Liquifaction, Transfer and Storage on Robotic Missions
    - 2003: Small Oxygen Production Capability
    - 2005: BYOP Mars Sample Return Using Cryogenic Oxygen (Fuel is TBD)
    - 2007: Mars Sample Return Using ISPP to Provide Ascent Stage Propellants

    (Note: JPL Carrying Parallel Code S Funded Propulsion Technology Development for Hypergolic Propellant; Downselect in 2000)

Cryo Fluid Management

Mars Human Mission Cryogen Storage Requirements

Mission Phase	Liquid Propellant	Quantity (Mg/m^3)	Temperature	Days of Operation	Operating Environments
TMI	H_2	60/850	20	150	Earth launch, 0-g, TMI burn
Descent	O_2 CH_2	16/14 4.6/11	90 112	500	Earth launch, TMI burn, 0-g, aerocapture, descent
ISRU seed	H_2	4.5/65	20	560	Earth launch, TMI burn, 0-g, aerocapture, descent, Mars surface
ISRU	O_2 CH_4	30.5/27 7.6/18	90 112	1200	Mars surface
Ascent	O_2 CH_4	30.5/27 7.6/18	90 112	1200	Mars surface, ascent
TEI	O_2 CH_4	25/22 7.2/17	90 112	1700	Earth launch, TMI burn, 0-g, aerocapture, TEI burn

Transportation Technology Challenges

Affordable Earth-to-Orbit Transportation

- **Low Cost Technologies Scaled to Large Launcher**
  - Tanks & Structures
  - Propulsion Systems
  - Shrouds
  - Upper Stages
- **Accommodate large-volume payload requirements**
- **Minimum on-orbit assembly costs**
- **Minimum impact to launch facilities**

Advanced Interplanetary Propulsion

- **All Chemical Propulsion Option**
- **Solar Electric Propulsion Option**
- **Nuclear-Thermal Option**
- **Ascent & Descent Propulsion**

Cryogenic Fluids Management

- **Long-Term (1700 days) Cryogenic Fluid Storage**
- **Cryogenic Liquefaction of In-Situ Propellants**
- **Cryogenic Refrigeration**
- **Zero-G Fluid Management**

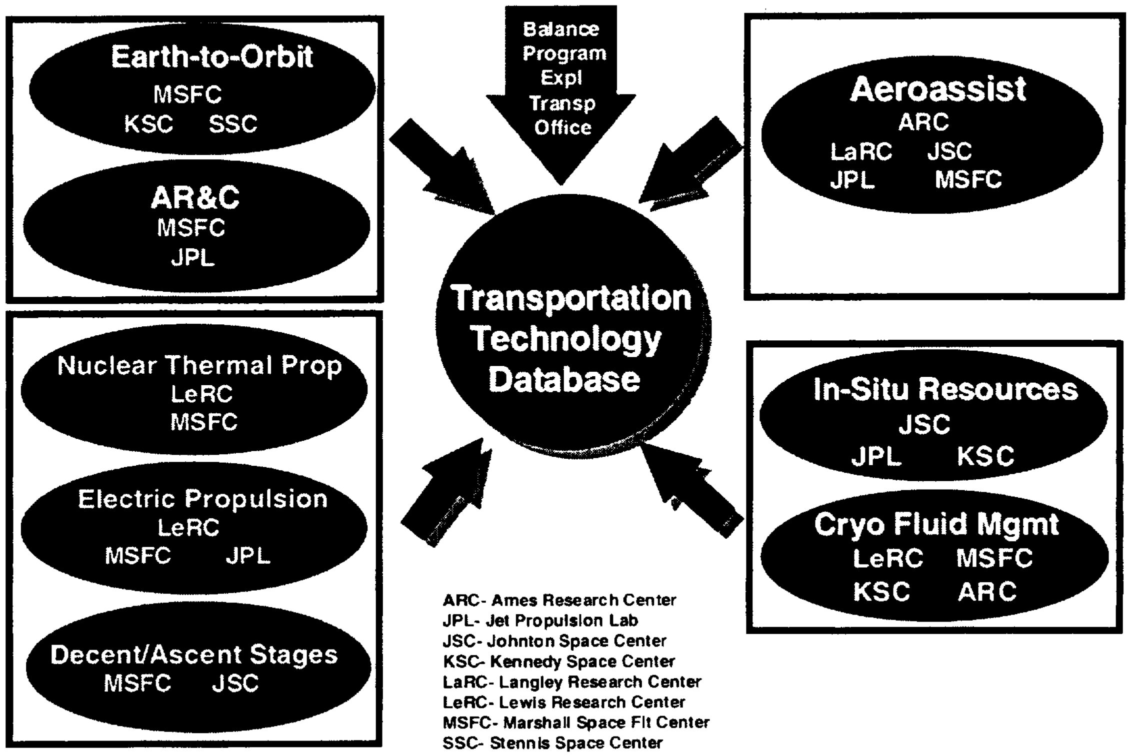
Aeroassist

- **Earth/Mars Orbital Insertion & Direct Entry**
- **Advanced Thermal Protection Systems**
- **Mars Atmospheric Modeling**
- **Guidance & Navigation for Precision Landing & Aerocapture**

In-Situ Resource Utilization

- **Propellant Production from Mars Atmosphere**
- **Human Mars Ascent Propellant**
- **Mars Sample Return Using In-Situ Resources**
- **Lunar Demonstration from Soil**

Exploration Transportation Technology Definition



Transportation Summary

- Human Exploration Is a Key Part of the NASA Strategic Plan
- Transportation Technology Development Is Required for Affordable Human Exploration
- Transportation Technologies Defined by Multi-Center Teams of Technical Experts
  - Anchored by Transportation Architecture Systems Analyses
  - Requirements and Goals Established to Guide Technology Definition
- Exploration Transportation Technology Update to be Performed as a Part of Budget Submission