CYCLIC VISITS TO MARS VIA ASTRONAUT HOTELS
OR
THE INTERPLANETARY RAPID TRANSIT (IRT) SYSTEM

Presentation to the
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Lunar and Planetary Institute, Houston TX

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The Interplanetary Rapid Transit (IRT) System

TOPICS

• Phase II Contributors
• Interplanetary Rapid Transit System (IRT) Concept Overview
• Visions, Goals, Assumptions, and Realities
• Orbital Tracks and Space Lines
• Using the Atmosphere To Put The Brakes On
• Taxi, Shuttle, Transport Hubs, and Hotel Design Concepts
• Example Transit Schedule
• Turning Planet Dirt Into Rocket Fuel and Other Useful Things
• Technologies To Build Upon
• What’s The Best Architecture and How Much Will It Cost?
• Summary
The Interplanetary Rapid Transit (IRT) System

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INTERPLANETARY RAPID TRANSIT (IRT) SYSTEM CONCEPT
# Mars Base Systems

<table>
<thead>
<tr>
<th>System</th>
<th># of Units</th>
<th>Unit Mass, mt</th>
<th>Total Mass, mt</th>
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<tr>
<td><strong>Life Critical Systems</strong></td>
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<tr>
<td>Habitat</td>
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<td>38.5</td>
<td>154.0</td>
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<tr>
<td>Washdown facility</td>
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<td>1.8</td>
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<td><strong>Mission Support Systems</strong></td>
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<td>120 kW Power Source (solar array @100W/kg)</td>
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<td>1.2</td>
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<td>Power Management, Distribution and Maintenance</td>
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<td>0.6</td>
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<td>Energy Storage (NRFC packages)</td>
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<td>1.1</td>
<td>2.2</td>
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<tr>
<td>Suitup/Maintenance Facility</td>
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<td>1.8</td>
<td>3.6</td>
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<tr>
<td>Pressurized Transporter</td>
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<td>9.1</td>
<td>27.3</td>
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<tr>
<td>Open Rovers</td>
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<td>1.0</td>
<td>3.0</td>
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<td>Inflatable Shelter w/Airlock</td>
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<td>0.5</td>
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<tr>
<td>Communication Satellites</td>
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<td>0.8</td>
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<td>Crane</td>
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<tr>
<td>Trailer</td>
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<td><strong>Science and Exploration Systems</strong></td>
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<tr>
<td>Mobile Laboratory</td>
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<td>200 m Drill</td>
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<td>UAV</td>
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<td>Robotic Rovers</td>
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<td>Weather Station</td>
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<td>1.0</td>
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<td>Survey Orbiters</td>
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<td>1.6</td>
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<td><strong>Total</strong></td>
<td></td>
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<td>278.9</td>
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</table>
VISIONS, GOALS, ASSUMPTIONS AND REALITIES
A VISION OF THE FUTURE

• Permanent inhabitation of Mars by scientists and explorers occurs as quickly as financially feasible

• Earth-Mars transit system is created providing safe, frequent and affordable travel

• Reduced reliance on Earth for space activities

• Pathways are opened for exploration beyond Mars
SUGGESTED DEVELOPMENT GOALS OF A FUTURE TRANSIT SYSTEM

• Demonstrate physiologically feasible travel to and from Mars (zero-g, radiation protection)
• Minimize transit system life cycle costs
• Maximize use of natural resources
• Establish context for future human space exploration and development, space technology advance, and robotic missions
• Incorporate advanced technology to lower costs and make trips safer
KEY ARCHITECTURE STUDY ASSUMPTIONS

• Sustained Mars Base of 20 people that is self sufficient except for hardware
• Earth launch costs are $2,000 per kg to low Earth orbit
• Use solar energy for space and surface power
• Use space resources to make rocket fuels
• Use currently and clearly foreseeable technologies
• Transport crews and cargo in efficient steps with specialized vehicles
• An Earth-Mars transportation system will be expensive and will require
  – imagination to minimize costs,
  – significant and sustained political leadership and
  – international collaboration

• If used, space nuclear reactor system costs will be very expensive without DOD and/or commercial applications

• Launch costs will be an order of magnitude less when they are
ORBITAL TRACKS AND SPACE LINES
The Interplanetary Rapid Transit (IRT) System

CYCLIC ORBIT OPTIONS

Low-thrust Aldrin Cyclers

- Up and Down Cyclers, two Astrotels
- Gravity assist to rotate orbits to achieve 15-year repeating sequence
- Low-thrust guidance maneuvers
- 5 month trips to and from Mars
- High Taxi ΔV to leave Mars

Semi-Cyclers

- Three Astrotels on 78 month trips between Mars arrival and departure
- High-thrust Mars escape / capture
- Five Earth flybys between Mars departure and arrival
- 6 month crew trips to / from Mars
- 1.5 year Astrotel stay time at Mars

Stopover Cyclers

- Two Astrotels on near-minimum energy orbits
- Stops at Earth and Mars
- High-thrust escape/capture
- 4-7 month trips depending on opportunity and fuel loading
- 1.5 year Astrotel stay time at Mars
The Interplanetary Rapid Transit (IRT) System

HYPERBOLIC RENDEZVOUS TRAJECTORY GEOMETRY

Spaceport Position (3 Burn)

Planet

ΔV₁

ΔV₂

ΔV₃

Rendezvous

Astrotel Trajectory

Spaceport Position (4 Burn)

Spaceport Position (2 Burn)

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KTN - Annual Meeting - June 12, 2002
USING THE ATMOSPHERE TO PUT THE BRAKES ON
The Interplanetary Rapid Transit (IRT) System

MARS AEROCAPTURE PROFILE

Entry
V = 11.5 km/s
\( \gamma = -10 \),
\( \alpha = -20^\circ \)

Entry Interface 125 km
Roll to modulate lift

Begin Aero-Cruise

In Orbit
V_{exit} = 4.4 km/s

Roll to reduce lift to exit

50-60 km Altitude

Scale Exaggerated

Aerocapture at Mars saves about 83 mt of fuel
10 crew, Earth / Mars aerocapture, 12 m diameter aeroshell (Elliptical Raked Cone), 16.1 mt vehicle dry
The Interplanetary Rapid Transit (IRT) System

**TAXI AEROCAPTURE G-LOAD**

- Taz’s Texas Tornado, 6-Flags, TX, 6.5 g
- Face/Off, King’s Is. OH, 5.0
- Revolution, 6-Flags, CA, 4.9 g
- Great White, Sea World, TX, 4.6 g
- Space Shuttle, 3.0 g
TAXI, SHUTTLE, TRANSPORT HUBS, AND HOTEL DESIGN CONCEPTS
KEY FEATURES

- Supports crew of 10 for 7 days
- Apollo accommodations
- G-aligned crew hammocks
- 7.2 mt including life support and power
- Taxi and Mars Shuttle vehicle versions
  - Mars Shuttle: No radiation shielding and minimal energy storage for <3 hour flights, add second airlock for Mars surface access
  - Taxi: Energy storage for 7 days, minimal radiation shield, single airlock
TAXI CONCEPT: LEAVING EARTH SPACEPORT

Crew Module

H₂ Propellant Tanks

Rocket Engines (Advanced RL-10 type, Extended Nozzle)

Taxi Dry Mass: 16.1 mt
Ion Engines
(Eight, 50 cm, 17 kW, 5000s)

Solar Array
(160 kW)

Cargo Pod

Hab Module

Astrotel Mass: 69.1 mt

TAXI DOCKING TO ASTROTEL
MARS SHUTTLE AT ENTRY

KEY FEATURES
- 10 crew
- Direct entry from Phobos orbit
- 10 mt cargo
- 17.9 mt vehicle (dry)

AEROBRAKE DESIGN
- 20 m diameter, Viking aeroshell shape, open back
- 30 deployable and stowable segments
- Al structure & honeycomb substrate, STS-type TPS
- Deployed at the Mars Spaceport
- Stowed before departure from Mars surface
MARS SHUTTLE LANDING
MARS SHUTTLE AFTER LAUNCH

Stowed Aerobrake

3 Rocket Engines
(Adv. RL-10 type, 2 req.)
The Interplanetary Rapid Transit (IRT) System

KEY ADVANTAGES OF ALDRIN CYCLERS

• Astrotels can take advantage of ion propulsions system (IPS) technology
• Astrotels never stop
• With IPS, one can incrementally increase the Astrotel capability over time with very little propulsion cost
  – Increase radiation shielding thickness
  – Incorporate artificial gravity if needed
  – Add redundant Taxi and/or escape vehicles
  – Grow a cache of repair hardware, propellants and consumables
TURNING PLANET DIRT INTO ROCKET FUEL AND OTHER USEFUL THINGS
TURNING NATURAL RESOURCES INTO ROCKET FUEL

- Moon --> Water from Polar ice
- Phobos --> $O_2$-bearing regolith
- Mars Surface --> Water-bearing regolith
- Spaceports --> Electrolysis of water to and/or storage of LH and LOX using solar energy
The Interplanetary Rapid Transit (IRT) System

**SPACE RESOURCE PROPELLANT PRODUCTION SYSTEMS**

**Excavator**
- Bucket wheel
- Scraper

**Transporter**
- Integrated with excavator
- Separate vehicle

**Reactor**
- Thermal extraction
- Carbothermal reactor
- Electrolysis
- Liquefaction

**Storage**
- Cryogenic
- Transfer

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The Interplanetary Rapid Transit (IRT) System

PHOBOS/MARS BUCKET WHEEL EXCAVATOR SYSTEM DEVELOPMENT

Resultant Forces on Excavator
- Horizontally along the boom axis
- Vertically downward toward the ground.
MARS PROPELLANT PRODUCTION AND STORAGE FACILITY CONCEPT

1: Water Docking Port
2: Human (For Scale)
3: Water Storage Tank
4: Electrolyzer/Dryers & Dryer Radiators
5: Solar Arrays
6: Liquifiers & Radiators
7: LH Tank
8: LOX Tank & Docking Port

SCALE
2 meters (Approximate)

Mars Surface Cryogenic Propellant Depot

LLJ-9/01
TECHNOLOGIES TO BUILD UPON
TECHNOLOGIES TO BUILD UPON

- Human physiology and life support in space
- Automation and robotics
- Assembly and operations in space
- Aero-assist
- Ion propulsion systems
- Space resource mining, processing and manufacture
- Photovoltaic energy generation
- Fuel cell energy storage
- High-strength, lightweight structures
- Advanced Computers
- High-bandwidth interplanetary communications
WHAT'S THE BEST IRT DESIGN AND HOW MUCH WILL IT COST?
MISSION ARCHITECTURE MODEL AND ANALYZER (MAMA) DESCRIPTION

• MAMA is a tool to support trade study analyses of Mars Astrotel Concepts

• MAMA integrates multiple lower-level models enabling assessment of technology selection-definition impacts on an overall Mars Astrotel scenario’s life cycle requirements

• MAMA maintains a database of past runs to allow comparison of features from different Astrotel scenarios

• MAMA will use a multi-level approach for collecting inputs

MAMA is better for comparing different options than generating absolute cost estimates
### Transportation Systems and Orbital Elements Outputs

#### Chart Outputs

<table>
<thead>
<tr>
<th>LUNAR/MARS BASES &amp; ISRU TANKERS</th>
<th>IN SITU RESOURCE UTILIZATION (ISRU) SYSTEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEST CONCEPT 1A</td>
<td></td>
</tr>
</tbody>
</table>

#### WBS Elements & Life Cycle Costs

- Master Equipment List
- ASSAULT维修
- Life Cycle Costs
- Flight System Development Costs
- Refurb HW Costs
- Initial HW Masses
- Refurb HW Masses

#### Delta-Y

\[
m_y = (MFX + C^*m_y^*MF3)^*MF1(A^*(1-MF1)+B^*MF1-C^*MF3+1)
\]

\[
m_y = m_y^*MF3/MF+m_y^*MF3
\]

- Mass of Propellant required at Mars every cycle (2.1/7 years)
- Total Mass of Propellant required at Mars for 15 year Cycle

- Mass of Propellant required at Phobos every cycle (2.1/7 years)
- Total Mass of Propellant required at Phobos for 15 year Cycle

#### MAMA Inputs and System Elements
The Interplanetary Rapid Transit (IRT) System

MAMA LIFE CYCLE COST OUTPUT

- Development & Launch
  - Adv Tech Dev
  - Adv Tech Testing
  - Flight System Design
  - Flight Subsys Fab
  - System Assy, Integ, Test
  - LV Ground Facility Proc
- Operations
  - Launch & Checkout
  - Orbital Assy, I&T
  - Startup Ops
  - SS Ops
  - Refurbishment Hardware
  - Disposal

* 15 Years

[$M$]
SUMMARY OF EARLY, ROUGH MAMA COST ESTIMATES

Development: ~$5B/yr for 10 years
Operations: ~$3B/yr

Assumes:
- Advanced Technology Development
- Flight System Development
- Launch (specific launch vehicle cost of $2000/kg)
- Operations (includes repair, refurbish, upgrade hardware & propellants/consumables)
- FY 2000 dollars
Select Architecture
- Low thrust Aldrin
- Semi Cycler
- Stopover

MAMA provides defaults for all inputs

View Results
- Details for Current Architecture Scenario
- Comparison of Multiple Scenarios from MAMA Database

Modify Level 1 Defaults
Sample Input Categories:
- NODES
  - Transportation Nodes
  - Transportation Node Locations
- ISRU
  - ISRU Propellant Production
  - Lunar Hydrogen?
  - Lunar ISRU Location
  - Phobos Water or Oxygen?
- Mars Surface Water?
- Mars ISRU Location
- Orbital Propellant Depot(s)
- INTER-NODE TRANSPORT
  - Earth/LEO
  - LEO/Earth Spaceport
  - Lunar ISRU/Earth Spaceport
  - Phobos ISRU/Mars Propellant Depot
  - Earth Spaceport/Astrotel
  - Mars Spaceport/Astrotel
  - Mars Spaceport/Mars Surface
  - Earth Spaceport/Earth Surface
- POWER GENERATION & ENERGY STORAGE
  - Large Surface Systems
  - Mobile Surface Systems
  - Space (zero-g) Systems
- PROPULSION
  - Ion Systems
  - LOX/LH2 Systems
  - Nuclear Thermal
  - Others(?)
- CREW ACCOMMODATION
  - Radiation Shielding
  - Artificial Gravity
  - Air/Water
  - Food
  - Crew Volume
  - Habitation Module
- AERO-ASSIST
  - Aeroshell Shape
  - Structure/TPS

Modify Lower-Level Inputs
- Provides visibility to lower-level model inputs and allows modification of selected inputs
- For more experienced users only
POSSIBLE MAMA STUDIES

- Different cyclic orbit options
- Alternative transportation nodes
- Solar vs nuclear reactor power
- No use of natural space resources
- Higher/lower launch costs
- ISRU aerobrakes
- Impact of cyclic orbit option on increased Astrotel mass for artificial gravity, increased radiation shielding, hardware & consumable reserves
SUMMARY
The Interplanetary Rapid Transit (IRT) System

SUMMARY

• The Astrotel interplanetary rapid transit system architecture:
  – Is cost effective because it reuses transit system elements
  – Uses natural space resources to produce low-cost propellants
  – Enhances human health and performance due to short trips
  – With Aldrin cyclers, can easily expand Astrotel to enhance system, and
  – Can rely entirely on solar power systems

• Concepts have been developed that could be utilized in robotic pathfinder exploration, high Earth orbit operations missions, and expedition phases of Mars exploration

• The tools developed during this study can be used to analyze and compare future technology and system options