Human Exploration of Earth’s Neighborhood and Mars

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Direct Entry Landing Locations

Entry Interface

Max Uprange (Heel)
Max Downrange (Toe)
Crossrange

Annulus of Landing Site Locations

Entry Interface
Heel of Landing Footprint (Max Uprange)
Toe of Landing Footprint (Max Downrange)

$V_\infty$

$i_{pole}$
2005 Opportunity - Type I

Landing Lighting and Latitude for Direct Entry JSC Mars Sample Return
(2005 Opportunity, Date/Time August 10, 2005 12:00:00.0, Trip Time 199 Days)

- V-Infinity = 3.08 km/s
- Inertial Entry Velocity = 5.81 km/s
- Min. Landing Latitude = -71.7 deg
- Max. Landing Latitude = 52.3 deg

Earth Departure Date
8/10/05

Earth Departure Energy
C3 = 15.9 km^2/s^2

Mars Arrival Date
2/25/06

Trip Time
199 days

Mars Inertial Entry Speed
5.81 km/s

Landing Site Latitude Access
-71.7° -> 52.3°
Earth-Mars Superior Conjunction

- **2005 Mission Opportunity**
  - Mars Arrival Date: 2/25/06
  - Trip Time: 618 days
  - Mars Entry Speed: 340 km/s

- **2007 Mission Opportunity**
  - Mars Arrival Date: 4/20/08
  - Trip Time: 628 days
  - Mars Entry Speed: 450 km/s

- **2009 Mission Opportunity**
  - Mars Arrival Date: 6/10/10
  - Trip Time: 636 days
  - Mars Entry Speed: 675 km/s

*Exceeds 7.36 km/s Mars entry speed limit*

**KEY**
- Mars Arrival Date
- Trip Time (days)
- Earth Departure C3 (km²/s²)
- Mars Entry Speed (m/s)
Lander Latitude Accessibility

Mars Sample Return - Direct Entry Lander Latitude Access 2005-2009

2005

- Type I: Pre-Conjunction Arrival
- Type II: Arrival @ Conjunction
- Type III: Post Arrival Conjunction

2007

Earth-Mars Trip Time (Days)

2009

- Type I: Pre-Conjunction Arrival
- Type II: Arrival @ Conjunction
- Type III: Post Arrival Conjunction

Legend:

- Dark Blue: Pre-Conjunction Arrival
- White: Arrival @ Conjunction
- Red: Post Arrival Conjunction

Graph showing the accessibility of Mars landers across different years and types.
Low Thrust – Earth Return Phase

- Two-body assumption with mass-matching at transition points, no shadowing
- Initial Conditions*
  - Mass = 350 kg
  - Power to thruster = 2.567 kW
  - Efficiency = 55.3%
  - $I_{sp} = 3127$ sec.

*Based on advanced NSTAR engine similar to that used with Deep Space 1
SEP Earth Return Sequence

Mars Spiral Out
- Depart 300 km circular parking orbit
- Initial mass = 350 kg
- Thrust along velocity vector
- Spiral to zero energy condition
- No shadow
- Transfer Time = 131 days
- Propellant = 34 kg

Earth ‘Spiral’ Down
- Depart 150,000 x 20,000 parking orbit
- Apogee Reduction to 20,000 km
  - Thrust perpendicular to line of apsides near perigee
- Spiral down to 500 km circular orbit
  - Thrust opposite velocity vector
- Preliminary 60 kg estimate for spiral down propellant (later optimized to 38 kg)

Heliocentric Transfer
- Depart Mars state
- Initial mass = 316 kg
- Optimal thrust direction (Calculus of Variations)
- Capture to a 150,000 x 20,000 km parking orbit
- Transfer time = 370 to 490 days
- Required mass in LEO > 200 kg
  - Assumes 60 kg propellant required to capture into HEO and spiral down to LEO

Coast

Deceleration Burn

150,000 x 20,000

20,000 x 20,000

500 x 500

300 x 300 km
Mission Map

Earth Departure/Arrival V-Infinity Magnitude

- Depart Earth
- Arrive Mars
- Surface Stay
- Arrive Earth
EARTH TO MOON TRANSFERS
DIRECT VS VIA LIBRATION POINTS (L1, L2)

Gerald L. Condon
Sam Wilson
Johnson Space Center / Aeroscience and Flight Mechanics Division

October 9, 2002
Libration Point Missions

- Earth-Moon L1
  - **Gateway station**
    - Sorties to the Moon
    - Satellite deploy, servicing
      - Next Generation Space Telescope
      - Terrestrial Planet Finder
    - Staging area for interplanetary and asteroid missions
- Earth-Moon L2
  - Robotic relay satellites
    - Communications relay
    - Navigation aid
- Sun-Earth L2
  - Human missions to extend human presence in space
**Expeditionary vs. Evolutionary**

- Single mission or mission set
- Completed mission satisfies mission objectives
- Close-ended missions

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**Apollo**
**Skylab**
**Apollo-Soyuz Test Project**
**Columbus' voyage of discovery to the new world**
Expeditionary vs. Evolutionary

- Ongoing missions
- Open-ended missions on which other missions can build
- Greater initial capital investment
Earth-Moon L1 – Gateway for Lunar Surface Operations

- Celestial park-n-ride
- Close to home (3-4 days)
- Staging to:
  - Moon
Earth-Moon L1 – Gateway for Lunar Surface Operations

- Celestial park-n-ride
- Close to home (3-4 days)
- Staging to:
  - Moon
  - Sun-Earth L2
  - Mars
  - Asteroids
  - ...

Lunar Lander transfers crew from L1 station to lunar surface

Lunar Lander

Moon

Libration Point Transfer Vehicle (LTV)

L1 Gateway Station

LTV transfers crew from Earth orbit to L1 station

Earth

Mars

Near Earth Asteroids

Sun-Earth L2

NGST TPF
Lunar Mission: Libration Point vs. LOR

Mission Scenario Advantages

Earth-Moon L1
- No lunar departure injection window
- Global lunar access
- Reusability
- Protection from failed station-keeping
- Specialized vehicle design

Lunar Orbit Rendezvous (LOR)
- Shorter mission duration
- Lower overall ΔV cost
- Fewer critical maneuvers required
Lunar Transfer/Orbit Diagrams
Trans-Lunar Trajectory from ISS Parking Orbit

TLI plane determined by the space station plane at departure (TLI) and the Moon's position at arrival

Moon at Lunar Arrival

Moon at Trans-Lunar Injection

DECLINATION OF MOON W.R.T. SPACE STATION ORBIT

INJECTION WINDOW EVERY 3-12 DAYS

Reference: K. Joosten
Lunar Outpost Site Location
Implications to Mission Planning
Trans-Earth Trajectories

Moon at Trans-Earth Injection (TEI)

-13 deg/Day

Earth Parking Orbit

EQUATOR

Earth Orbit Insertion

TEI plane determined by Moon’s position at departure (TEI) and the space station plane at arrival

DECLINATION OF MOON W.R.T. SPACE STATION ORBIT

INJECTION WINDOW EVERY 3-12 DAYS

Reference: K. Joosten
Lunar Outpost Site Location
Implications to Mission Planning
Parking Orbit Considerations

Reference: L. Wagner
Reference: K. Joosten
Lunar Outpost Site Location
Implications to Mission Planning
Effect of Lunar Parking Orbit Inclination on Lunar Transfer Opportunities → Moon to Earth Transfer

Polar Orbit
Departure Opportunity
1- Impulse TEI
   Plane ΔV Penalty = 2223 m/s
3- Impulse TEI
   Plane ΔV Penalty = 1167 m/s

Equatorial Orbit
Departure Opportunity

Polar Orbit
Departure Opportunity
1- Impulse TEI
   Plane ΔV Penalty = 0 m/s
3- Impulse TEI
   Plane ΔV Penalty = 0 m/s

Equatorial Orbit
Departure Opportunity

Reference: G. Condon
Exploration Blueprint
Landing Latitude Restrictions

Lunar descent & landing generally occur in rendezvous orbit plane

Region of unattainable landing sites

In-plane Lunar ascent & rendezvous available about every 27 days

Parking orbit inclination

Equator

Rendezvous orbit remains nearly fixed, inertially

Region of unattainable landing sites

Source: K. Joosten
Lunar Outpost Site Location Implications to Mission Planning
Comparison of
Opposition Class (Short-Stay) and
Conjunction Class (Long-Stay)
Missions for the Human Exploration of Mars

Exploration Office
NASA/JSC
March 1998
Mars Mission Planning

- **Earth-Mars Mission Planning**
  - Trips to Mars and back are, in effect, a double rendezvous problem
  - First rendezvous outbound must be developed considering influence of the rendezvous inbound
  - Practical considerations dictate favorable (and different) planetary alignments relative to the sun for both transfers

- **Synodic Period**
  - is the period of time necessary for the phase angle between Earth and Mars to repeat itself
  - Repetition rate for identical Earth-Mars phasing, and therefore launch opportunities for similar mission classes, is ~26 months
  - The eccentricity of Mars' orbit causes significant variations in Earth-Mars relative distance and velocity from one opportunity to the next
  - The entire range of Earth-Mars geometry is encompassed by seven launch opportunities, or about 15 years
  - Before definitive claims of mission characteristics or propulsion system capabilities are made, analysis across the 15-year cycle should be performed
Conjunction: Maximum Earth-Mars distance varies from 350-400 million km. Round-trip communication time varies from 40-45 minutes; also solar occultations (i.e., no communication) for approx. 2 weeks.

Opposition: Minimum Earth-Mars distance varies from 60-100 million km. Round-trip communication time varies from 6-11 minutes.

Mars
- Perihelion: 1.4 AU
- Aphelion: 1.6 AU
- Orbital period: 687 days
- Mean velocity: 24 km/sec
- Equatorial radius: 3398 km

Earth
- Perihelion: 1.0 AU
- Aphelion: 1.0 AU
- Orbital period: 365 days
- Mean velocity: 30 km/sec
- Equatorial radius: 6378 km
Delta-V Variations

Short-Stay Missions (Opposition Class)

Long-Stay Missions (Conjunction Class)
Mars Mission Duration Comparison

- **Long-Stay Mission (180-Day Transits)**
  - Return Transit: 200 days
  - Time at Destination: 500 days
  - Outbound Transit: 300 days

- **Short-Stay Mission (Minimum Energy)**
  - Return Transit: 100 days
  - Time at Destination: 400 days
  - Outbound Transit: 500 days

- **Vasco Da Gamma (1497)**
  - Return Transit: 150 days
  - Time at Destination: 550 days
  - Outbound Transit: 300 days

- **Amerigo Vespucci (1501)**
  - Return Transit: 100 days
  - Time at Destination: 500 days
  - Outbound Transit: 400 days

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*Example Lift Capability Needed* (Magnum-Class)

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*Mission Duration, Days*

* Assuming NTP=925 sec Propulsion
Artificial Gravity for Human Exploration Missions

NEXT Status Report
July 16, 2002
Current Configuration

- **Masts**
  - Deployable
  - Element zero-g positional control
  - Power, data cable support
  - Light compression during spinup/spindown

- **Main Power**
  - Redundant Reactors
  - Redundant Power Conversion
  - Reactor Rad Shielding

- **Suspension Cables**
  - Main rotational tension loads

- **Control Jets**
  - Spinup/spindown Steering

- **Crew Module**
  - Inflatable Pressure Shell
  - Radiation Shielding
  - Micrometeoroid Protection
  - Life Support
  - EVA Support
  - Body-Mounted Radiator

- **Spars**
  - Guy Cable Support

- **Main Thrusters**
  - Primary TVC via vehicle pointing

- **Main Power Radiators**
  - Flexible, Deployable

- **Zero-G Docking Port**

- **125 m**
### NEP Thruster Location Trades

**Vehicle Rotation**

<table>
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<tr>
<th></th>
<th>Original Asymmetric</th>
<th>Symmetric Central (Selected Config.)</th>
<th>Symmetric Terminal</th>
<th>Asymmetric CG</th>
<th>Asymmetric Counter</th>
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<td><strong>Power Level</strong></td>
<td>-- High Power Variation</td>
<td>+ Counter-cycling (near constant power)</td>
<td>+ Counter-cycling (near constant power)</td>
<td>+ Counter-cycling (near constant power)</td>
<td>+ Counter-cycling (near constant power)</td>
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<tr>
<td><strong>Power Lines</strong></td>
<td>+ Short power lines</td>
<td>-- Long power lines</td>
<td>-- Long power lines (no worse than previous)</td>
<td>-- Long power lines</td>
<td>+ Short power lines</td>
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<tr>
<td><strong>Prop Lines</strong></td>
<td>-- Long prop lines</td>
<td>+ Short prop lines</td>
<td>-- Long prop lines</td>
<td>-- Long prop lines</td>
<td>-- Long prop lines</td>
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<tr>
<td><strong>Turn Rates</strong></td>
<td>+ Higher turn rates</td>
<td>-- Lower turn rates</td>
<td>+ Best turn rates</td>
<td>+ Higher turn rates</td>
<td>-- Lower turn rates</td>
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*For constant mass flow rate approach*
• Technique for rotating thrust vector 180°
• Rotation about vehicle z-axis
• Applications:
  – Midcourse turnaround
  – Planetary spirals (if required)
    • ~36% loss of propulsive efficiency vs. tangential thrusting
• Other possible implementation: second set of thrusters (-x thrust direction)
  – Thruster mass/expense vs. propellant required for rotation
Example Load Paths (cont)

- Mast loads for spinup, spindown
  - Mast will be under compression only during period when Hab Module/Power Module "weight" is less than compression load
    - Only mast loads identified to date
  - After that, no load (suspension cables support loads)
  - For spinup/spindown times less than 24 hours, compression loads will not exceed 100N (22 lbs)
  - Maximum mast loads may result from zero-g operations (hard to quantify at this time)
    - Docking forces
    - Plume impingements

- LaRC Analysis
  - Providing finite element modeling and analysis for load conditions
    - 1-g
    - Spina/spindown
    - Maneuvers during transit
  - From loads analysis, determine low lightweight a structure (such as inflatable/rigidizable structures) could be used for mast
  - Status
    - Modeling nearly complete
    - Analysis to begin shortly

<table>
<thead>
<tr>
<th>Thrust Level, N</th>
<th>Spinup Time, hrs</th>
<th>Anch Power, kWe</th>
<th>Guy Tension, N</th>
<th>Max. Mast Compression, N</th>
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</table>

ArcJet Computations Assume:
Efficiency 30%
isp 800 sec

RCS Thrust

Guy Tension

Mast Compression

Hab "Weight"

Finite Element Model

Reactor Mass

Tankage Mass

Radiator Mass

HabitatMass