Architectures for Human Exploration of Near Earth Asteroids

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Human Exploration of NEAs Key Factors

◆ **Challenges of supporting humans for long-durations in deep-space**
  - How short can the trip times be reduced in order to reduce crew exposure to the deep-space radiation and micro-gravity environment?

◆ **Incorporation of advanced technologies**
  - Are there options to conduct easy, early missions?
  - What is the affect of infusion of advanced propulsion technologies on target availability

◆ **Mission design constraints:**
  - When do the departure opportunities open up?
  - How frequent are they?
  - How long is the departure window

◆ **How many launches are required to conduct a round trip human mission to a NEA**
Overview

- NHATS [Near-Earth Asteroid (NEA) Human Space Flight (HSF) Accessible Targets Study] trajectory scans by both the GSFC and JPL teams produced millions of potential trajectories to thousands targets.
- Of those millions of trajectories, thousands may represent “good” candidate mission opportunities.
- Several different transportation technologies considered, including:
  - All chemical propulsion
  - Nuclear Thermal Propulsion (NTR)
  - Electric Propulsion (Solar Electric) for the deep space portion of the mission
  - Hybrid Propulsion as characterized by chemical boost + Solar Electric
- Architecture mass estimated for each unique trajectory to help facilitate the strategic planning process.

CAUTION: Due to time limitations and the sheer magnitude of number of simulations to be run, only parametric mass sizing was implemented. Although the parametric results have been validated with results from more detailed assessments, the results contained herein should be used for comparative assessments only.
Applied Methodology

**Trajectory Scans**

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<th>Year-ID</th>
<th>Launch Date</th>
<th>End Date</th>
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**Operational Concept**

Concept of Operations (NEO crowded Missions, 100 t HLLV)

**Mission Payload Definition**

In-Space Mission Elements for DRM 4

- **Sample Data**: 5.2, 4.3, 4.5
- **Mission Duration**: 7.2
- **Launch Location**: 23.2, 8
- **Target Date**: 5.1, 2

**Propulsion System Parametric Sizing**

$R = e^{\frac{\Delta V_{prop}}{I_{sp}}}$

$\text{Mass}_{prop} = \text{Mass}_{payload} \times (R - 1) \times \frac{(1 - f_{nert})}{I - R \times f_{nert}}$

$\text{Mass}_{nert} = \text{Mass}_{prop} \times \frac{f_{nert}}{1 - f_{nert}}$

$\text{Mass}_{edge} = \text{Mass}_{prop} + \text{Mass}_{nert}$

$\text{Mass}_{phase} = \text{Mass}_{edge} + \text{Mass}_{payload}$

**Define Simulation Variables**

To account for early conceptual designs

**Simulation Results**

- 90th Percentile
- Expected Value
- 10th Percentile
All Nuclear Thermal Propulsion NEA Mission Operations

- **NEO**: NEA Orbit Insertion → NEA Exploration
  - Drop Tanks Expended (as necessary)
  - SEV continues operations at NEO
  - Drop Tanks Expended (as necessary)

- **Trans-NEA Coast**: Drop Tanks Expended (as necessary)

- **Trans-Earth Coast**: Direct Entry Water Landing
  - NTR & Deep Space Habitat Expended
  - Direct Entry Maneuver (if required)
  - Deep Space Maneuver (if required)

- **Trans-NEA Injection**: Drop Tanks Expended (as necessary)

- **Trans-NEA Coast**: Drop Tanks Expended (as necessary)

- **Trans-Earth Coast**: Drop Tanks Expended (as necessary)

- **LEO (ref. 400km circ)**: Moderate HLV Launches (# TBD)

- **Earth**: All Nuclear Thermal Propulsion NEA Mission Operations
Example Mass Trends Between Datasets
All Chemical Propulsion Architecture

GSFC Dataset

JPL Dataset

Typical reasonable mass limit
Example Sensitivity of Delta-v and Trip Time
Near Earth Asteroid 2009 HC

Regions of short mission duration but high mass (delta-v)

Regions of lower mass (delta-v) but longer mission duration

Increasing Delta-v = Increasing Mass

Total Mission Delta-v (km/s)

Roundtrip Flight Time (days)

Earth Departure Date


Courtesy GSFC
Example Sensitivity of Number of Launches and Trip Time
All Chemical Propulsion Architecture

Near Earth Asteroid 2009 HC

- 2 launches
- 3 launches
- 4 launches
- 5 launches

Based on mass only. Volume and packaging not yet addressed.
Example # of Expected Targets for Various Transportation Architectures

Circa 2020-2035, Asteroids > 30m, Approximately 3 Launches, < 1 Year Duration

All Chemical Architecture

All NTR Architecture

All SEP for Deep Space

SEP/Chemical Architecture

Results associated with the JPL data set
Summary

- Mission design and architectural assessments still under way
- No firm decisions yet on specific technologies or NEA targets have been made
- Key focus is on understanding the key capabilities and technologies required for a broad range of exploration architectures including human exploration of NEAs
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