Asteroid Redirect Mission and Human Space Flight
Briefing to National Research Council
Committee for Study on Human Space Flight Technical Panel
Steve Stich- Deputy Director JSC Engineering
June 19, 2013
• NASA is aligning key activities in Science, Space Technology, and Human Exploration and Operations Mission Directorates
  – Asteroid Identification and Characterization efforts for target selection
  – Solar Electric Propulsion for transport to and return of the target asteroid
  – Autonomous guidance and control for proximity operations and capture
  – SLS and MPCV missions for asteroid rendezvous
  – EVA technologies

• Each individual activity provides an important capability in its own right for human and robotic exploration

• We are working to utilize all of these activities to
  – Identify, capture and redirect a small NEA; and
  – Investigate and return samples with our astronauts using the Orion and Space Launch System assets.

• The FY14 budget supports continued advancement of the important individual elements and furthers the definition of the overall potential mission.
Capability Driven Framework

Incremental steps to steadily build, test, refine, and qualify capabilities that lead to affordable flight elements and a deep space capability.

- Initial Exploration Missions
  - International Space Station
  - Space Launch System
  - Orion Multi-Purpose Crew Vehicle
  - Ground Systems Development & Operations
  - Commercial Spaceflight Development

- Extending Reach Beyond LEO
  - Translunar Space
  - Geostationary Orbit
  - High-Earth Orbit
  - Lunar Flyby & Orbit

- Into the Solar System
  - Interplanetary Space
  - Initial Near-Earth Asteroid Missions

- Exploring Other Worlds
  - Low-Gravity Bodies
  - Full-Capability Near-Earth Asteroid Missions
  - Lunar Surface
  - Phobos/Deimos

- Planetary Exploration
  - Mars
  - Solar System

- Mars: Ultimate human destination in the next decades
Overall Mission Consists of Three Main Segments

**Identify**

Asteroid Identification Segment:

Ground and space based NEA target detection, characterization and selection

**Redirect**

Asteroid Redirection Segment:

Solar electric propulsion (SEP) based robotic asteroid redirect to trans-lunar space

**Explore**

Asteroid Crewed Exploration Segment:

Orion and SLS based crewed rendezvous and sampling mission to the relocated asteroid
Asteroid Capture & Redirect Reference Mission Concept

• Capture and redirect a 7-10 meter diameter, ~500 ton near-Earth asteroid (NEA) to a stable orbit in trans-lunar space known as a Distant Retrograde Orbit (DRO)

• Enable astronaut missions to the asteroid using Orion as early as 2021

• Parallel and forward-leaning development approach
Reference Mission Design Executive Summary

1. Launch (2 Options)
   1a. Atlas V – Low Thrust Spiral to Moon
   1b. SLS or Falcon Heavy – Direct Launch to Moon or to Asteroid

2. Lunar Flyby to Escape (If Needed)

3. Low Thrust Trajectory to Asteroid

4. Low Thrust Trajectory with Asteroid to Earth-Moon System

5. Lunar Flyby to Capture

6. Low Thrust Trajectory to Storage Orbit

7. MPCV Rendezvous
A short list of candidate asteroids that potentially meet target requirements (size, mass, spin-state and know orbits with return dates in the early 2020’s) have been identified. All require further observation.

Very small asteroids (<10m) are difficult to detect, track and characterize.
- NASA’s Near Earth Object Observation Program plans to enhance ground-based observation capabilities for potential near-term detection rate increase to several/year
- Assured target detection and characterization of such small asteroids may require space-based capabilities

SEP technologies currently under development for future exploration are enabling for the robotic redirect mission.

Among options for asteroid locations within the earth-moon system, we have established the lunar Distant Retrograde Orbit (DRO) as a reference
- Long-term stability (> 100 years) and SLS – Orion accessible
- 22-25 day nominal Orion mission

The addition of mission “kits” for the Orion vehicle appear to enable asteroid exploration and sampling.

No show stoppers for mission feasibility have emerged.
Asteroid Redirect Human Mission Design Philosophy

- Perform sample return mission in two launches: Asteroid Redirect Robotic Spacecraft and Orion/SLS with Crew
- Minimize changes to Orion design for EM-2 Mission
- No changes to SLS Block 1 Design
- Affordability key consideration in every design trade
- Develop additional Orion mission hardware in add on kits
  - Lightweight EVA Suit/Primary Life Support System
  - EVA Tools & Translation Aids
  - Sample Container
  - EVA Communications
  - Relative Navigation Sensor System
  - Grapple Arm or Docking Kit (Option Under Assessment)
- Utilize robotic spacecraft for Extra-Vehicular Activity (EVA) augmentation (e.g. tool stowage, handholds)
- Provide capabilities that enhance future exploration goals
Explore: Orion Mission Overview

1. Deliver Crew in Orion
2. Attach Orion to robotic spacecraft
3. Return crew safely to Earth with asteroid samples in Orion
4. Perform Extra-Vehicular Activity (EVA) to retrieve asteroid samples
Nominal Orion Mission Summary

- **Outbound**
  - Flight Day 1 – Launch/Trans Lunar Injection
  - FD 2-FD 5 – Outbound Trans-Lunar Cruise
  - FD 6 – Lunar Gravity Assist (LGA)
  - FD 7-FD 9 – LGA to DRO Cruise

- **Joint Operations**
  - FD 10 – Rendezvous
  - FD 11 – EVA #1
  - FD 12 – Suit Refurbishment, EVA #2 Prep
  - FD 13 – EVA #2
  - FD 14 – Contingency/Departure Prep
  - FD 15 – Departure

- **Inbound**
  - FD 16 – DRO to Lunar Cruise
  - FD 17 – Lunar Gravity Assist (LGA)
  - FD 18-FD21 – Inbound Trans-Lunar Cruise
  - FD22 – Earth Entry and Recovery

Mission Duration and timing of specific event will vary slightly based on launch date.
Notional Design For Grapple: Robotic Spacecraft

**Grapple Fixture**
- Orion approaches to berthing box,
- Orion grapple arm aligns to grapple fixture and captures the robotic spacecraft

**Docking Target**
- Augmented with features for relative navigation sensors
- Visual cues for crew monitoring
Notional Design for EVA: Robotic Spacecraft

**Translation Boom and Attach Hardware**
- Translation from Orion to spacecraft
- Translation from spacecraft to capture device bag for asteroid access

**Hand Rails**
- Translation path from aft end of spacecraft to capture device
- Ring of hand rails around spacecraft near capture device

**EVA Tether Points**
- Hand-over-hand translation
- Temporary restraint of tools
- Management of loose fabric folds

**Pre-positioned EVA Items**
- Tool box to offset mass in Orion
- Two additional translation booms
Notional EVA Operations From Orion

- Two EVAs executed from Orion
- Crew translates from Orion to robotic spacecraft
- EVA Tool box prepositioned on spacecraft
- Telescoping booms pre-stowed on spacecraft
- Crewmember stabilized on Portable Foot Restraint for Worksite
- Loops available on Capture Mechanism Bag for additional stabilization
Notional Rendezvous/Prox Ops Sensor Kit

- Rendezvous, proximity operations and capture sensor consists of the Vision Navigation Sensor (VNS) and Docking Camera (DC) rolled into a single package called Laser Optical Camera Instrument (LOCI)
  - Mounted to the interior side of docking hatch by crew prior to AR&D operations
  - VNS and DC tested on STS-134 Space Shuttle Mission in STORRM DTO

- Docking Lights
  - Mounted to exterior of docking hatch, encompassing docking hatch window perimeter

<table>
<thead>
<tr>
<th>Relative Navigation</th>
<th>Qty</th>
<th>Rate (kg)</th>
<th>Subtotal</th>
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<tbody>
<tr>
<td>LOCI</td>
<td></td>
<td></td>
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<tr>
<td>Vision Navigation System</td>
<td>2</td>
<td>13</td>
<td>26.0</td>
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<tr>
<td>Docking Camera</td>
<td>2</td>
<td>1</td>
<td>2.0</td>
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<tr>
<td>Sensor cabling/ connectors</td>
<td>1</td>
<td>10</td>
<td>10.0</td>
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<tr>
<td>Lights</td>
<td></td>
<td></td>
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<tr>
<td>Docking light</td>
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<td>2</td>
<td>4.0</td>
</tr>
<tr>
<td>Docking light power cable</td>
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<td>2</td>
<td>2.0</td>
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<tr>
<td><strong>Total Loading</strong></td>
<td></td>
<td></td>
<td><strong>44.0</strong></td>
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</table>
Orion Stowed EVA Tools Kit

- EVA tools launched on Orion
  - Required for contingency EVA
  - Needed for Orion egress
  - Sensitive hardware which might not survive long duration
  - Unique geological tools designed and added to manifest after asteroid capture
- All other EVA tools launched on robotic spacecraft

<table>
<thead>
<tr>
<th>Description</th>
<th>Mass (kg)</th>
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<tbody>
<tr>
<td>Suit-Worn EVA Tools (Unit x 2 Suits)</td>
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<tr>
<td>85' Safety Tether</td>
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<tr>
<td>2 Waist Tethers</td>
<td>4.0</td>
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<tr>
<td>Equipment Tethers</td>
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<tr>
<td>Mission EVA Tools (Stowed In Orion)</td>
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<tr>
<td>Boom mounting bracket</td>
<td>2.0</td>
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<tr>
<td>Boom</td>
<td>13.6</td>
</tr>
<tr>
<td>Geological Tools Allocation</td>
<td>13.6</td>
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<tr>
<td>ORU Bags</td>
<td>6.8</td>
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<tr>
<td>Misc. support Equipment (Stowage, battery chargers, PLSS Checkout, Drink Bags, Etc.)</td>
<td>39.2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>90.0</strong></td>
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Asteroid Redirect Mission Alignment with Human Spaceflight Strategic Principles

1. Executable with current budget with modest increases.

2. Application of high Technology Readiness Level components and systems for near term missions

3. Near-term mission opportunities with a defined cadence of compelling missions
   - Build incremental capabilities for more complex missions over time

4. Opportunities for US Commercial Business to further enhance experience and business base

5. Multi-use Space Infrastructure when possible

6. Significant International participation, leveraging current International Space Station partnerships
## Elements Required By Potential Destination

<table>
<thead>
<tr>
<th>Phase</th>
<th>Capability</th>
<th>Potential Required Element</th>
<th>Translunar</th>
<th>Asteroid</th>
<th>Mars Orbit / Moons</th>
<th>Mars Surface</th>
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<tbody>
<tr>
<td>Getting There</td>
<td>BEO Access</td>
<td>Space Launch System (SLS)</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td></td>
<td>Crew</td>
<td>Orion</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td></td>
<td>High Thrust/Near Earth</td>
<td>Cryo Propulsion Stage (CPS)</td>
<td>X</td>
<td>X</td>
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<td>Option</td>
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<tr>
<td></td>
<td>Low Thrust/Near Earth</td>
<td>Solar Electric Propulsion (SEP)</td>
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<td>Option</td>
<td>Option</td>
<td>Option</td>
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<td></td>
<td>High Thrust/Beyond LEO</td>
<td>Nuclear Thermal Propulsion (NTP)</td>
<td>Option</td>
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<td>Low Thrust/Beyond LEO</td>
<td>Nuclear Electric Propulsion (NEP)</td>
<td>Option</td>
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<tr>
<td></td>
<td>Habitation</td>
<td>Habitat</td>
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<td>Option</td>
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<td>X</td>
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<tr>
<td></td>
<td>Descent</td>
<td>EDL / Landers</td>
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<td></td>
<td></td>
<td>X</td>
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<tr>
<td>Working There</td>
<td>Habitation</td>
<td>Habitat</td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>Micro-g Sortie and Surface Mobility</td>
<td>Robotics and Mobility</td>
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<td>Option</td>
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<td>In Situ Resource Utilization</td>
<td>In-Situ Resource Utilization (ISRU)</td>
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<tr>
<td></td>
<td>Surface Power</td>
<td>Fission Surface Power System</td>
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<td>EVA (nominal)</td>
<td>EVA Suits</td>
<td>X</td>
<td>X</td>
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<td>Coming Home</td>
<td>Ascent</td>
<td>Ascent Vehicle</td>
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<td>X</td>
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<td></td>
<td>Crew Return</td>
<td>Orion</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

**Note:**
- **X** – Required Elements/Capabilities for these potential destinations
- **Option** – Element/Capability may be needed or multiple options could exist to enable missions for that specific potential destination or could be for verification for future needs.
- Early builds of circled elements utilized in Asteroid Redirect Mission
Asteroid Mission Supports
Long-Term Human Mars Exploration Strategy

• Demonstration of Core Capabilities for deep space missions:
  – Block 1 SLS, Orion
  – 40kW Solar Electric Propulsion System
  – EVA, rendezvous, proximity operations, docking or grapple, deep space navigation and communications
  – Human operations and risk management beyond low earth orbit
  – Sample acquisition, caching, storage operations, and crew transfer operations for future Lunar/Mars sample return missions

• Demonstrates ability to work and interact with a small planetary body:
  – Systems for instrument placement, sample acquisition, material handling, and testing
  – Understanding of mechanical properties, environment, and mitigation of hazards
Mars Exploration Capability Build-Up
Using Asteroid Redirect Mission and ISS

Outside line indicates capabilities needed for Mars missions

Green shaded area represents capabilities demonstrated by ARM mission

Yellow shaded area represents gaps in Mars required capabilities

Blue shaded area represents additional capabilities matured by ISS

In-Space Crew Duration
365+d (Full Habitat)
180-365d (Full Habitat)
~51d (Orion + Enhancement)
21d - 4 crew (Orion)
21d - 2 crew (Orion)
Contingency EVA
Orion EVA
Exploration Class EVA
EVA
Rendezvous & Docking without real time telemetry

Launch Capability
# of Crew
130 t
105 t
83 t
55 t
40 t
25 t

11.5 km/s
9.5 km/s
11.2 km/s
10 km/s
8 km/s
6 km/s

Entry
Trajectory
HLO, L2, DRO
L1
LLO
NEA
Mars Vicinity
Interaction with low g bodies
Rendezvous
Capture
Berthing
Docking
AR&D

None
None
Capture
Docking
Interaction with low g bodies
HLO, L2, DRO
L1
LLO
NEA
Mars Vicinity
Surface Access
Human EDL
Class Lander
~10 t
~25 t
21d - 4 crew (Orion)
21d - 2 crew (Orion)
Contingency EVA
Orion EVA
Exploration Class EVA
EVA
Rendezvous & Docking without real time telemetry

Launch Capability
# of Crew
6

Yellow shaded area represents gaps in Mars required capabilities

Green shaded area represents capabilities demonstrated by ARM mission

Blue shaded area represents additional capabilities matured by ISS
Asteroid Redirect Mission benefits near term exploration objectives for carrying humans further into space than ever before while providing the building blocks for even more ambitious future missions to Mars.
Recent and Next Steps

- **June 18: Asteroid Initiative Industry and Partner Day**
  - Open invitation, including international
  - Communication of what we are doing, discussion, and engagement plans

- **June 18: Request for Information Release**

- **July 9: Target NEO 2 Workshop**
  - Workshop sponsored by SBAG and others in planetary science community to assess the challenges with very small asteroid detection, characterization and science

- **July 18: RFI Response Date**

- **July 30: Mission Formulation Review**
  - Continued pursuit of overall mission
  - Planning content for budget process
  - Decisions on path forward: content, structure, Center assignments, supporting Center assignments, make-or-buy planning, impact on the workforce

- **Sept TBD: Mission Open Ideas Event/Workshop**
  - RFI Input Synthesis
  - Input to Mission Planning