National Aeronautics and Space Administration

Asteroid Redirect Mission Technology Needs

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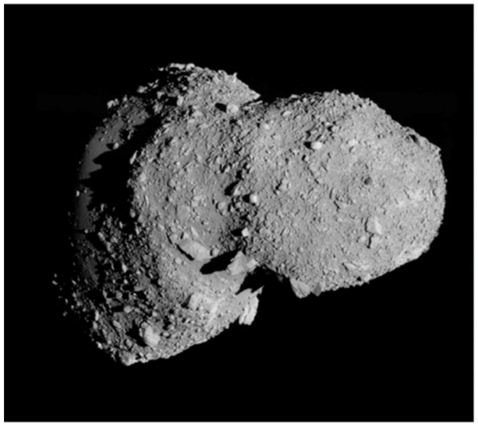
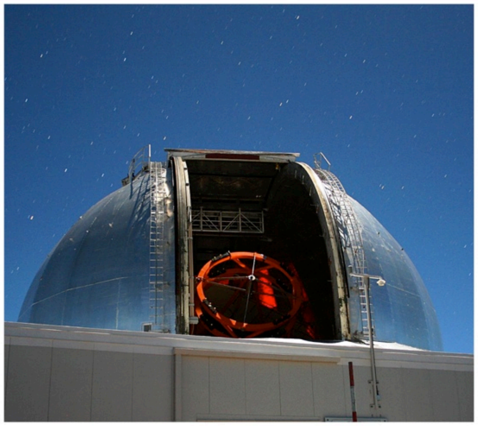
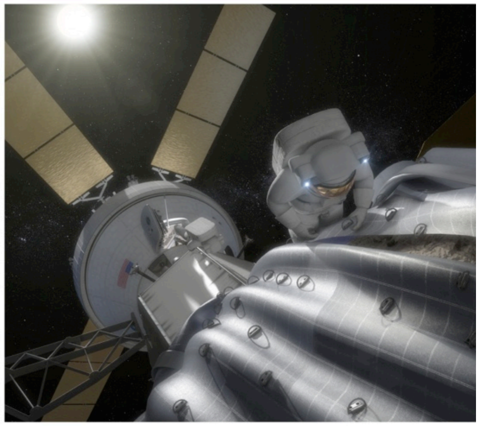





PREFACE

In response to recommendations from the previous forum, we are providing this summary of technology needs related to the Asteroid Redirect Mission, ongoing technology development efforts, and examples of additional technology development that could enhance the ARM as well as extend capabilities for future exploration missions and commercial applications.

Some of these areas are addressed in the BAA and others are not addressed.

Technology Needs

- **Solar Electric Propulsion**
  - Solar arrays
  - Electric propulsion thrusters
  - Power processing units
  - Propellant tanks

Not addressed in BAA

- **Asteroid Rendezvous & Capture**
  - Rendezvous sensors
  - Asteroid capture system

Addressed in BAA

- **Crewed Mission**
  - EVA suits
- **Enhancing and Extending Technologies**
  - In-Situ Resource Utilization (ISRU)
  - Additional Technologies

May be addressed through partnership opportunities in BAA

Solar Arrays

TRL = 5+	State of the Art	Mission Need
Power	25 kW	50 kW (2 wings)
Power to Mass Ratio	60 W/kg	> 100 W/kg
Stowage Efficiency	10 kW/m^3	> 40 kW/m^3
Operating Voltage	70 - 160 V	300 V*

*reference configuration uses 300V, but 100-300V range will be considered

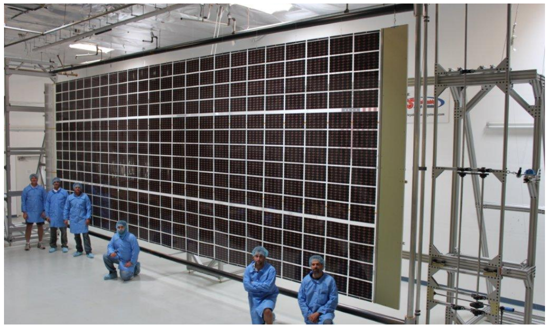
Technology Development Status

NASA STMD Solar Electric Propulsion Project

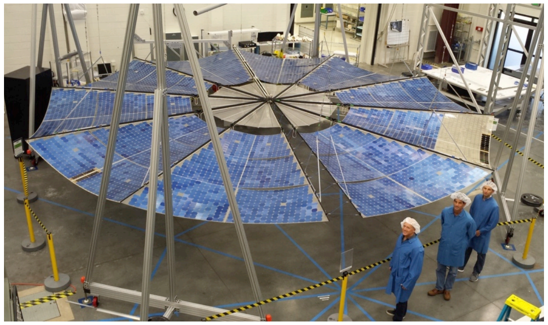
- Solar array contracts underway - TRL 5 expected by mid-2014
    - MegaFlex "fold-out" solar array (ATK)
    - ROSA "roll-out" solar array (DSS)
- Arrays sized to provide ~20kW per wing at beginning of life
    - Compatible with triple junction and IMM cells
    - Operable from 160 to 300 Vdc main bus voltage
- Single-axis array drive assembly derived from heritage technology, may need re-qualification for high voltage and higher loads

Existing PV cell technology is adequate (~29% efficiency)

- Lower cost and other improvements are desirable



DSS ROSA "roll-out" solar array



ATK MegaFlex "fold-out" solar array

Electric Propulsion Thrusters

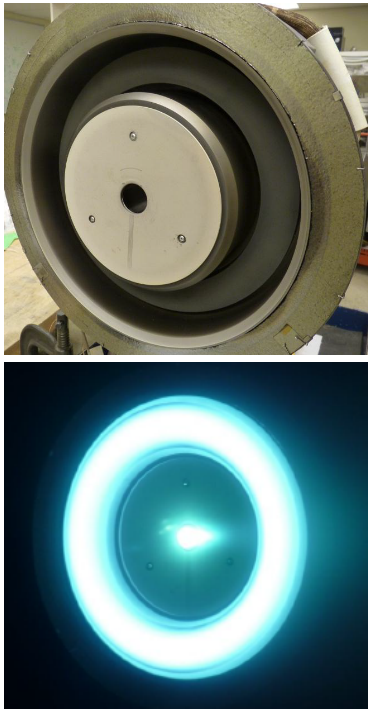
TRL = 4/5	State of the Art *	Mission Need
Input Power/unit	4.5 kW	12.5 kW
Thrust/unit	0.235 N	0.53 N
Specific Impulse	2040 sec	2000 - 3000 sec
Propellant Throughput/unit	450 kg	3,300 kg

* Example: BPT-4000 Hall Thruster

Technology Development Status

NASA STMD Solar Electric Propulsion Project

- Baseline concept utilizes magnetically-shielded Hall thrusters
- 12.5 kW magnetically-shielded Hall thruster development unit designed and currently in fabrication
- Baseline performance and wear testing (500+ hours) to be performed by end of FY 2014
- Viability of magnetic shielding to mitigate channel erosion was demonstrated at 3000-sec specific impulse at 9 kW (with JPL H6) and at 20 kW (with NASA-300M)
- Xenon throughput design goal of 3300 kg/unit



NASA-300M with magnetic shielding

Power Processing Units (PPU)

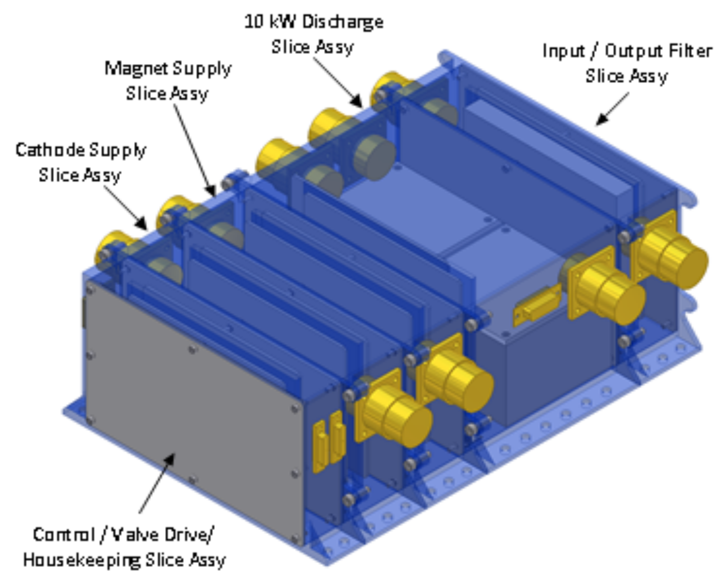
TRL = 4	State of the Art	Mission Need
Input Power	4.5 kW	13.3 kW
Input Voltage	70 - 100 V	300 V*
Output Voltage	250 - 400 V	800 V
Efficiency	90 - 92%	≥ 92%

*reference configuration utilizes 300V, but voltages from 100-300V will be considered

Technology Development Status

NASA STMD Solar Electric Propulsion Project

- Brass board PPU with single-stage 300V input and 400V output developed
- Brass board PPU with single-stage 120-150V input and 800V output designed and currently in fabrication
- Stacking 120-150V input stages provides alternative approach to 300V input
- Brass board PPU function will be demonstrated in integrated test with 12.5kW thruster by end of FY'14



Brass board PPU

Propellant Tanks

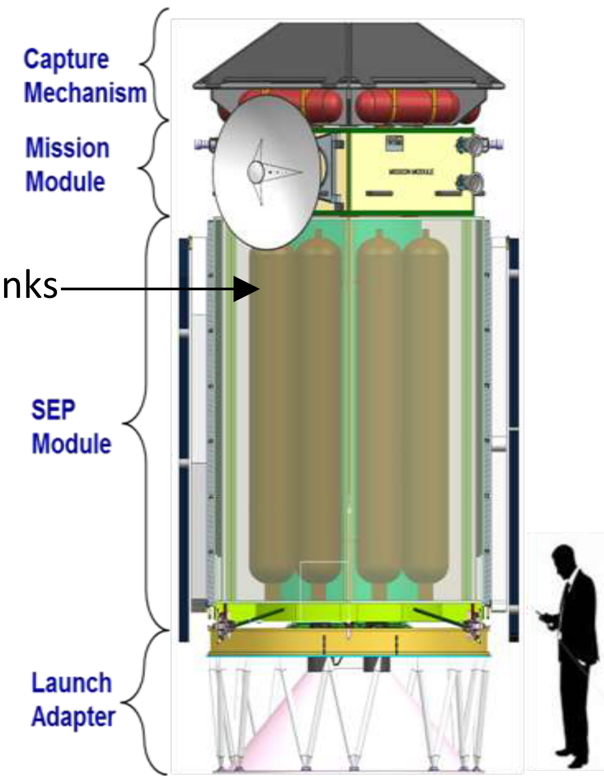
TRL = 5	State of the Art	Mission Need
Total Capacity	425 kg (Dawn spacecraft)	10,000 kg
Mass fraction	5%	4%
Cost per tank	$1M	$0.1M (goal)

NASA STMD Solar Electric Propulsion Reference Concept

- Baseline concept requires 10,000 kg of Xenon propellant
- Eight cylindrical tanks with a capacity of 1250 kg each
- Seamless, aluminum-lined, composite-overwrapped pressure vessels
- Length: 130 in
- Diameter: 22 in
- Mass Fraction: 3.7%

Dawn Xenon tank: composite overwrap with titanium liner

1 of 8 Xenon tanks



ARM Vehicle Concept

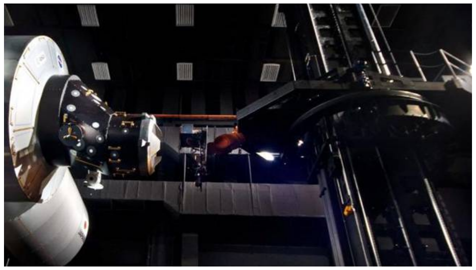
Rendezvous Sensors

NASA is interested in developing a common rendezvous sensor suite consisting of visible and infrared cameras and 3D LIDAR for a wide range of missions

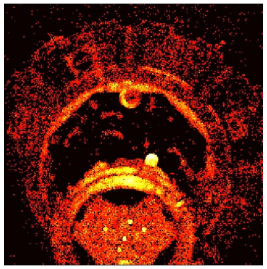
State-of-the-Art TRL = 6

- Visible Camera: High and medium resolution cameras (share back-end electronics with selectable lenses) – flight heritage on STORRM and other Shuttle flight tests; modification needed to meet ARM environments
- IR Camera: Flight heritage on multiple LEO missions
- 3D LIDAR: Flight heritage on STORRM with significant ground testing; modification needed to meet ARM performance levels

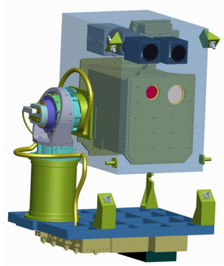
Mission Need	Visible Camera	IR Camera	3D LIDAR
Minimum Range	1 m	1-2 m	1 m
Maximum Range	> 50,000 km (bearing only)	100-200 m (bearing only)	2-3 km (bearing & range)
Field of View	Rendezvous: 0.5-1.5 deg Prox Ops: 30-45 deg	20-30 deg	±30 deg ARV ±10 deg Orion



Closed-loop AR&D ground testing



STORRM LIDAR image

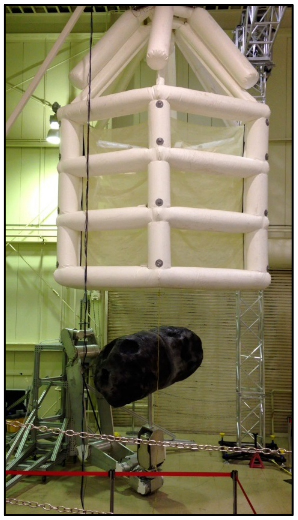


Raven demo on ISS

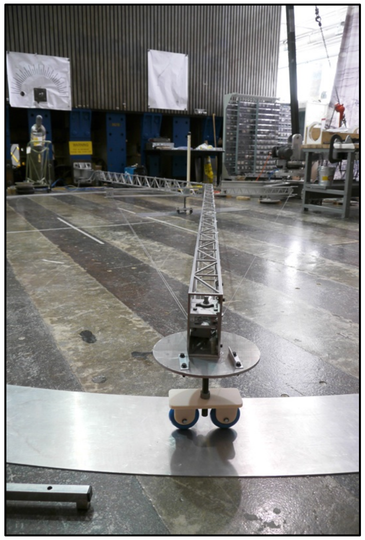
Asteroid Capture System

TRL = 2	State-of-the-Art	Mission Need
Inflatable or Deployable Capture System	1/5-scale testbed for inflatable capture system	Capture 4-10 m asteroid rotating at <0.5 RPM
Robotic Manipulators	Articulated space frame truss; 7 DOF manipulators (Dextre on ISS)	Extract 1-5 m boulder from asteroid surface

The Asteroid Capture System must be capable of autonomous operations during the capture phase, and restraining a 30 to 1,000-metric ton asteroid mass against the robotic spacecraft.



Inflatable capture system 1/5-scale testbed



Articulated space frame truss

Robotic manipulators for satellite servicing

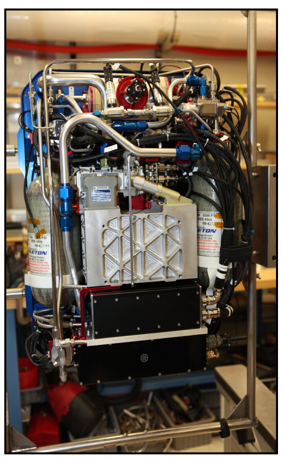
EVA Suits

ARM Need TRL = 4

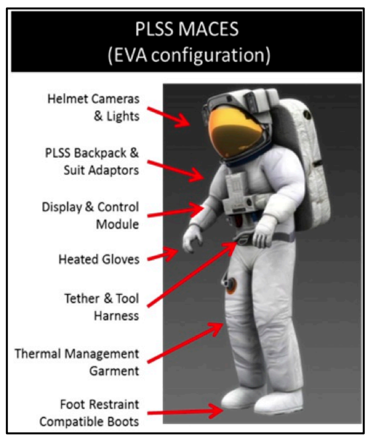
EVA Suit: 2 crew; two 4-hour EVAs; single mission

Technology Development Status

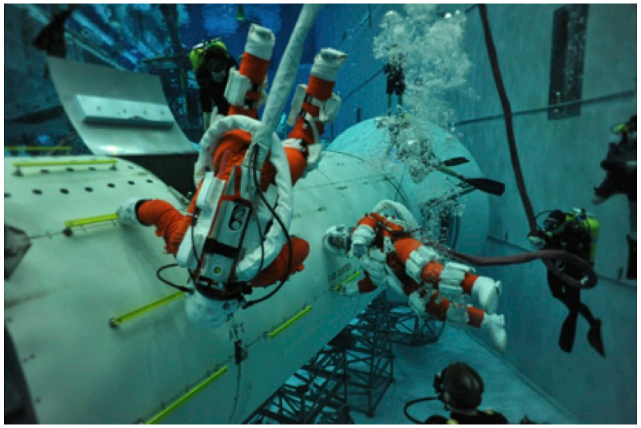
- Multi-suit compatible Portable Life Support System (PLSS)
  - Initial prototype completed in FY13.
  - Integrated metabolic and functional testing in FY14
- Enhancements to Modified Advanced Crew Escape Suit (M-ACES) that allow for extended EVA
  - Testing mobility in Neutral Buoyancy Lab and performing simulated ARM tasks.



Prototype PLSS



M-ACES Suit



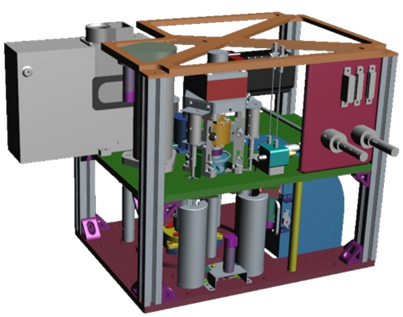
M-ACES testing in Neutral Buoyancy Lab

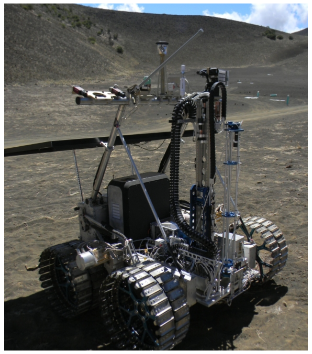
In-Situ Resource Utilization (ISRU)

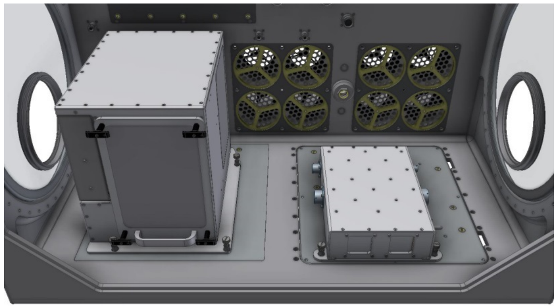
TRL = 4	State of the Art	Mission Need
Prospecting	Subsurface lunar ice (Resource Prospector Mission)	Locating ice and other volatiles, metals, rare earth elements on asteroids
Resource Characterization & Processing	Water extraction & oxygen production from simulated lunar regolith (RESOLVE)	Producing propellants & metals from asteroid materials
In-Space Manufacturing	3D printer demonstration on ISS	Using asteroid materials for in-space manufacturing

Technology Development Status

- NASA formulating Resource Prospector Mission to prospect for ice and other volatiles on the Moon.
- RESOLVE payload with subsurface sampling drill, miniature oven and mass spectrometer to measure volatiles in lunar regolith has been demonstrated in field tests.
- 3D Printer for fabricating plastic spare parts to be demonstrated on ISS in 2014.


RESOLVE payload for extracting water from lunar regolith


Resource Prospector Mission field test in Hawaii


3D Printer Demo on ISS

Enhancing and Extending Technologies

Technologies to Enhance ARM and Extend Capabilities for Future Exploration Missions and Commercial Applications

- Reducing mass, volume, power, or crew risk for Orion
  - Logistics packaging
  - Dust mitigation
  - Human waste system
  - Crew exercise equipment
  - Sample containers and options for maintaining cold samples
- Exploration-class suit for increased EVA time, greater mobility and dexterity
  - Multiple 8-hour EVAs; multiple missions
- New EVA tools and techniques for zero-g sample handling and curation with planetary protection
- High power solar electric propulsion systems (>100 kW and higher)
- Closed loop environmental control and life support
- Radiation Shielding
- Long duration food storage (>3 years without a freezer)
- Autonomous vehicle and crew operations
- Terrain-relative navigation
- Tele-operation of surface assets from orbit