Panel 14.02 "Technology Needs for the Next Generation of NASA Science Missions"

Panel Chair: David Anderson

Panelist: Erik Nilsen, Pat Beauchamp, Chad Edwards, and Tibor Kremic

March 6, 2013

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ABSTRACT: The panel will discuss the technology needs for the next generation of NASA science missions.

Topics will include: technology developments and mission implementation options being pursued under SMD and OCT technology programs which are applicable to planetary science missions. Some technology topics to be discuss will be communications, balloon science, and power and propulsion.

David Anderson:	Spacecraft technology needs identified in the Planetary Decadal Survey
Erik Nilsen:	Technology Needs identified in the MPPG related to future Mars exploration
Pat Beauchamp:	OCT technologies that apply to PSD mission needs
Chad Edwards:	Communication technologies for planetary science missions
Tibor Kremic:	Planetary science from a balloon platform

Decadal Core Multi-mission Technology Needs

Any planetary spacecraft, regardless of its specific destination, must cope with the fundamental challenges of **traveling long distances** from the Earth and Sun, **surviving and operating over the resulting long mission** duration, and **operating without real-time control** from Earth and with limited data streams.

As future mission objectives evolve, meeting these challenges will require continued advances in several technology categories, including the following:

- Reduced mass and power requirements for spacecraft and their subsystems;
- Improved communications yielding higher data rates;
- Increased spacecraft autonomy;
- More efficient power and propulsion for all phases of the missions;
- More robust spacecraft for survival in extreme environments;
- New and improved sensors, instruments, and sampling systems; and of course
- Mission and trajectory design and optimization.

Decadal Recommends Multi-Mission Technologies

- The highest priority for near-term multi-mission technology investment is for the completion and validation of the **Advanced Stirling Radioisotope Generator (ASRG)**.

- Robust Discovery and New Frontiers programs would be substantially enhanced by such a **commitment to multi-mission technologies**
  - For the coming decade, it is imperative that NASA expand its investment program in these **fundamental technology areas** with the twin goals of both
    - **<u>reducing the cost</u> of planetary missions**
    - **<u>improving</u> their scientific <u>capability and reliability</u>**

- Requirements will vary from mission to mission. The scope of these challenges requires careful planning so that research and development can establish the proper technological foundation.
  - NASA should **expand its program of regular future <u>mission studies</u>** to **identify** as early as possible the **technology drivers and common needs** for likely future missions.

Panel Key Technology Findings & Recommendations

Primitive Bodies	Inner Planets	Mars	Giant Planets	Satellites
Continue technology developments in: • **ASRG** • **Thruster packaging and lifetime** • **Thermal protection systems** • Remote sampling and coring devices • Methods of determining that a sample contains ices and organic matter and preserving it at low temperatures • **Electric thrusters (SEP)** mated to **advanced power systems** Bridge the TRL 4-6 development gap for flight instruments	Continue current initiatives. Possibly expand to include capabilities For: • **Surface access and survivability** for Venus's surface • Frigid polar craters on the Moon.	Key technologies necessary to accomplish Mars Sample Return are: • **Mars ascent vehicle** • **Rendezvous and capture** of orbiting sample return container, and • Planetary protection technologies • ***Solar electric propulsion*** *(per MPPG)*	Continue developments in: • **ASRG** • **Thermal protection for atmospheric probes** • **Aerocapture** • and/or **nuclear electric propulsion** • **Robust deep-space communications** capabilities.	Develop technology necessary to enable Jupiter Europa Orbiter. Address technical readiness of orbital and in situ elements of Titan Saturn System Mission Including: • **Balloon system** • Low mass/ power Instruments • Cryogenic surface sampling systems.

Decadal Flagship Technology Needs

MAX-C	Jupiter Europa Orbiter	Uranus Orbiter and Probe	Enceladus Orbiter	Venus Climate Mission
• Sample acquisition, processing, and encapsulation on Mars	• Designing and packaging science instruments, especially the detectors, to be able to acquire sufficiently meaningful data in the jovian radiation environment • Longer-term: Supporting instrument technology program aimed specifically at the issue of acquiring meaningful scientific data in a high radiation environment	• Long-lived, flight qualified **ASRG**s, with lifetimes in excess of 15 years • **Lightweight materials for the orbiter structure and subsystems** • **Thermal protection systems for the probe** • **Availability of a flight-tested, comparatively inexpensive SEP** • **Aerocapture capability** for Uranus and Neptune	• Mass spectrometer • Thermal mapping radiometer, • Dust analyzer, an imaging camera • Magnetometer. • Ensuring reliability & lifetime of **ASRG**s. • Planetary protection	• **Packaging of the mini-probe** and the drop sondes, especially integration of a sophisticated neutral mass spectrometer in the mini-probe • **Entry flight system itself is still a significant design and development challenge**

Planetary Technology Needs

- **Multi-mission Technologies**
  - Enable access to more challenging solar system destinations
  - Core Multi-mission technologies which are applicable to Discovery, New Frontiers, and Flagship mission classes
  - System capability driven (systems to TRL $\geq$6 rather than just sub-components)
- **Spacecraft bus components <u>and</u> platforms**
  - Spacecraft bus components
    - Propulsion, power (Solar/RPS), structures and mechanisms, PMAD, energy storage, thermal, spacecraft communications (transmitters, amplifiers, antennas), on-board processing, etc.
  - Spacecraft and platforms
    - PAV/MAV, EEV, ERV, EDL, mobility systems, etc…
  - System capabilities
    - EDL, orbital rendezvous & docking, engineering instrumentation for spacecraft/platforms, etc…

Planetary Technology Needs

- **Spacecraft bus components <u>and</u> platforms - continued**
  - Tools associated with specific spacecraft systems
    - Part of the system capability approach
    - Such as astrodynamics/celestial mechanics/trajectory tools optimized for spacecraft/platform technologies like electric propulsion and Aerocapture (Low Thrust Trajectory Tool (LTTT), Multi-mission Systems Analysis for Planetary Entry (M-SAPE), Advanced Propulsion Sizing tool), etc…
- **Science Instrumentation Technologies**
  - PI/Science driven instruments specific to the measurement at the destination
  - Includes all orbital and in situ instruments used for scientific measurements
    - Includes cryogenics, high temperature or radiation environments, coring, drilling, sample handling, in situ processing/assessment/science

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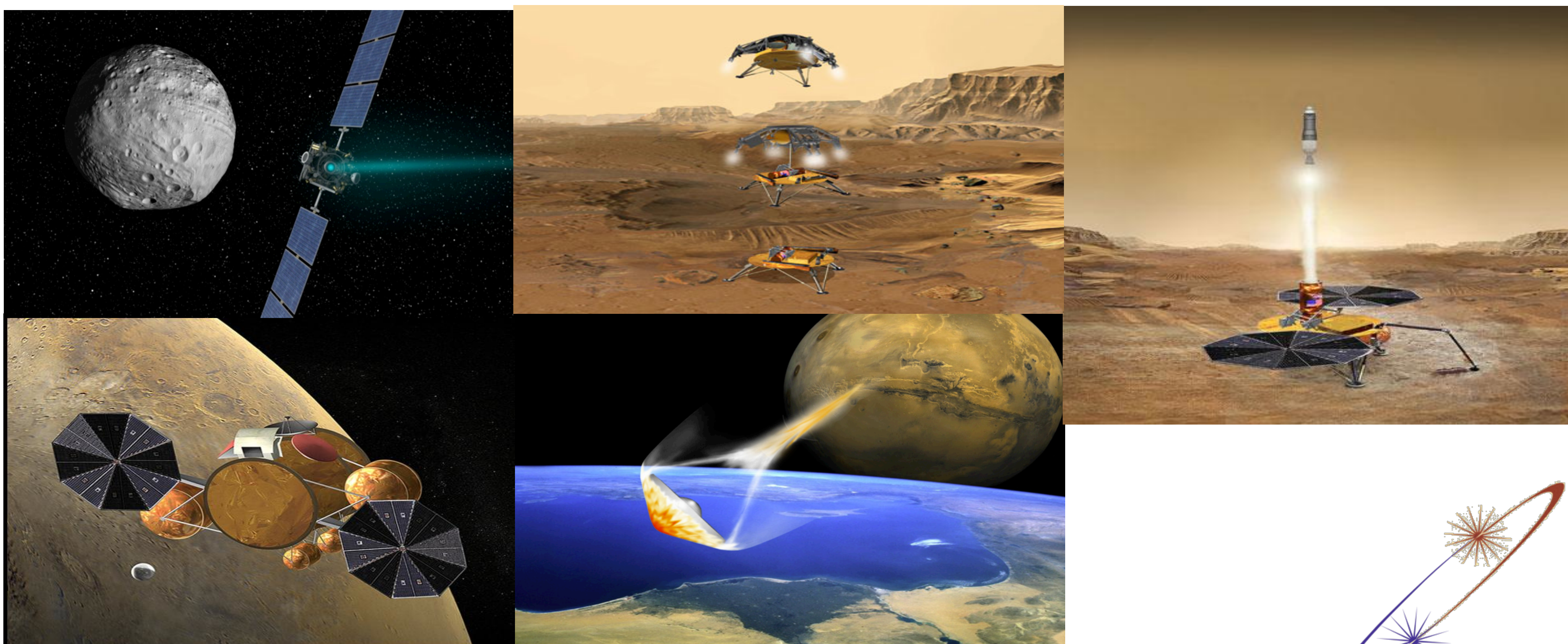
Propulsion technologies relevant to Mars



David Anderson
IEEE Aerospace Conference, Big Sky, MT
March 6, 2013

NASA's In-Space Propulsion Technology (ISPT) Program

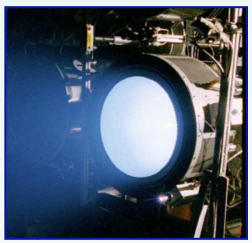
NASA's ISPT Program develops critical propulsion, entry vehicle, and other spacecraft and platform subsystem technologies to enable or significantly enhance future planetary science missions. The current ISPT focus is TRL 3-6+ product development.

- *Develop technologies that enable access to more challenging and interesting science destinations or benefit the agency's future robotic science missions by significantly reducing travel times to distant bodies, increasing scientific payload capability, or reducing mission cost and risk.*

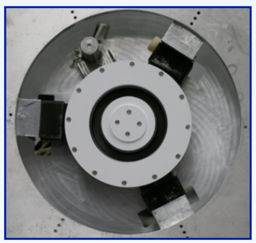
Propulsion System Technologies

AMBR High-Temp Rocket Engine

7 kW NEXT Ion Propulsion System

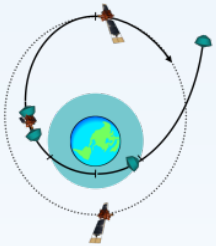


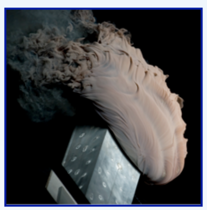
4 kW HIVHAC Thruster & Hall Propulsion System



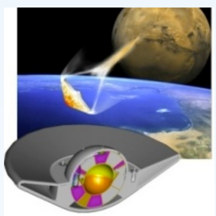
Entry Vehicle Technologies

Aerocapture





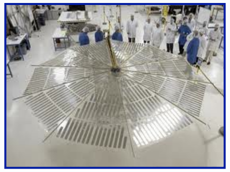
Multi-Mission Earth Entry Vehicle



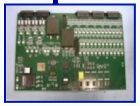
Spacecraft Bus & Sample Return Technologies

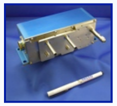
Mars Ascent Vehicle

PV Array Systems for planetary missions

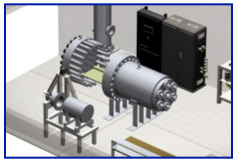


Spacecraft Bus Components



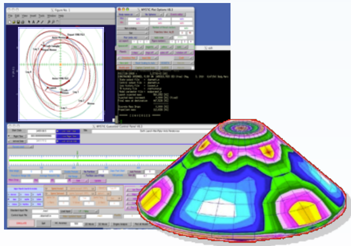


Extreme Environments

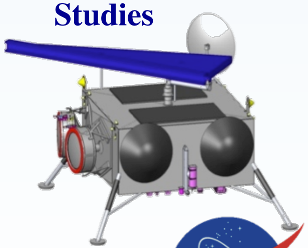


Systems & Mission Studies

Mission Analysis Tools

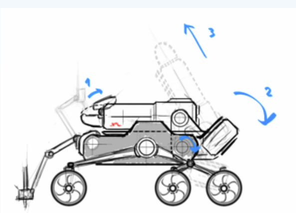


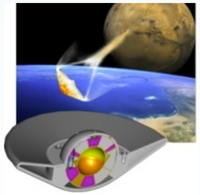
Mission and System Studies

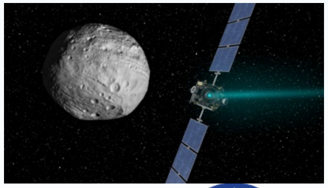


ISPT & JPL Innovation Foundry Study
Identification of Key Technologies

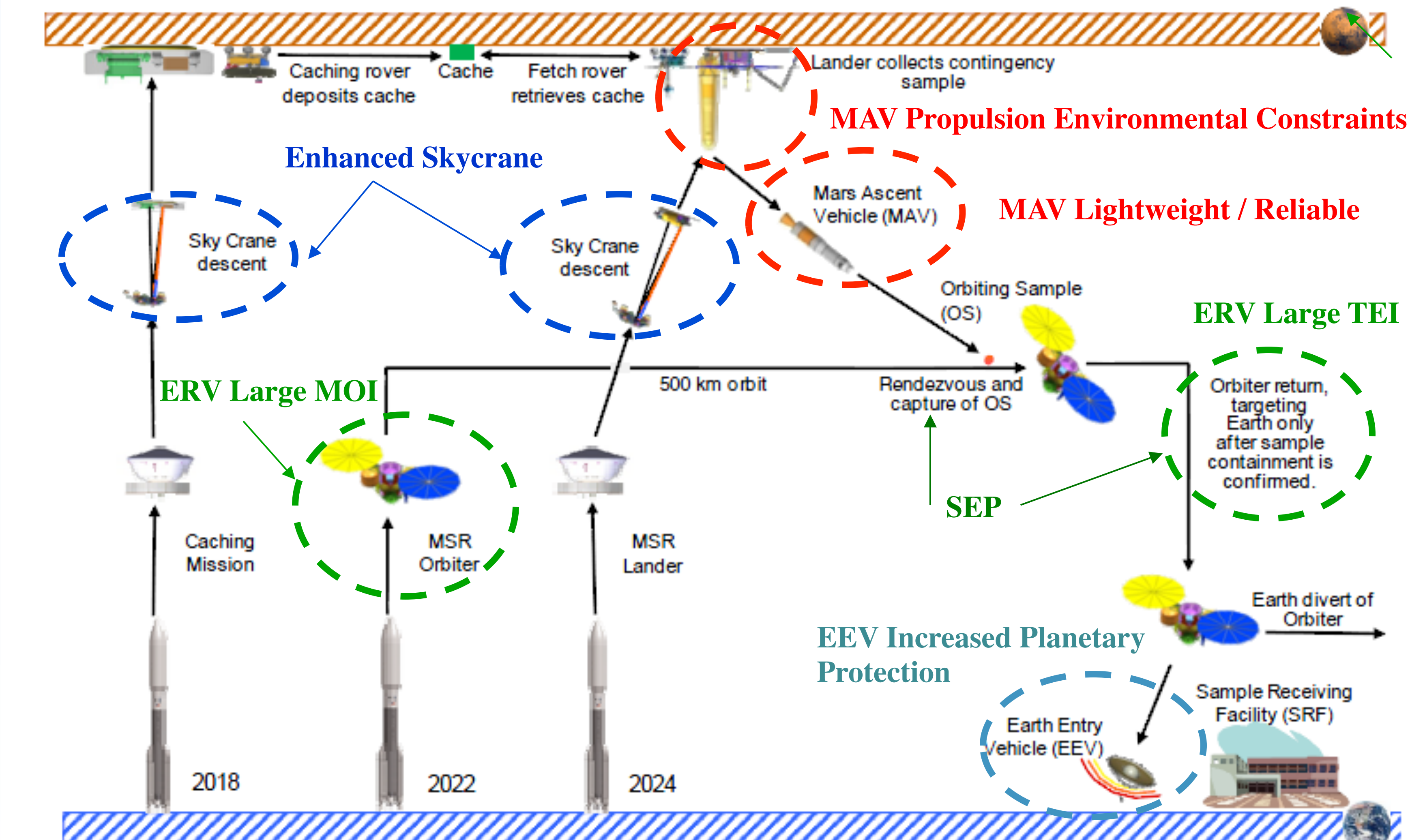
- MAV/Mobile-MAV technologies are enabling for all mission architectures
- SEP and advanced Mars EDL technologies are either enhancing or enabling
- Autonomous Rendezvous & Docking technologies are enabling
  - Except for the ones that use a Nano-Sat to return the sample without a transfer to an Earth return vehicle (ERV).
- Planetary Protection technologies are crucial for MSR, and impact ISPT efforts
- Based on the technology requirements of the mission architectures considered, the order of importance of the technology needs would be:
  1. Mars Ascent Vehicle (MAV) & Mobile MAV
  2. Solar Electric Propulsion (SEP)
  3. Advanced Mars Entry Descent and Landing (EDL)
  4. Sample Retrieval in Space
  5. Surface Mobility







MSR Architecture



Multiple Propulsion Needs for the MSR Campaign

Solar Electric Propulsion Mission Analysis

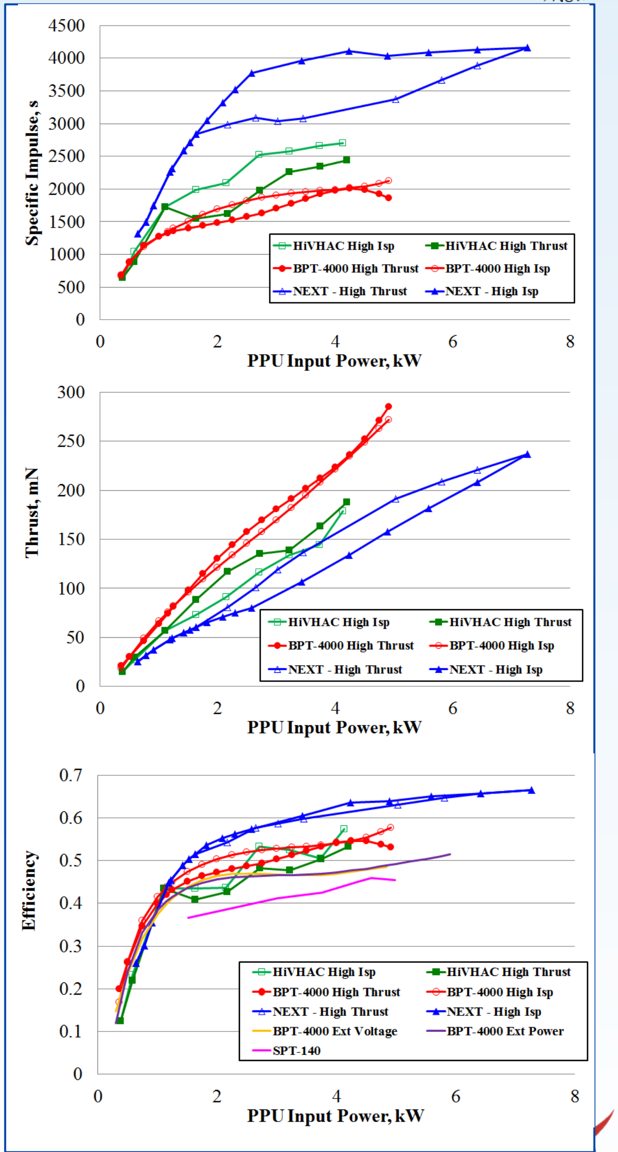
- **HIVHAC and BPT-4000 performance Comparison**

Performance Characteristics of HIVHAC vs. SOA Hall (BPT-4000).

Characteristic	BPT-4000	HIVHAC
Thruster Power Range, kW	0.3-4.5	0.3-3.9
Throttle Ratio	15:1	12:1
Operating Voltage, V	150-400	200-700
Specific Impulse, sec	710-2100	860-2700
Thrust, mN	22-260	20-207
Efficiency	0.25-0.58	0.32-0.62
Propellant Throughput, kg	450	>300

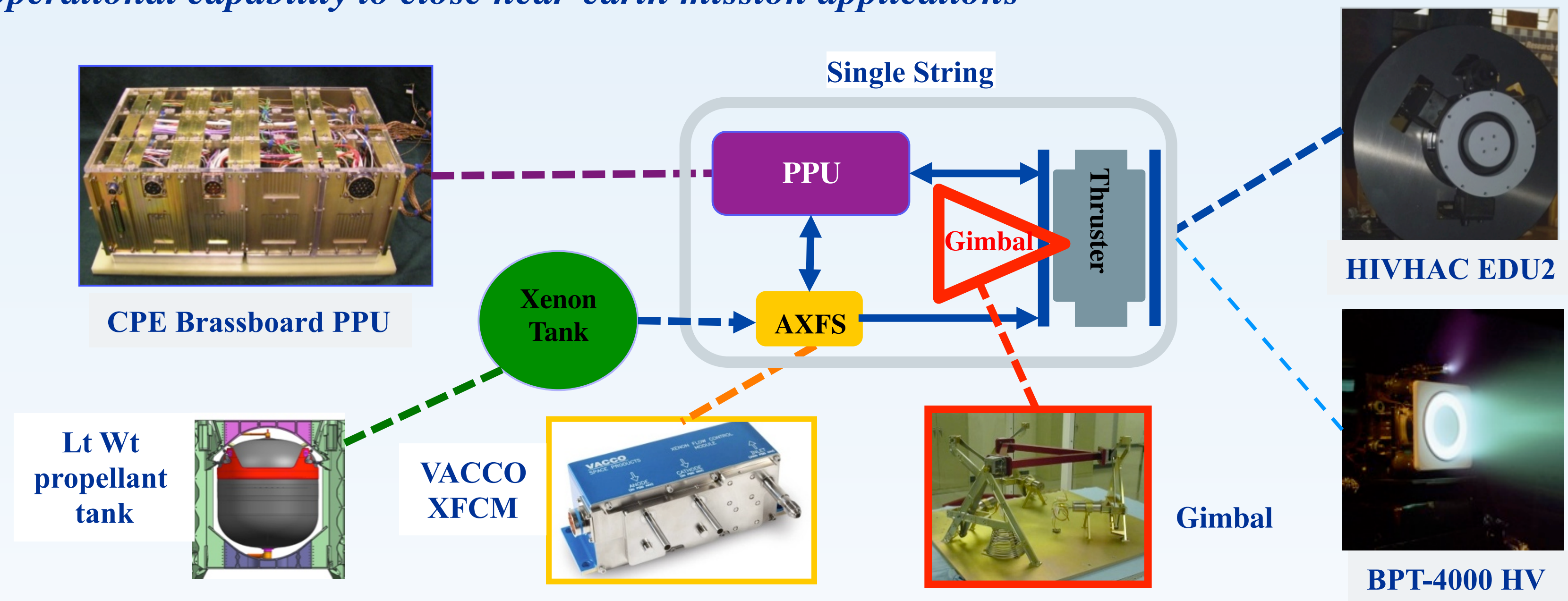
BPT-4000	HIVHAC
NEA Rendezvous	NEA Rendezvous
NEA Sample Return	NEA Sample Return
Mars Sample Return	Multi-Main Belt Rendezvous
	Comet Rendezvous
	Dawn

- **Development to go**
- **Nth User Cost**
- **Capability**
- **Science Return**



High Voltage Hall Accelerator (HIVHAC)
Electric Propulsion for low cost Discovery-class and Sample Return Missions

Objective: *Develop key components of a HIVHAC Hall propulsion system (thruster, PPU/ DCIU, feed system) to TRL 6 to enable/enhance new SMD Discovery missions; expand operational capability to close near-earth mission applications*



- **The HIVHAC EDU thruster offers improved performance and mission benefits over SOA**
- **The HIVHAC project has leveraged OCT SBIR funding to advance the HIVHAC thruster system readiness**
- **A flight-qualified VACCO XFCM was delivered to NASA GRC in March 2012 and will be integrated with the HIVHAC thruster**

Ultra Lightweight Tank Technology (ULTT) for future planetary missions

Objective:

- To design ultra-lightweight propellant and pressurant tanks sized for MSL/MSR Skycrane with an option to manufacture and qualify.
- Goal: Achieve highest mass saving with reliability

Description

- This effort aims to develop the Composite Overwrapped Pressure Vessel (COPV) tanks for propellants and pressurants for Mars Sample Return (MSR) mission
- Tanks are most often the heaviest component on a spacecraft
- Currently component technologies are maturing and ready to be "harvested"

Benefits

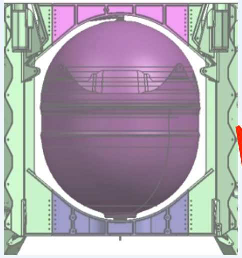
- **23** kg mass savings are achievable for 3 tanks sized for the Skycrane **(48% mass reduction)**
  - Mass savings can be passed on to the scientific payload or increase mass margin
- Broad impact to virtually ALL space missions as most use liquid propellants or pressurant
  - Europa Explorer tank mass can be reduced by 60 kg

Baseline Approach

- To complete CDR design package (June 2013)
- Option: Build and test three (3) Skycrane size tanks
- Option: Ready the tanks for flight demonstration in 2019 or beyond

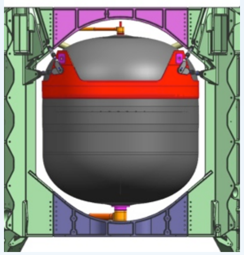
Descent Stage Propellant Tanks

Existing MSL Titanium Tank

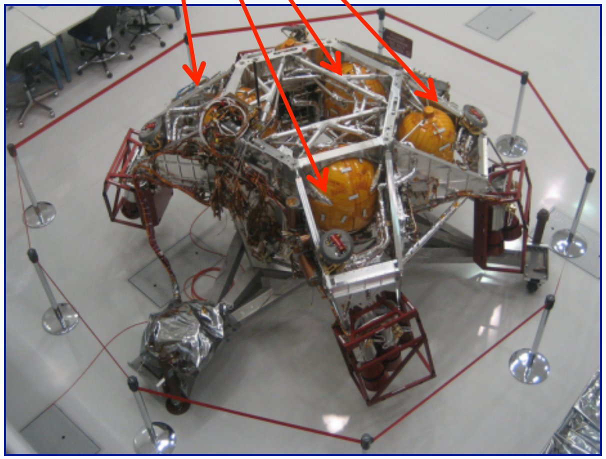


594mm Diameter, ~720mm Tall

Drop in replacement ultralight tank



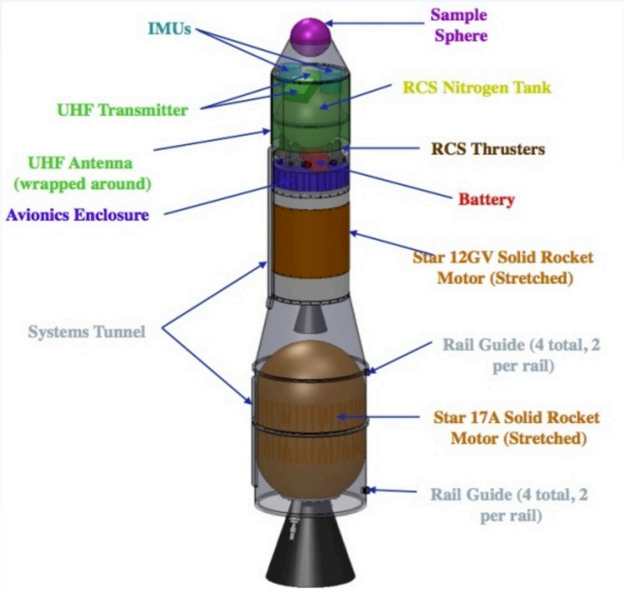
594mm Diameter, 684mm Tall



Mars Ascent Vehicle (MAV)

Top Level Requirements

- Launch to Mars orbit
  - 500 km ±100 km
  - 45^o latitude
  - Delta V > 3.3 km/s
- MAV spends 90 + sols on Martian surface
- 5 kg Orbiting Sample (OS), with 0.5-1.0 kg of samples
- Single-fault tolerant avionics & thermal control
- Desire to meet interface requirements of MSL EDL. EDL produces ≥ 20 g's

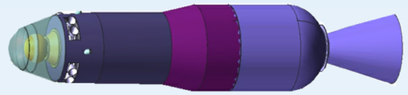


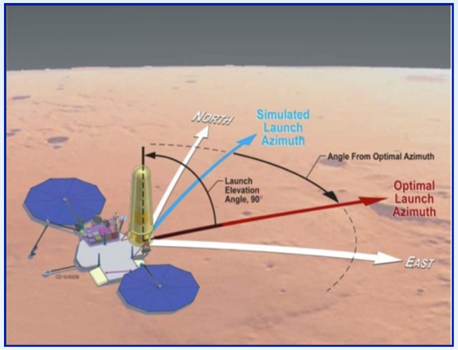
MAV Notional Development Plan

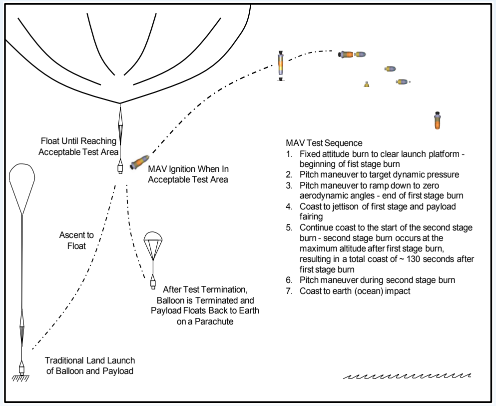
- **Phase 1: Early investment**
  - System definition and development studies (~6 months)
  - Propulsion subsystem development and tests for select MAV concepts (~3 years)
- **Phase 2: Component technology development to TRL 6 and system architecture selections (~3-year, ~$40M)**
  - Develop component technologies to reach TRL6. Test components' performance in realistic temperatures, storage, EDL g-loads as appropriate.
  - Culminates in the final downselect to a single concept, whose high-risk components have known performance and survivability characteristics
- **Phase 3: Integrate and develop a MAV. Perform integrated testing and qualification. (~5 years, ~$210M, includes Phase 3 options)**
  - Perform three high-altitude flight tests to assure at least two successful tests and measure performance prior to MSR lander PDR.
  - At least one flight test must be performed on unit that has successfully completed environmental qualification/life testing

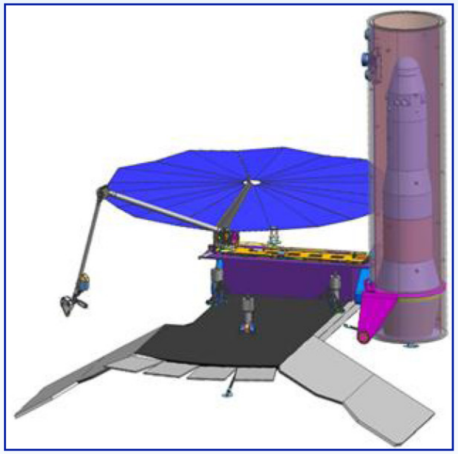
MAV Component Technology Development

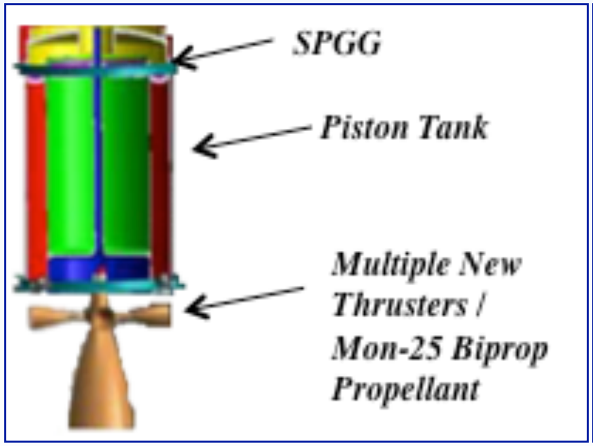
- Published MAV study guidelines
- Completed multiple MAV concurrent engineering studies
- Awarded 3 contracts to Lockheed Martin, ATK, and Northrop Grumman to develop preliminary concepts and ID technology gaps
- Completed High Altitude Balloon launched MAV Flight Test Study
- Initiated solid rocket motor propellant aging test effort

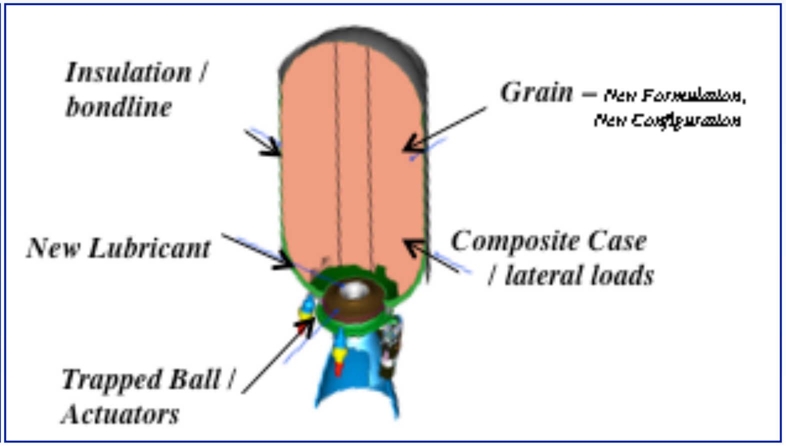








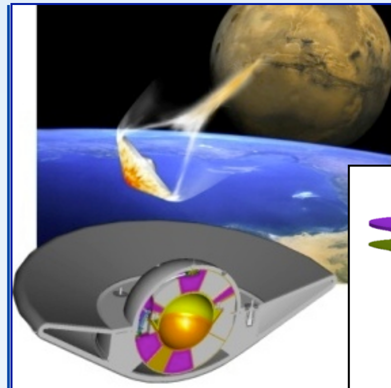


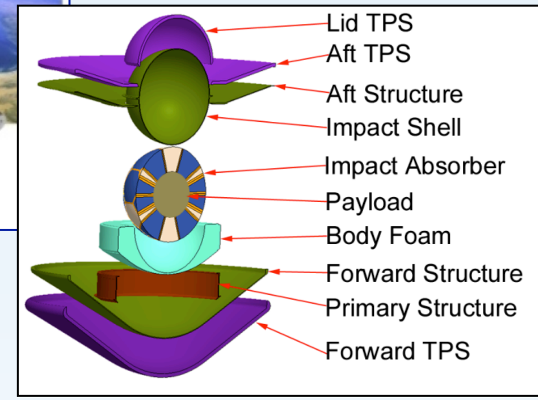


Multi-Mission Earth Entry Vehicle (MMEEV) Technology

Description

- Earth Entry Vehicles (EEVs) are necessary for bringing samples of material from our Solar System safely back to Earth’s surface.
- The Multi-Mission EEV approach seeks to develop and implement common design principles on multiple missions such as New Frontiers, Discovery, and eventual planetary sample returns.





Objective

- To develop technologies that enable future sample return missions
- To apply common design features to multiple flights, to improve reliability to the 10^{-6} level

Benefits

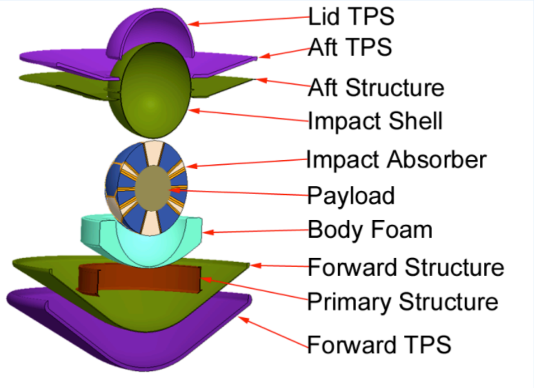
- Maximize efficient use of technology investments, saving Agency costs over the long term
- Establish validation data for risk reduction on future missions that require extremely high probabilities of success.

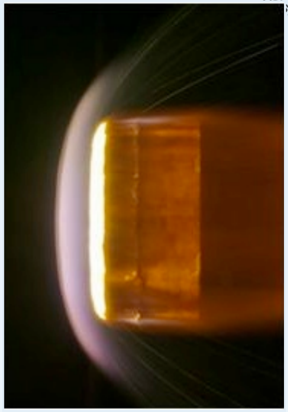
Discipline Areas

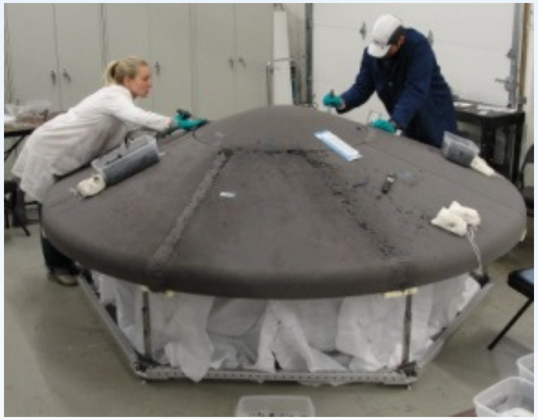
- Materials development
- Aerodynamics
- Aerothermodynamic modeling
- Systems engineering and integration
- Advanced materials for TPS, structures, and impact protection
- Thermal control
- Mechanical Design/Packaging
- Systems Engineering

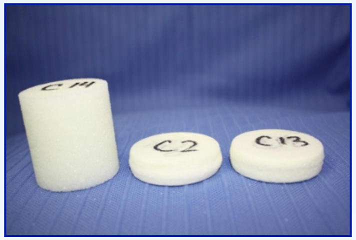
Multi-Mission Earth Entry Vehicle (MMEEV) Concept

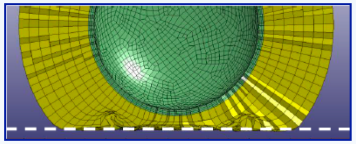
- Passive, Single-Stage EDL method to minimize cost and risk
- Eliminates limited-reliability systems
- Well-suited for Mars Sample Return (MSR) and other sample return missions
- Detailed models in the M-SAPE tool



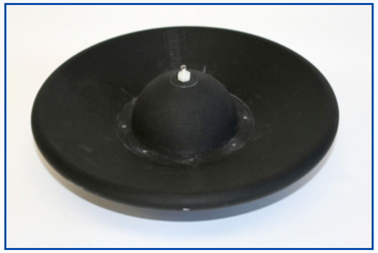


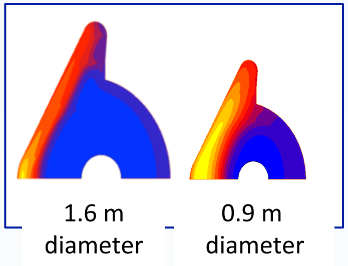






MMEEV Parametric Variable	Range
Payload	5 to 30 kg
Vehicle Diameter	0.5 to 2.5 m
Inertial Entry Velocity	10 to 16 km/s
Inertial Entry Flight Path Angle	-5° to -25°





Questions?

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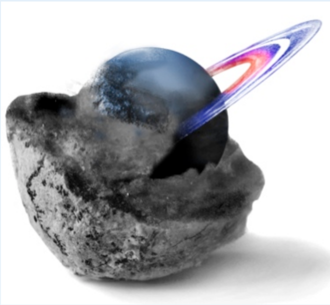
Back-up

Study Architectures

ISPT & JPL Innovation Foundry Study

Goal:

- **Evaluate technologies within the domain of ISPT that can significantly reduce the cost and complexity of the Mars Sample Return (MSR) campaign.**



Objectives

1. Identify Mars Sample Return mission architectures that are enhanced by technologies in the ISPT office's domain.
2. Identify new Mars Sample Return mission architectures that are enabled by technologies in the ISPT office's domain.
3. Compare the relative cost, risk, and scientific merit of these mission architectures.
4. Identify the maturation path for the enhancing and enabling technologies for the attractive mission architectures.

Participants	Roles
David Anderson	Client (NASA GRC ISPT Office)
John Dankanich	Client (NASA GRC ISPT Office)
Nathan Strange	Study Lead (JPL)
Nimisha Mittal	Assistant Study Lead (JPL)
Randii Wessen	Facilitator (JPL)
Charles Whetsel	Mars Program (JPL)
Erik Nilsen	Mars Program (JPL)
John Ziemer	JPL Innovation Foundry (JPL)
John Brophy	Electric Propulsion (JPL)
Tom Randolph	Systems Engineering (JPL)
Doug Hofmann	Materials (JPL)
Tim McElrath	Navigation & MAV (JPL)
Brian Wilcox	Robotics & MAV (JPL)
Mark Adler	out-of-session consultant (JPL)

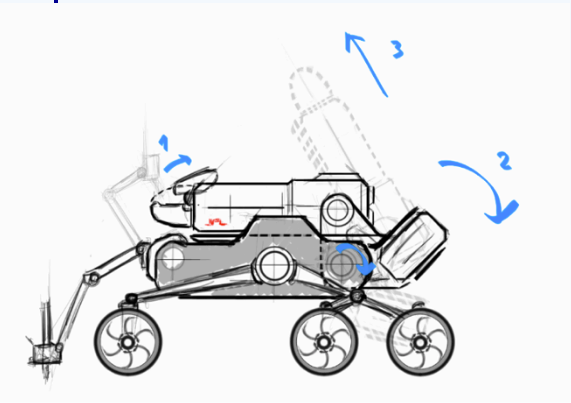
ISPT & JPL Innovation Foundry Study
Key Technologies

Mars Ascent Vehicle (MAV) & Mobile MAV

- Unguided or "loosely-guided" MAV → enabled by Solar Electric Propulsion (SEP) collection of the Orbiting Sample canister (OS)
- Mini-MAV; technologies that enable a < 200 kg MAV → "Mobile MAV" concept
- Single stage MAV

- MAV support and erection structures; MAV spin table
- Lightweight MAV structure
- Miniaturized (low mass/low power) MAV sub-systems like avionics/deep space radio (i.e. smaller SDST) to enable smart OS or Nano-Sat sample capsule
- Deployable insulation such as spray foam
- Proper orientation and alignment of an unguided MAV

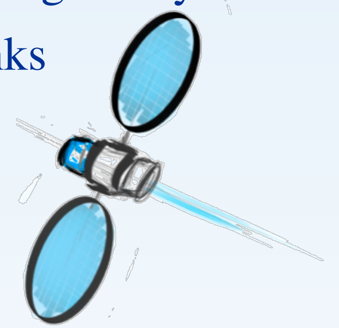
- Low temperature, higher Isp solid or liquid propellants
- Hybrid propellant MAV
- In-Situ Resource Utilization (ISRU) for MAV propellant



ISPT & JPL Innovation Foundry Study
Key Technologies

Solar Electric Propulsion (SEP) for orbiters and Earth Return Vehicles (ERV)

- Long-life Hall thrusters, and Low-cost SEP lifetime testing
- Simplified PPU's, including driving the EP system directly from high-voltage arrays
- Higher power arrays for electric propulsion, and high capacity Xenon tanks
- SEP and associated GNC techniques for capturing OS
  → Unguided MAV enabled by SEP for OS collection
- SEP return to a cislunar waypoint
- Micro-SEP (e.g. electrospray thruster) enabled Nano-Sat sample return capsule that launches on MAV and returns sample to a cislunar waypoint



- Low Energy / Low Thrust trajectory design tool to develop SEP trajectories that take full advantage of n-body manifolds
- Tools for rapid analysis of SEP Lunar escape trajectories to develop SEP trajectories that take full advantage of Lunar gravity-assists

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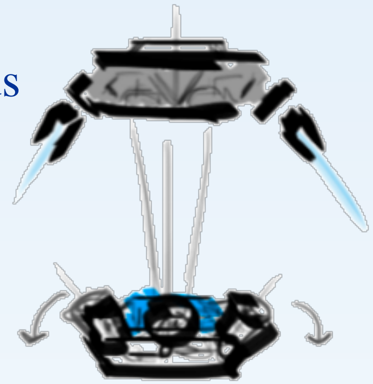
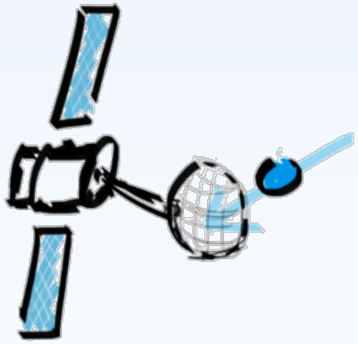
Key Technologies

3. Advanced Mars EDL



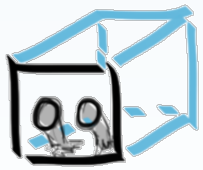
- Improved EDL thrusters using lighter tanks, higher Isp fuel, airbags
- Supersonic Retro-Propulsion (SRP) to enable the landing of payloads on Mars with higher ballistic coefficients
- Precision landing technologies
- Automated landing hazard avoidance (e.g. ALHAT)
- Low density supersonic decelerator (e.g. LDSD)
- Hypersonic/Supersonic inflatable aerodynamic decelerators (e.g. HIAD/SIAD)

4. Sample Retrieval in Space



- Miniaturized low-power radio beacon for orbiting sample
- Autonomous Rendezvous and Docking (AR&D) sensors and software
- Capture mechanism for orbiting sample
- Ranging sensors for relative navigation between orbiter and OS

5. Planetary Protection



- Earth entry vehicle technologies (PP drives EEV reliability requirement)
- Identification of long-term stable orbits for cislunar sample return

ISPT & JPL Innovation Foundry Study Enabling Architecture Concepts

1. Multiple Mini-Mars Ascent Vehicle (MAV) on Mobile Platform (Med. Cost/Low Risk/High Science)

- Architecture concept involves at least two small MAVs (<200 kg), which would be mounted on MSL derived rovers, and allows sample collection from diverse sites.
- A Solar Electric Propulsion (SEP) science orbiter would first be launched from Earth and sent to Mars during the 2018 launch opportunity.
  - The orbiter will be equipped to retrieve the orbiting samples after the conclusion of its science mission.
  - The orbiter would act as an Earth Return Vehicle (ERV) and then bring the samples back to the Earth to either direct entry or to a cislunar gateway.
- A second launch carrying two mobile miniature rovers and MAVs would take place in 2020.
  - Each rover will be equipped to drill, collect a sample, and load into the MAV.
  - The MAVs will launch from the Martian surface, eject the orbiting samples (OS) at a point where the existing SEP ERV orbiter would collect them.

ISPT & JPL Innovation Foundry Study
Enabling Architecture Concepts – Technologies Needed

1. Multiple Mini-MAV on Mobile Platform

Propulsion Technologies that could enable this concept include:

1. Mobile MAV and Miniaturized MAV support systems such as radios, software, and structures.
2. Solar Electric Propulsion (SEP) and associated GNC techniques for capturing multiple orbiting samples
3. Autonomous Rendezvous & Docking (AR&D) technology, and an orbiting sample capture mechanism
4. Required mass performance from airbags for a MER-type landing

Propulsion Technologies that would enhance such architecture include:

1. Improved MAV
   - Higher Isp, and lightweight avionics to reduce the overall mass
   - Low temperature Solid Rocket Motors
   - Mobility range of the rovers carrying the MAVs, for better sample collection
2. Better SEP systems, and Micro-SEP technology for OS (e.g. Nanosat OS)
3. Precision landing – could remove (or reduce) the need for mobility on the Martian surface

ISPT & JPL Innovation Foundry Study
Enabling Architecture Concepts

2. SEP Tug (Med. Cost / Low Risk / Med. Science)

- In this concept, a single SEP tug stage will first deliver a lander to Mars orbit.
- The lander would use a skycrane-type landing system to enter Mars from orbit, enabling a landing at any latitude.
- The lander could be equipped with a mobile, unguided MAV.
- After sample collection and MAV launch to orbit, the SEP tug stage will also capture the OS, and return it to Earth for direct entry or to cis-lunar space.

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Enabling Architecture Concepts – Technologies Needed

2. SEP Tug

Propulsion Technologies that could enable this concept include:

1. MAV support systems
2. Planetary Protection Technologies
3. Autonomous Rendezvous & docking (AR&D)

Propulsion Technologies that would enhance such architecture include:

1. Mobile MAV, Unguided MAV, or a single stage MAV
2. SEP Long life Hall thrusters, SEP Direct drive, or Large high power SEP
   - High Capacity Xenon tanks
   - Low thrust trajectory tools
   - Large lightweight solar arrays
3. Improved EDL thrusters with lighter tanks and higher Isp
4. HIAD or SIAD, Supersonic Retro-Propulsion, and Precision landing

ISPT & JPL Innovation Foundry Study
Enabling Architecture Concepts

3. Mobile MAV with Nanosat (Low Cost / Med. Risk / Med. Science)

- This concept consists of a single MSL-derived Mobile MAV that lands with the MSL skycrane landing system.
- The Mobile MAV collects the samples and places them in a ~200 kg MAV.
- The MAV then launches a ~12 kg nanosat with the samples.
- The nanosat then uses miniaturized SEP (such as electrospray propulsion) to fly from Mars to cislunar space where it could later be retrieved by a human cislunar mission.

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Enabling Architecture Concepts – Technologies Needed

3. Mobile MAV with Nanosat

Propulsion Technologies that could enable this concept include:

1. Mobile MAV
2. Micro SEP technology for OS
3. Miniaturized Deep Space Radios (a smaller SDST)
4. Small, low-power avionics

Propulsion Technologies that would enhance such architecture include:

1. Improved MAV, with a higher Isp, and lightweight avionics to reduce the overall mass
   - Low temperature Solid Rocket Motors
   - Increased mobility range of mobile MAV, for better sample collection
2. Better SEP systems
3. Precision landing – could reduce the need for mobility on the Martian surface