National Aeronautics and Space Administration

Technology & Innovation Committee

NAC Advisory Council

Dr. Bill Ballhaus, Chair

December 12, 2013

Technology & Innovation Committee

"The scope of the Committee includes all NASA programs that could benefit from technology, research and innovation."

T&I Committee Meeting Participants
December 10, 2013

- Dr. William Ballhaus, Chair
- Dr. Randall Correll, Consultant
- Mr. Gordon Eichhorst, Aperios Partners LLC
- Dr. Dava Newman, MIT
- Mr. David Neyland, Draper Laboratory
- Dr. Mary Ellen Weber, Stellar Strategies, LLC

T&I Committee Meeting Presentations

- Welcome to KSC
  - Robert Cabana, Director, Kennedy Space Center
- Space Technology Mission Directorate Update
  - Dr. Michael Gazarik, Associate Administrator, STMD
- Update on Solar Electric Propulsion
  - Chuck Taylor, Principal Investigator for In Space Propulsion and Space Power Generation
- Update on Cryogenic Propellant Storage and Transfer
  - Susan Motil, Project Manager, Cryogenic Propellant and Storage Transfer Project
- Chief Technologist Update and update on Technology Roadmapping
  - Dr. Mason Peck, NASA Chief Technologist, OCT
- Barriers to Innovation and Innovation Enablers
  - Karen Thompson, KSC Chief Technologist; Marty Waszak and Harold Gerrish, KSC

National Aeronautics and Space Administration

Overview
Strategic Integration Activities

NAC Technology and Innovation Committee Meeting
December 10, 2013
Kennedy Space Center

Mason Peck
Office of the Chief Technologist

Background: Roadmap and Strategic Space Technology Investment Plan (SSTIP)

FY 2010

Space Technology Roadmaps

- *140 challenges (10 per roadmap)*
- *320 technologies*
- *20-year horizon*

- *Revised every 4 years*

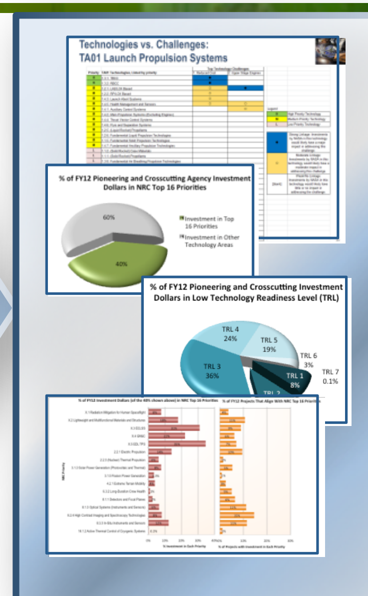
FY 2011

National Research Council (NRC) Study

Prioritization:

- 100 top technical challenges
- 83 high-priority technologies (roadmap-specific)
- 16 highest of high technologies (looking across all roadmaps)

- Requested every 4 years



FY 2012

SSTIP Development

Updated ST Roadmaps:

- Incorporate NRC Study Results

Developing a Strategic Space Technology Investment Plan:

- current investments
- current MD/Office priorities
- opportunities for partnership
- gaps vs. current budget and capabilities
- 20-Year horizon with 4-year implementation cadence

- Revised every 2 years

FY 2013

Execution

Investment Portfolio

- NASA Technology Executive Council Uses SSTIP to Make Decisions
- Must accommodate:
  - Mission Needs & Commitments
  - Push Opportunities
  - Affordability
  - Technical Progress
  - Programmatic Performance

- Budgeted annually

2012 Roadmap

<u>**Needed Improvements**</u>

- Address Missing Technical Areas (TAs) & Associated Technologies
- Inclusion of New Science Decadals
- Inclusion of HEOMD Capability Driven Framework (architecture and capability studies)
- Reduction of duplication and provide consistent types of data
- Some TAs <u>Lack A Real Starting Point</u> – Start with State of Art (SOA)
- Vague – Some TAs <u>Lack a Real Ending</u> Point (e.g., more reliable)
  What's the goal? When will you reach goal and do something else? - Add Capability Goals
- Different End Dates (18, 20, 25 years) – Provide a Consistent 20 Year Horizon
- Unreadable Graphics – Improve Graphics Legibility
- Standardization in Definitions, Symbols, Format or Type of Content
- Internal: Insufficient Opportunity to Participate In Reviews

Space Technology Roadmap
14 Technical Areas + Additional Areas

TA01 
- LAUNCH PROPULSION SYSTEMS

TA02 
- IN-SPACE PROPULSION TECHNOLOGIES

TA03 
- SPACE POWER & ENERGY STORAGE

TA04 
- ROBOTICS, TELE-ROBOTICS & AUTONOMOUS SYSTEMS

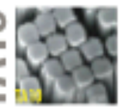
TA05 
- COMMUNICATION & NAVIGATION

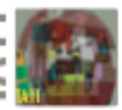
TA06 
- HUMAN HEALTH, LIFE SUPPORT & HABITATION SYSTEMS

TA07 
- HUMAN EXPLORATION DESTINATION SYSTEMS

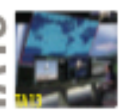
TA08 
- SCIENCE INSTRUMENTS, OBSERVATORIES & SENSOR SYSTEMS

TA09 
- ENTRY, DESCENT & LANDING SYSTEMS

TA10 
- NANOTECHNOLOGY

TA11 
- MODELING, SIMULATION, INFORMATION TECHNOLOGY & PROCESSING

TA12 
- MATERIALS, STRUCTURES, MECHANICAL SYSTEMS & MANUFACTURING

TA13 
- GROUND & LAUNCH SYSTEMS PROCESSING

TA14 
- THERMAL MANAGEMENT SYSTEMS

TA15 
AERONAUTICS

Autonomous Systems & AI Enhancements

Avionics Tech Enhancements

Radiation Tech Enhancements

Information Technology Section Expanded

Include NITRD and more

Space Weather Tech

Roadmap Update Schedule

Activity	Date
Kick Off Meeting	January 2014
Complete Drafts	July 2014
Center Review of Draft Roadmaps	August 2014
Disposition Comments	Sept 2014
Headquarters Review	Oct 2014
Finalize Roadmaps	Dec 2014
Provide to Independent Review Organization	Dec 30, 2014

National Aeronautics and
Space Administration

Space Technology Mission Directorate

NAC T&I Committee

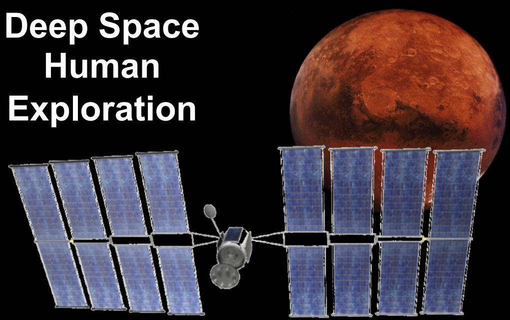
Presented by:
Dr. Michael Gazarik
Associate Administrator

December 2013

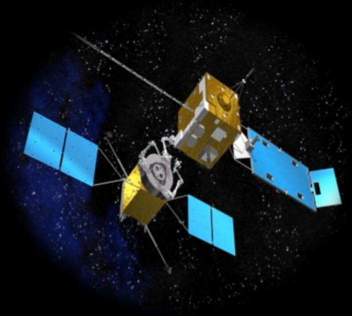
www.nasa.gov/spacetech

High-powered SEP Enables Multiple Applications

Deep Space Human Exploration

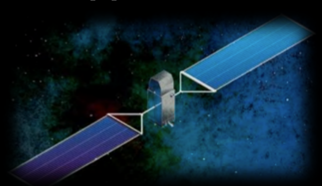


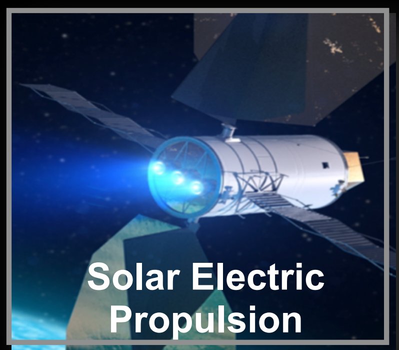
Satellite Servicing



Payload Delivery

Commercial Space Applications



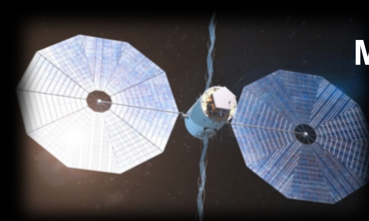


ISS Utilization

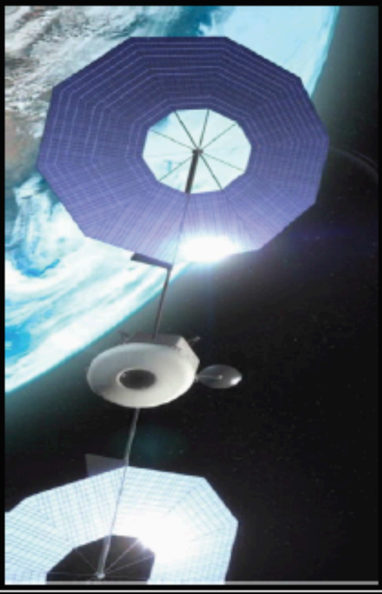
Orbital Debris Removal

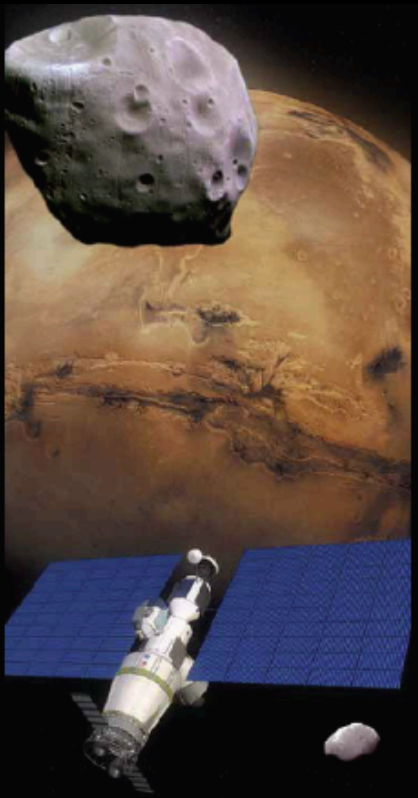
Space Scien
Mission

OGA Missions



SEP Mission Continuum





Deep Space 1 1998	**Dawn 2007**	**AEHF Rescue 2010**	**Asteroid Redirect Mission**	**Far-term Exploration Missions circa 2030's**
Technology Demonstrator	Deep-Space Science Mission	MILSATCOM Satellite saved with Hall Thrusters	Robotic Mission to Redirect Asteroid to Trans-Lunar Orbit	Crewed mission beyond Earth space
490kg	1220kg	6000 kg	13,000 kg	70,000 kg
2.5 kW power system 2kW EP system	10 kW power system 2.5kW EP system	~15kW-class power ~4.5kW-class EP	50kW-class power system 10 kW-class EP	350kW-class power system 300kW-class EP
$\Delta V = 2.7$km/s	$\Delta V = 10$km/s	$\Delta V > 10$km/s	$\Delta V \approx 10$ km/s	$\Delta V \approx 8$ km/s

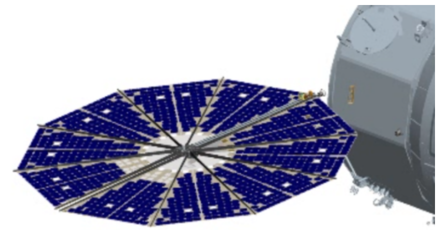
The First Steps Upwards to Mars……

Mission / Sequence	Current ISS Mission	Asteroid Redirect Mission	Long Stay In Deep Space	Humans to Mars Orbit	Humans to Surface, Short Stay	Humans to Surface, Long Stay
In Situ Resource Utilization & Surface Power						X
Surface Habitat						X
Entry Descent Landing, Human Lander					X	X
Aero-capture				X	X	X
Advanced Cryogenic Upper Stage				X	X	X
Deep Space Habitat	*		X	X	X	X
High Reliability Life Support	*		X	X	X	X
Autonomous Assembly	*		X	X	X	X
Solar Electric Propulsion for Cargo		X	X	X	X	X
Deep Space Guidance Navigation and Control		X	X	X	X	X
Crew Operations beyond LEO (Orion)		X	X	X	X	X
Crew Return from Beyond LEO – High Speed Entry (Orion)		X	X	X	X	X
Heavy Lift Beyond LEO (SLS)		X	X	X	X	X

Future Technology Development

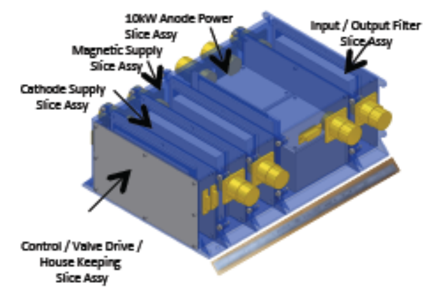
Large autonomously deployable solar arrays:

- 300kW class array systems (150kW per wing)
- Increased packing density and lower mass arrays
- Reductions to cost of arrays
- Increased operational voltage



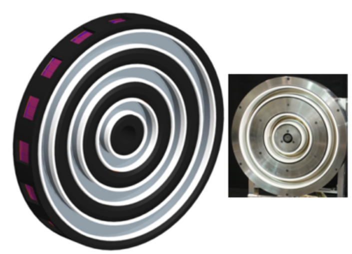
High Power PPU (Power Processing Unit)

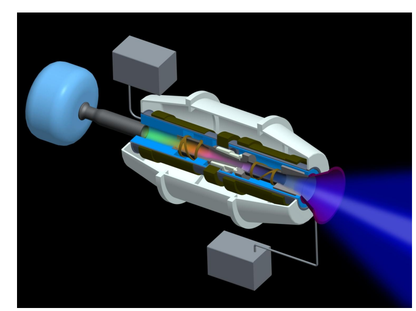
- High efficiency operation (> 96%)
- High temperature operation (~100^{0}C)
- Space qualified parts for 300V operation

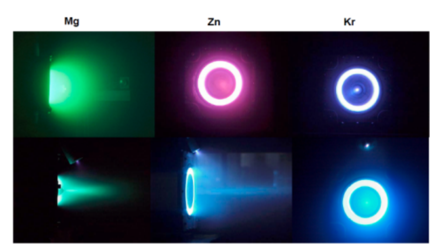


High Power Thruster

- 100 kW Class Thruster
- 20,000hr - 40,000hr Life
- Variable ISP
- Alternate Propellants



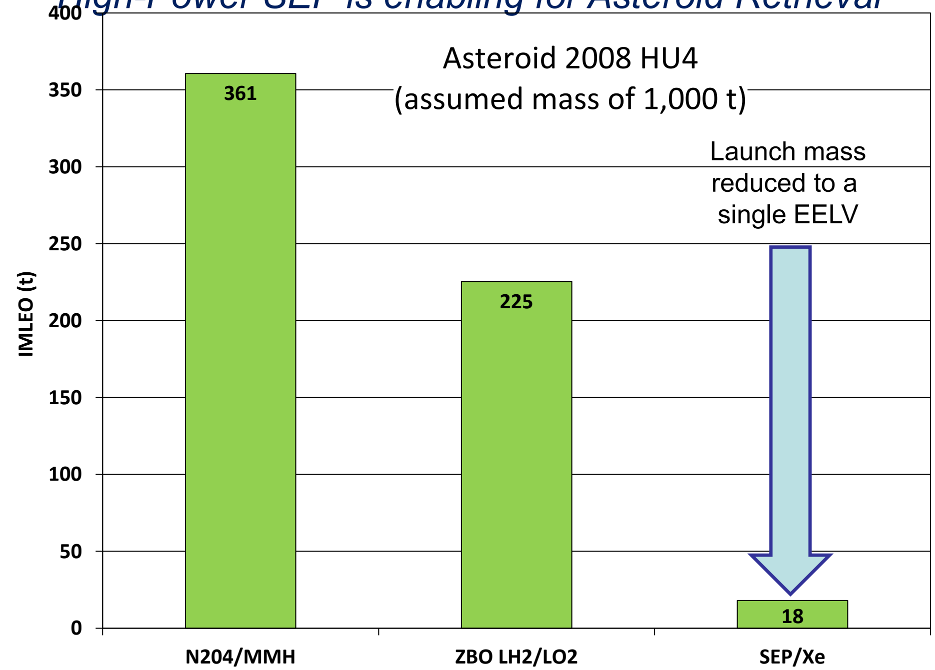




ARRM -- STMD SEP TDM Synergy

- ❑ **STMD is seeking an affordable demonstration of high-power, 30- to 50-kW, light-weight solar arrays and high-power electric propulsion**
- ❑ **The electric propulsion technology under development by STMD is enabling for an Asteroid Retrieval Mission**
- ❑ **Combining the SEP Technology Demonstration Mission (TDM) with the Asteroid Retrieval Mission would validate:**
  - ✓ High-power, light-weight solar arrays
  - ✓ High-power SEP
  - ✓ Asteroid retrieval

High-Power SEP is enabling for Asteroid Retrieval




30-kW SEP Technology Demonstration Concept (GRC)

Summary

- SEP chosen for ARRM because it reduces launch mass, which is a proxy for total mission cost
- SEP is a credible alternative for multiple future Human Exploration Mission Concepts
- STMD is leading the way developing the technologies required to execute these missions concepts

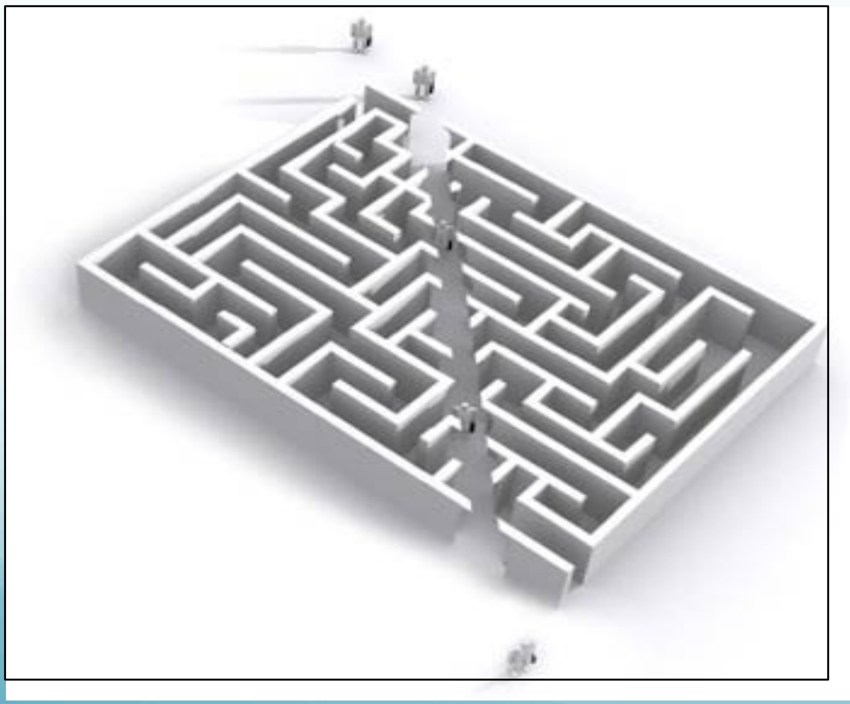
SEP is a Viable, Low Cost Solution for NASA's Future Missions

Findings

- Technologies under development by STMD have proven critical to the recently-defined Asteroid Retrieval Mission (ARM)
  - This proves that the roadmapping and strategic investment planning processes were effective at identifying these technologies
  - The ARM provides a stretch goal that is important to enable focus on needed technologies
  - Importantly, a demonstration as been incorporated into the ARM
- The committee is pleased that the process for updating the NASA Technology Roadmaps at Strategic Technology Investment Plan now appears to be an established process with appropriate cadence for periodic updates

Barriers to Innovation (B2I)

Executive Summary



Briefing for

NASA Advisory Council Technology and Innovation Committee

Presenters

Marty Waszak

and

Harold Gerrish

Kennedy Space Center
10 December 2013

Consensus Recommendations

Protect and sustain resources for innovative ideas and provide opportunities, assistance, and recognition to innovators

Top 5 Solutions

1. **Corporate Time for Creative Thinking -** Replicate best practices of companies where employees are allowed, ***and encouraged***, to spend a % of time (min-max) to pursue innovative ideas, whether or not directly related to their current projects.

2. **Innovation Labs & Creative Spaces -** Sustain *highly flexible* innovation labs and/or creative spaces that enable and support cross-discipline collaboration on ideas, prototypes, solutions, etc.

3. **Innovation Funding & Project Investments in Innovation -** Require *new* flight programs/projects to include an element of innovation (e.g., hardware, software, process, procurement) that contains potential for high-payoff and promotes acceptance of informed risk.

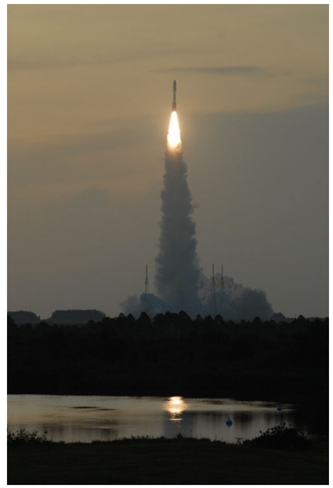
4. **Process Streamlining -** Mandate reduction of process requirements with thresholds to enable tailoring and streamlining (especially critical for low TRL projects).

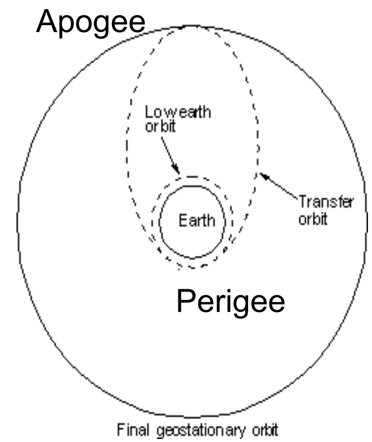
5. **Skunkworks -** Establish a true, sustainable NASA “Skunkworks” as a critical innovation pathway strategically aligned with NASA challenges.

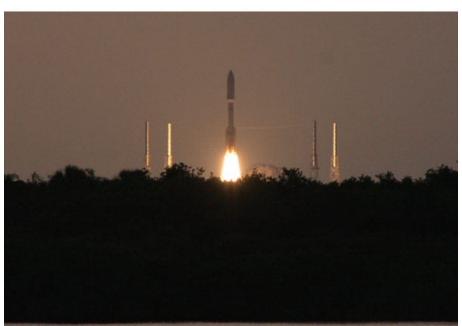
Back Up

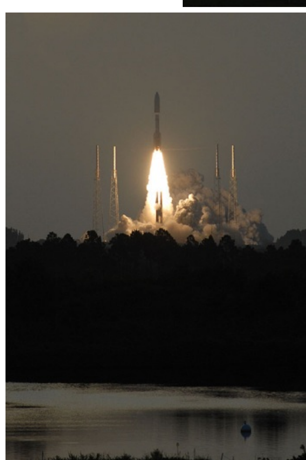
EP Coming of Age,….or the Advanced EHF Story

August 14, 2010: Launched on a ULA Atlas 531 with 3 Aerojet solid boosters and a Centaur upper stage









Typical launch drops in a Geosynchronous Transfer Orbit (GTO)

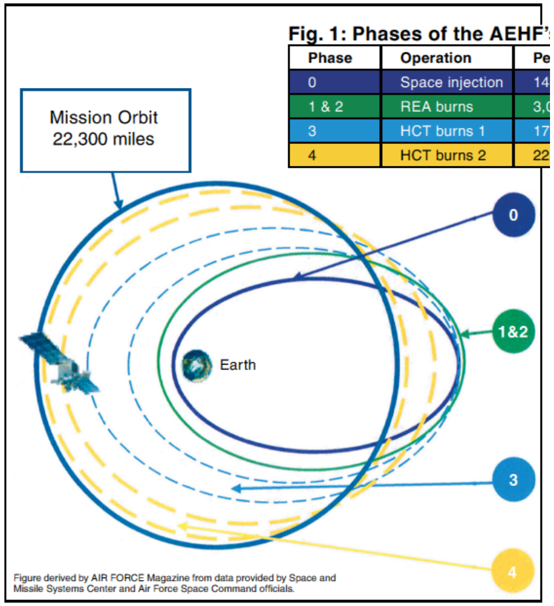
- **185 km (115 mi.) x 36,000 km (22,200 mi.) x 27 deg inclination**
- **Burn Liquid Apogee Engines (LAE) to circularize at GEO**
- **Typically half the launch mass is propellant for this burn**

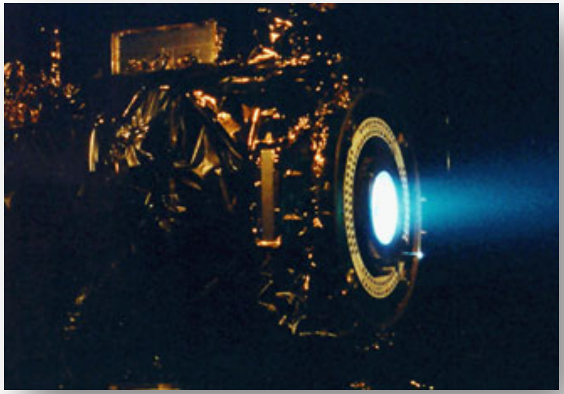
AEHF so large, planned to use Electric Propulsion Hall thrusters to do partial orbit transfer

- **Initial GTO is 225 km x 50,000 km**
- **LAE burns raise perigee to 19,000 km**
- **Hall thrusters do the rest**
- **AEHF uses 2500 kg propellant to get to orbit, but saves nearly 1000 kg over full chemical**

Los Angeles, We Have a Problem

- **<u>August 15, 2010</u>: Attempted to ignite apogee engine, shut down after a few seconds as spacecraft detected a problem. Not yet highly concerned**
- **<u>August 17, 2010</u>: Attempted to ignite a second time, also shut down. Signs of overheating.**
- **Tiger team rapidly determined that there was a propellant line blockage and further attempts at firing could cause an explosion.**
- **Spacecraft is losing 5 km altitude a day and accelerating.**
- **<u>August 22, 2010</u>: Plan formulated to save the spacecraft:**
  - **Use 22 N (5 lb.) hydrazine engines to raise perigee to avoid decay**
  - **Use .25 N (0.06 lb.) Hall thrusters to perform most of the transfer**
- **<u>September 22, 2010</u>: Perigee is raised by the hydrazine engines to 4900 km – safe from orbital decay from aerodynamic drag.**
- **<u>October 24, 2011:</u> Hall thrusters complete transition from GTO to GEO**
  - **What was going to take 3 months took a little over a year**
  - **The spacecraft had a launch mass of over 6 metric tons and was lugging almost 500 kg of useless oxidizer**
  - **If the original plan was to use Hall thrusters for the entire orbit raising operation, it would have saved several additional tons of propellant**



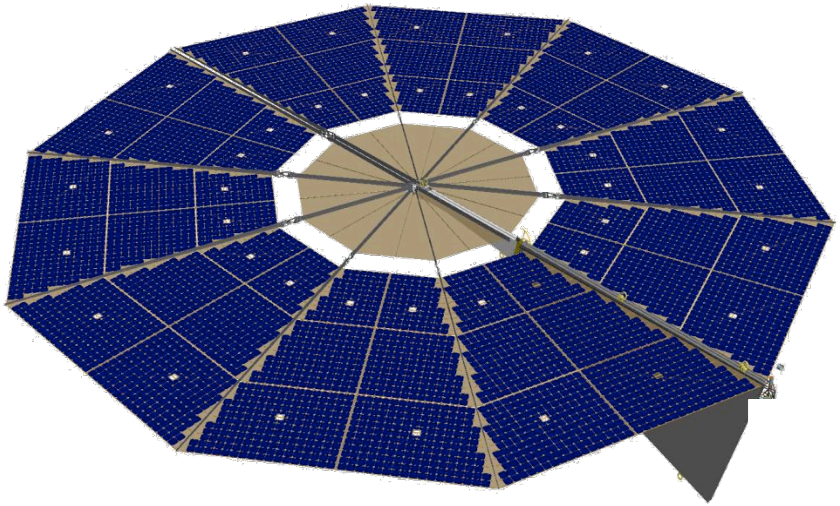


The Hero

STMD Solar Array System (SAS) Project

- **Solar Array Systems Project**
  - ATK MegaFlex
    - 12m diameter
    - 20kW EDU
  - DSS Roll Out Solar Array (ROSA)
    - 5.5m x 15-20m
    - 20kw-25kw
- **Common Elements**
  - High Power Density (150w/kg)
  - High stowed power density (>50 kW/ m^3)
  - 300V buss operation
  - Designs extensible to 300kW objective system

ATK MegaFlex



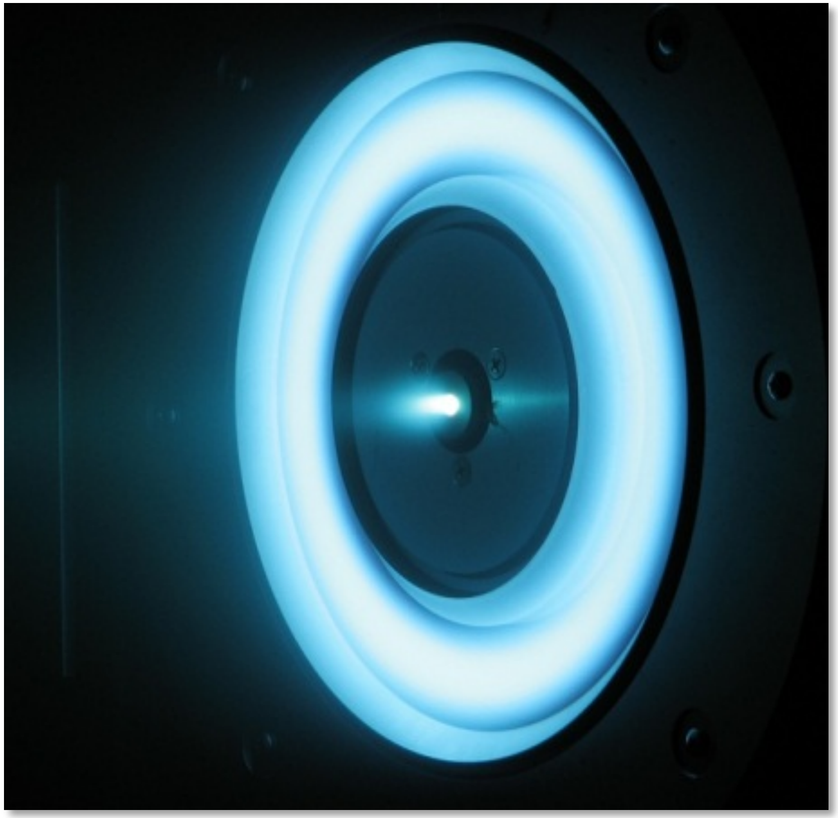
STMD Advanced In Space Propulsion (AISP) Project

Thrusters

- Present TRL 9 “Industry Benchmark” is the Aerojet BPT-4000
  - 4.5-kW, 2000-s Hall thruster
- AISP Thruster Focused on future HEOMD Applications
  - Magnetically Shielded Hall Effect Thruster
  - 12-15kW
  - 2000s-3000s ISP
- Miniature Electrospray Propulsion (MEP) Thruster
  - Small Satellite mN thrust applications
  - Potential to grow to larger missions

Power Processing Unit (PPU)

- High voltage input
- Direct Drive Unit (DDU) research
- High Operating Temperature



NASA’s 3000-s Isp, Magnetically-shielded Hall Thruster

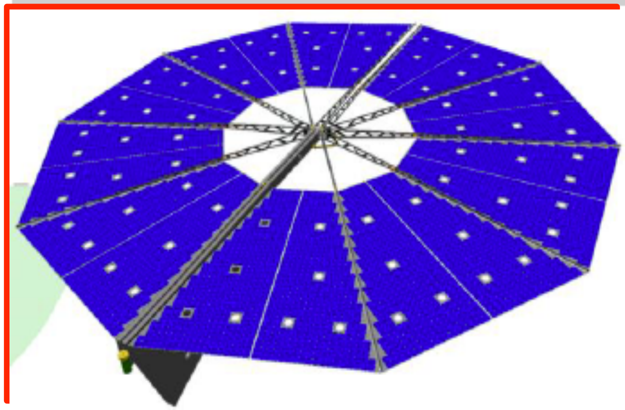
SEP Technology Investment

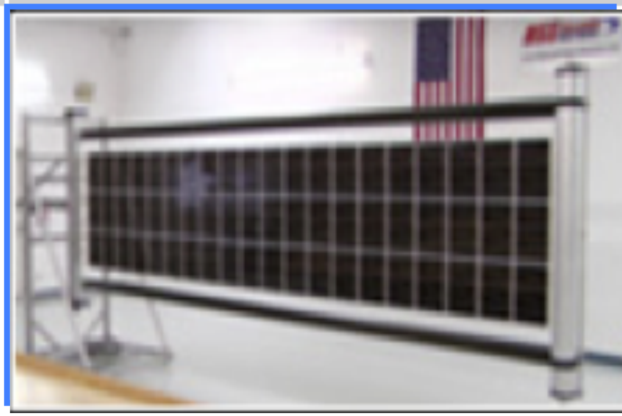
- Current focused NASA STMD investments on advanced next-gen solar arrays and higher power electric propulsion technologies to enable 30kW-class SEP
- Two providers selected through competitive NRA for development of solar array systems (SAS): Alliant Techsystems Inc. (ATK) & Deployable Space Systems (DSS)
- NASA in-house EP development of 15kW class HET system using either direct-drive and/or high voltage power processing unit
- Additional investments in PV cells and HV, rad-hard electronic parts

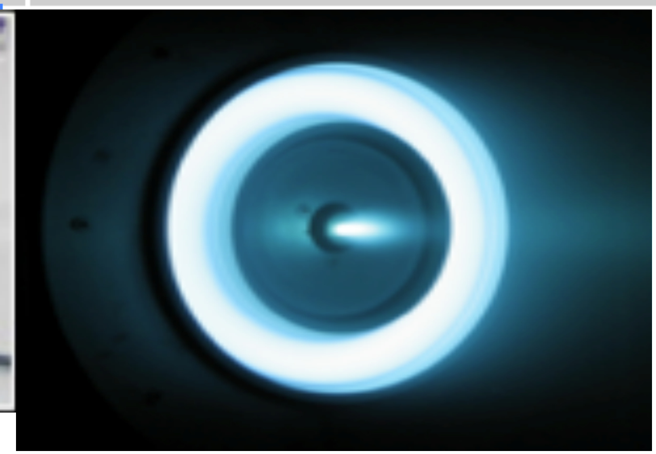
ATK MegaFlex:
Partners – AMA, Ball, Emcore, JPL, SpectroLab
Start Date: October 2012
Anticipated Duration: 18 months

DSS Roll Out Solar Array (ROSA):
Partners - Emcore and JPL
Start Date: October 2012
Anticipated Duration: 18 months

In-house EP System Development:
Partners - GRC and JPL
Start Date: January 2012
Anticipated Duration: 36 months







1. Time for Creative Thinking

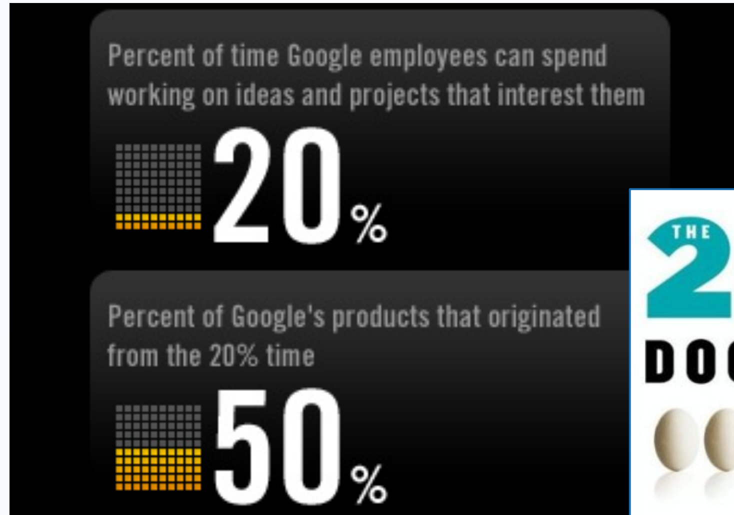
Description: Replicate best practices of companies where employees are allowed, ***and encouraged***, to spend a % of time (min-max) to pursue innovative ideas, whether or not directly related to their current projects.

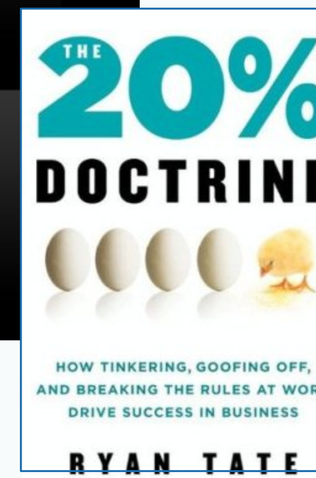
Benefits:

- Incentivizes innovative thinking
- Allows people the freedom to find their creative strengths
- Enables exploration of solutions to strategic needs even beyond the immediate sandbox

Actions:

1. *Solicit support from NASA senior management and joint leadership teams for flexible charging*
2. *Demonstrate concept relevance to NASA's strategic goals*
3. *Specifically include people reassigned to work urgent mission needs, so they are allowed keep their hand in innovative projects*





Related Activities:

- **NASA OHCM Study Team**
- **Center Innovation Funds (CIF's)**
- **Relaxed FTE charge codes (several Centers)**
- **Collaboration spaces (several Centers)**
- **GRC R&T Directorate declared 10% time for Innovation & Creativity**

2. Innovation Labs & Creative Spaces

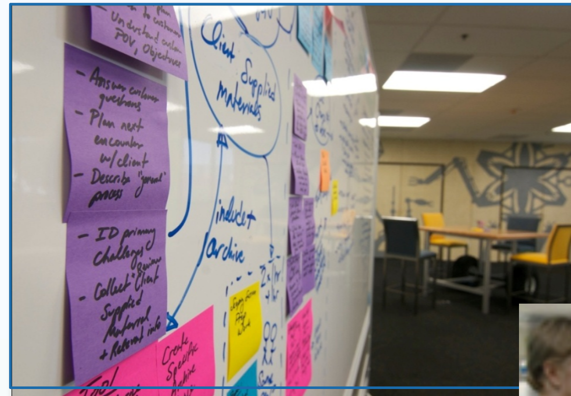
Description: Sustain *highly flexible* innovation labs and/or creative spaces that enable and support cross-discipline collaboration on ideas, prototypes, solutions, etc.

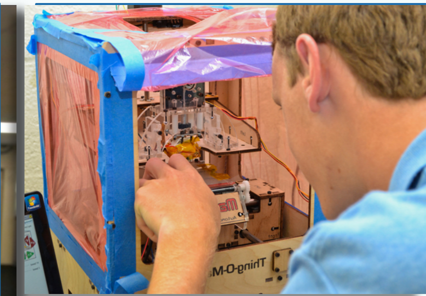
Benefits:

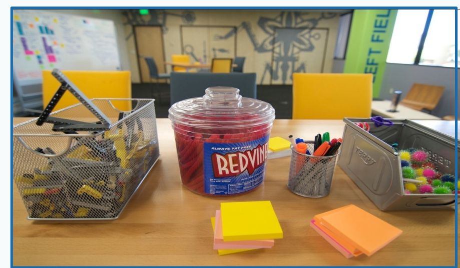
- Recognizes that creative problem-solving requires different skills and mindsets
- Avails ongoing Center investments and establishes best practices & lessons learned for future innovation labs & spaces
- Identifies unique facilities available to increase & *leverage* collaboration among Centers
- Provides a basis for virtual Agency-wide "skunkworks" *(links to other recommendations)*

Actions:

1. *Encourage all Centers to establish dedicated support for Innovation Labs & other creative spaces*
2. *Encourage cross-center sharing of methods, best practices, successes, and instructive failures.*
3. *Identify associated POC's as resources for other centers planning or developing similar or unique facilities*







Related Activities:

ARC: **Quickshop, Spaceshop, ARC Tek Forum**
GRC: **Creativity & Innovation Commons, I-Lab**
GSFC: **Mission Design, Instrument Design, and Architecture Design Labs**
KSC: **Cyber Café, Innovation SPACE, Design Visualization Lab**
JPL: **Left Field, Innovation Foundry**
JSC: **Collaboration Centers & creative spaces, IRAD Poster Sessions**
LaRC: **NavCenter, pFAB/iFAB**
MSFC: **Propulsion Research Lab**

3. Projects & Innovation Funding

Description: Require *new* flight programs/projects to include an element of innovation (e.g., hardware, software, process, procurement) that contains potential for high-payoff and promotes acceptance of informed risk.

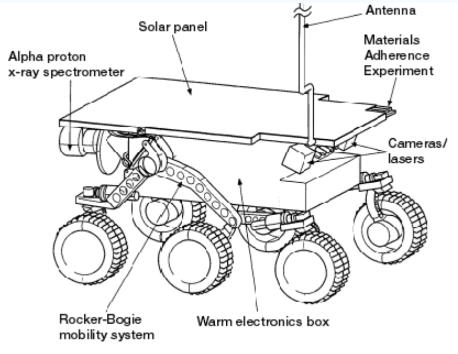
Benefits:

- Establishes a cultural norm – expectation that projects will factor in (accept) informed, appropriate R&D risk
- Affords contractors opportunities to be key contributors to NASA's vision (current contracts can act as limiters)
- Increases resources available for investment in new ideas/solutions

Actions:

1. *Form a tiger team with OCFO, Procurement, and Legal to lay out a pathfinder strategy*
2. *Include innovative solutions/approaches in project formulation and assessment*
3. *Fence a % of new project budgets for innovative technology development*

Sojourner



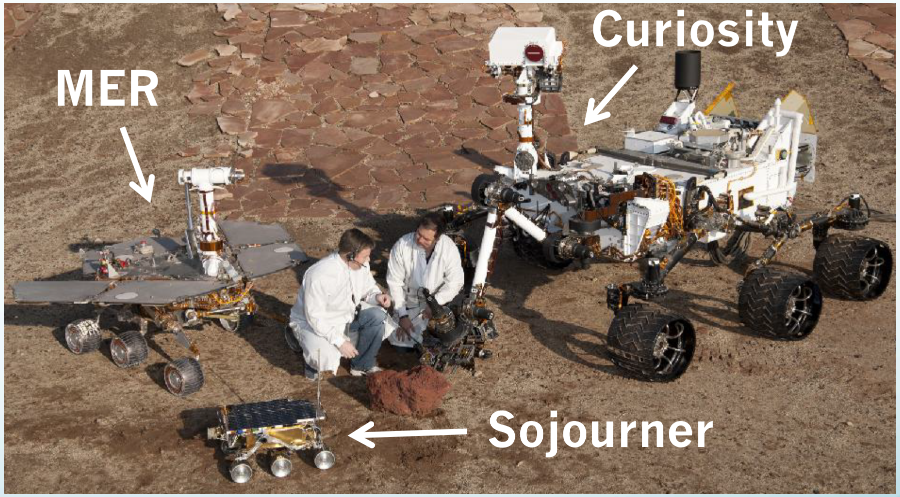
Pathfinder Mission leadership did not want Sojourner

Many scientists saw no need for a mobile platform

It was developed by a small team, largely in a rundown building on the edge of lab

The team was left mostly to themselves

… yet a $25M flight experiment revolutionized planetary exploration

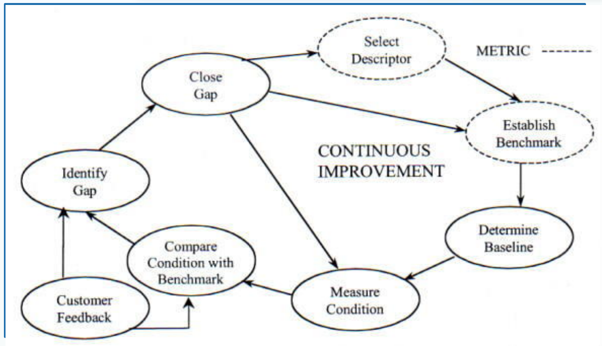


Related Activities:

- **HEOMD - AES, HRP**
- **OCT Game-Changing**
- **ARMD Seedling Fund**

4. Process Streamlining

Description: Mandate reduction of process requirements with thresholds to enable tailoring and streamlining (especially critical for low TRL projects).



Benefits:

- Recognizes tendency to be overly conservative / risk averse – implication of compliance costs and accumulation of requirements
- Reduces burden of too many approvers – review by specified SME's
- Avoids new processes.

Actions:

1. *Streamlined Class D requirements for low-cost missions (quick-turnaround).*
2. *Tailor 7120 guidelines based on project dollar value and/or complexity.*
3. *Allow specific tailoring for low TRL's* and set a goal as guidance (e.g., 50% of 7120 process requirements)
4. *Apply metrics such as Reduce Cycle Time.*
5. *Encourage ISO/ASI compliance vs. 3rd party registration (more labor- & resource-intensive)*

Related Activities:

- **7120 Updates**
- **LCROSS**

5. NASA Skunkworks

<u>Description</u>: Establish a true, sustainable NASA "Skunkworks" as a critical innovation pathway strategically aligned with NASA challenges.

<u>Benefits</u>:

- Demonstrates commitment to fostering breakthrough, revolutionary challenges
- Specific mechanism to integrate innovation initiatives (creative spaces, dedicated resources (time, funding), process streamlining, etc.
- Innovation solutions, game-changers (S-Curves) and possible breakthroughs.

<u>Actions</u>:

1. *Identify a key challenge and provide seed money/ sponsor.*
2. *Competitively select composite team (multi-disciplinary, multi-Center, etc.).*
3. *Add team position of "Scrounger" (searches across the Agency for non-$$ resources)*
4. *Buffer the team from external influences and include both collocated and virtual project teams.*
5. *Link to/leverage Innovation Labs across the Agency.*

<u>Related Activities</u>:

- **Centaur 2 Rover/Excavator**
- **Robonaut 2**
- **NESC MLAS and Composite Crew Module**