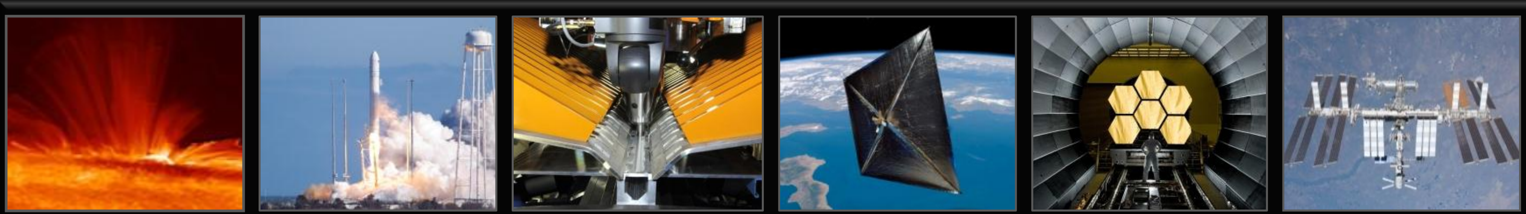
Marshall Space Flight Center Technology Investments Overview

MSFC-Industry Strategic Investment Symposium
February 24, 2014

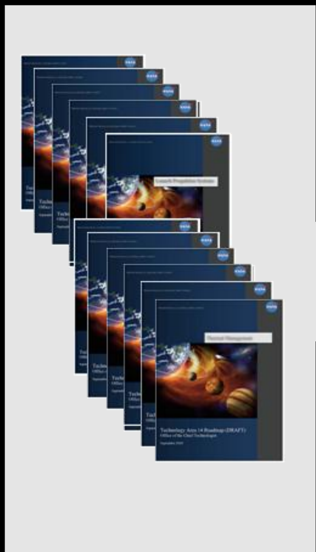


marshall

Mike Tinker
Deputy Center Chief Technologist

NASA's Space Technology Portfolio Perspectives and Process

What NASA could do.



Space Technology Roadmaps

- 140 challenges (10 per roadmap)
- 320 technologies
- 20 year horizon
- Revised every 4 years

What NASA should do.

NRC Study

Gives priority to:

- 100 top technical challenges
- 83 high priority technologies (roadmap-specific)
- 16 highest of high priority technologies (looking across all roadmaps)
- Immediate 5 year horizon

What NASA plans to do.

Space Technology Investment Plan

Updated ST Roadmaps:

- Incorporate NRC Study Results

Developing a Strategic Space Technology Investment Plan:

- Identify current investments
- Identify current MD/Office priorities
- Identify opportunities for partnership
- Analyze gaps against current budget and capabilities
- Develop immediate 4-year horizon

What NASA is doing.

Execution

Technology Portfolio Investments

- Technology Developments (across full TRL spectrum)
- Flight Demonstrations

Must reflect:

- Affordability
- Technical Progress and Performance
- Mission Needs and Commitments
- Stakeholder Guidance

NASA Strategic Space Technology Investment Plan (SSTIP) Overview

- NASA is moving forward with prioritized technology investments that will support NASA's exploration and science missions, while benefiting other Government agencies and the U.S. aerospace enterprise.
  - The plan provides the guidance for NASA's space technology investments during the next four years, within the context of a 20-year horizon
- This plan will help ensure that NASA develops technologies that enable its 4 goals to:

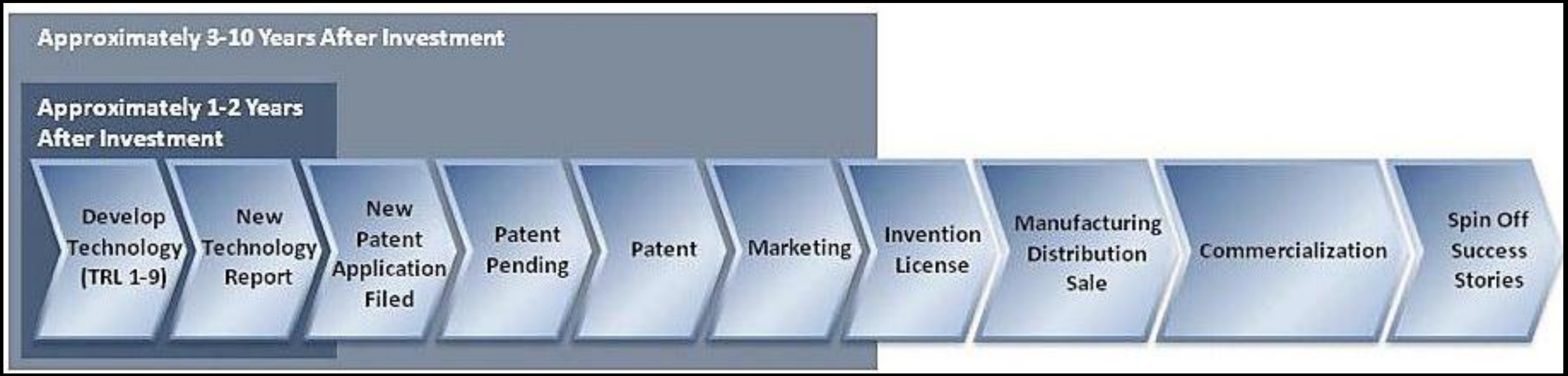
1. Sustain and extend human activities in space,
2. Explore the structure, origin, and evolution of the solar system, and search for life past and present,
3. Expand our understanding of the Earth and the universe and have a direct and measurable impact on how we work and live, and
4. Energize domestic space enterprise and extend benefits of space for the Nation.

SSTIP Overview
Principles of Investment and Execution

Principles optimize investments, maintain a balanced portfolio, use developed technologies, and provide transparency to the American public

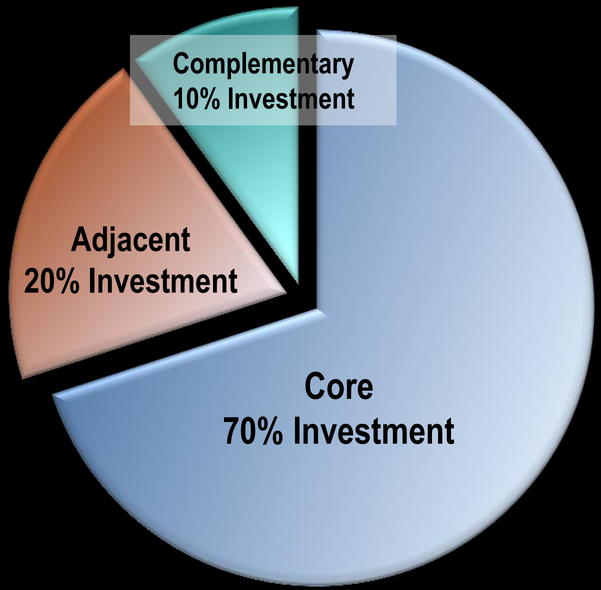
Principles Guide Future Portfolio Investment and Execution

- Achieve the agreed upon balance among investments:
  - Across all 14 Space Technology Areas in the Roadmaps
  - Across all levels of technology readiness
- Ensure developed technologies are infused into Agency missions
- Develop technologies through partnerships and ensure developed technologies are infused throughout the domestic enterprise
- Use a systems engineering approach when planning technology investments
- Reach out to the public and share information about its technology investments



NASA Strategic Space Technology Investment Plan Overview

- 4-year Investment Approach
  - ➢Three levels of investment
    - Core (70%)
    - Adjacent (20%)
    - Complementary (10%)
  - ➢Together these investments:
    - Span the four goals
    - Include pioneering, crosscutting and mission specific technology development
    - Guide future technology expenditures
    - Rapidly produce critical capabilities
    - Seed future innovation
- Governance: NASA Technology Executive Council (NTEC)
- Principles of Investment and Execution



SSTIP can be downloaded at:
http://www.nasa.gov/sites/default/files/files/space_tech_2013.pdf

SSTIP Overview
Core Technology Investments

- **Core technologies represent 8 focus areas of technology investment that are indispensable for NASA's present and planned future missions**
- **Core technologies are the central focus of technology investment and will comprise approximately <u>70%</u> of the Agency's technology investment of the next 4 years (★ = highest Agency investments now)**

Launch and In-space Propulsion ★

Environmental Control and Life Support Systems

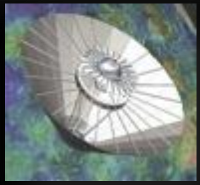
High Data-Rate Communications

Space Radiation Mitigation

Lightweight Space Structures and Materials

Scientific Instruments and Sensors ★

Robotics and Autonomous Systems ★



Entry, Descent, and Landing ★

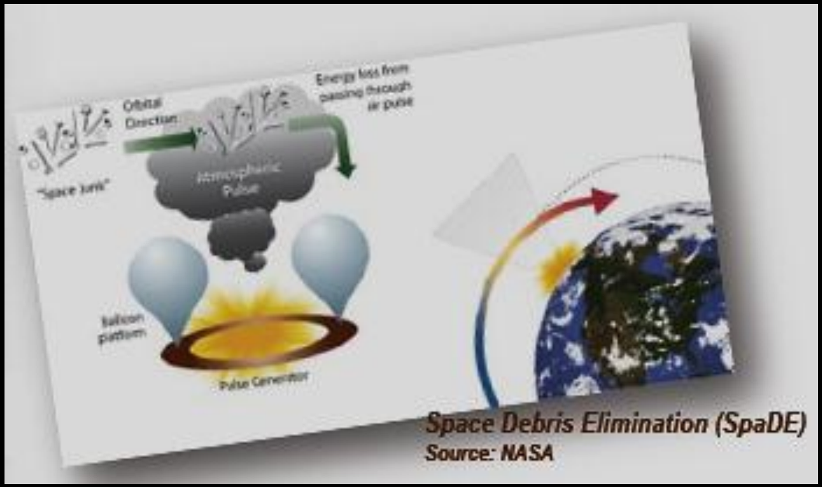
SSTIP Overview
Adjacent Technology Investments

- Adjacent technologies represent several areas of technology investment that are not part of the Core, but are still high priority and integral to NASA's missions; these technologies are closely related to and can benefit from Core investments
- Adjacent technologies are a significant focus of technology investment and will comprise at least 20% of the Agency's technology investment over the next 4 years
- Example Adjacent technologies shown in the table below; others include nanotechnology, cryogenic thermal management, modeling and simulation, and EVA

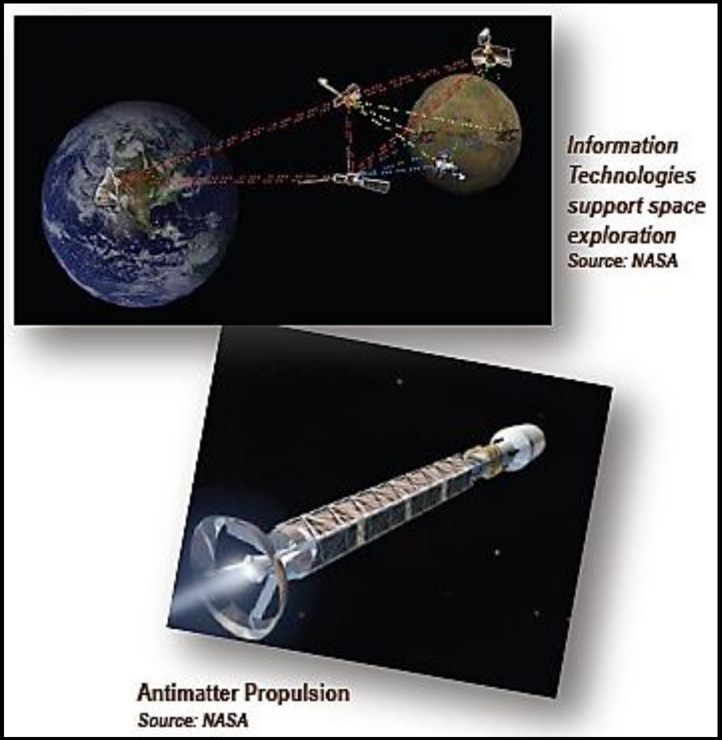
Technology Investment Classification	Associated SSTIP Technical Challenge Area	TABS	Associated NRC High Priorities
Adjacent	Advanced Power Generation, Storage and Transmission; Increased Available Power	3.2	Batteries
Adjacent	Efficient Accurate Navigation, Positioning and Timing	5.4	Timekeeping and Time Distribution
Adjacent	Long Duration Health Effects	6.3	Long Duration Crew Health
Adjacent	Surface Systems	7.4	Smart Habitats; Habitation Evolution
Adjacent	Improved Flight Computers	11.1	Flight Computing; Ground Computing

SSTIP Overview
Complementary Technology Investments

- **Complementary technologies represent opportunities to invest in future technologies beyond nearer-term needs; include low-TRL innovations**
- **Complementary technologies will comprise <u>10%</u> of the Agency's technology investment over the next 4 years**
- **Example Complementary technologies include the following:**
  - **Concepts for mitigating orbital debris**
  - **Innovative propulsion concepts**
  - **Ground processing technologies**
  - **New Information Technologies (IT)**



Space Debris Elimination (SpaDE)
Source: NASA

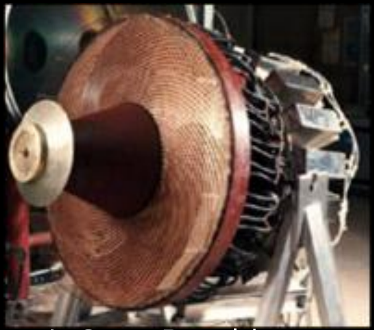


Information Technologies support space exploration
Source: NASA

Antimatter Propulsion
Source: NASA

MSFC Technology Emphasis Areas

Advanced In-Space Propulsion and Cryogenic Technologies



In-Space Propulsion (Pulse Power, Electric)

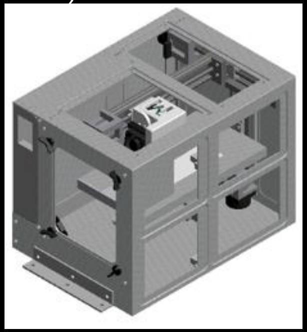
In-Space Propulsion (Nuclear)

In-Space Propulsion (Solar Sail, Tethers)

Affordable, Innovative Technologies for Landers and Sample Return

Low Cost/Responsive Launch for Small Payloads

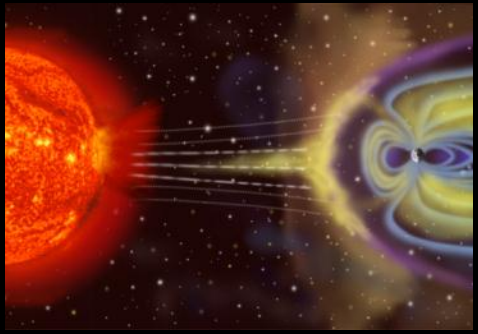
Innovations and Technologies Supporting Small, Affordable ISS Payloads



Advanced Manufacturing with Emphasis on In-Situ Fabrication and Repair

In-Space Habitation Technologies with Emphasis on Nodes and Life Support Systems

X-ray Astrophysics and Telescope Systems



Space Environments, Space Weather Prediction and Assessment

Small Satellite and Small Spacecraft Technologies

Rapid, Innovative, Affordable Manufacturing of Propulsion Components

Marshall’s Role in Agency Missions

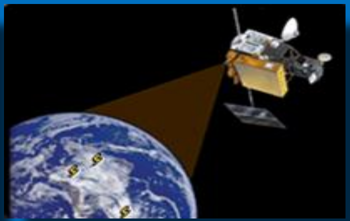
Four Core Technology Themes

Space Transportation/Launch Vehicle Technology and Development

Propulsion Systems Technology and Development

Space Systems Technology, Development, and Integration

Scientific Research



MSFC Business Development Strategic Vectors

	Tier 1	Tier 2	Tier 3
Propulsion Systems	Goal: Lead the Agency in developing new space propulsion and transportation systems for human exploration and space operations, support the development and application of advanced propulsion technologies, and jointly steward the national propulsion industrial base.		
	▪ In-Space Propulsion with Emphasis on Cryogenics	▪ Rapid, and Affordable Advanced Manufacturing with Emphasis on Propulsion Components ▪ In-Space Propulsion with Emphasis on Nuclear Propulsion ▪ In-Space Propulsion with Emphasis on Green Propellants ▪ In-Space Propulsion with Emphasis on Electric Propulsion	▪ In-space propulsion / sails, tethers ▪ Propulsion test beds & demonstrations
Space Transportation Systems	▪ Affordable, Innovative Transportation Architectures and Technologies for Beyond Earth Orbit (BEO) Exploration	▪ Affordable, Innovative Transportation Architectures and Technologies for Low Earth Orbit (LEO) Delivery of Small Payloads	▪ Enablement of the Commercial Crew and Cargo Sector
Space Systems	Goal: Support the Agency in next generation systems for living and working in space, with emphasis on human exploration.		
	▪ Support the development of next generation habitation structures, life support systems, and element outfitting	▪ Identify and develop small, affordable ISS payloads ▪ Develop in situ fabrication and repair technologies for infusion into human exploration operations	▪ Develop robotic capabilities to enhance exploration objectives, such as small spacecraft and asset management technologies
Scientific Research	Goal: Sustain and advance scientific research in support of the Agency's strategic goal of expanding the scientific understanding of the Earth and the universe in which we live within niche areas of Marshall focus and technical capabilities.		
	▪ Advance the state of the art in X-ray astrophysics capabilities to enable next generation observation objectives	▪ Future Heliophysics Explorer Opportunities ▪ Space Environments and Space Weather Research to Operations	▪ Scientific Instruments for Missions of Opportunity and Directed Missions

MSFC Technology Overview: Recent and Current Projects

- MSFC has a strong and diverse portfolio of technology development projects, ranging from flight projects to very low Technology Readiness Level (TRL) laboratory projects

- This overview is organized by NASA Mission Directorate and MSFC internal activities:
  - *Human Exploration and Operations Mission Directorate (HEOMD)*
    - Advanced Exploration Systems (AES)
  - *Science Mission Directorate (SMD)*
    - Planetary Science Division
    - Astrophysics Division
  - *Space Technology Mission Directorate (STMD)*
    - Technology Demonstration Missions (TDM)
    - Centennial Challenges
    - Game Changing Development (GCD)
    - Center Innovation Fund (CIF)
  - *MSFC Internal Research and Development*

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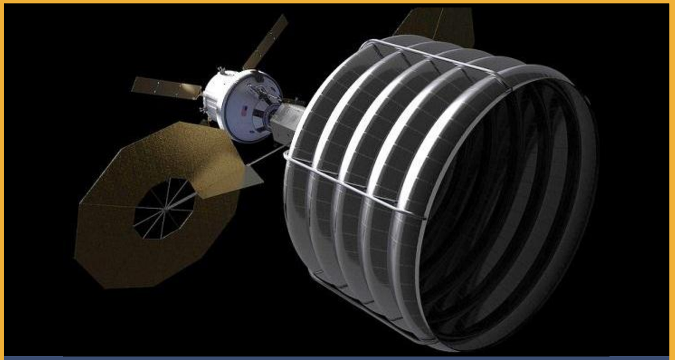
Human Exploration and Operations



Space Technology

Science

Aeronautics Research

Marshall supports three of the NASA Mission Areas.

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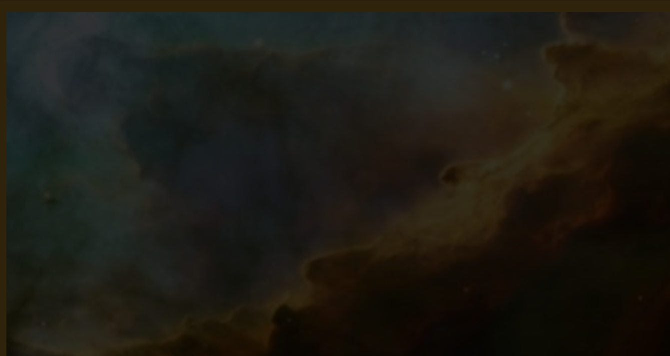
Human Exploration and Operations



Science

MSFC Participation in HEOMD Technology Divisions:

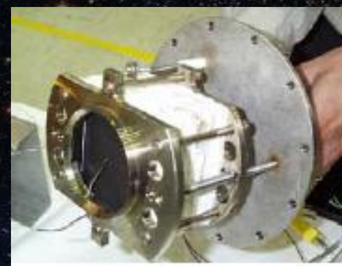
- Advanced Exploration Systems (AES):
  - Atmosphere Resource Recovery and Environmental Monitoring (ARREM)
  - 3D Printing in Zero-G (3DP) —also funded by ISS and STMD/GCD
  - Nuclear Cryogenic Propulsion Stage (NCPS)
  - Advanced Neutron Spectrometer (ANS)
  - Deep Space Habitat (DSH) Concept Demonstrators

Marshall supports three of the NASA Mission Areas.

Atmosphere Resource Recovery & Environmental Monitoring (ARREM)

CO_2 Removal

Oxygen Recovery



Trace Contaminant Control

Integrated Atmosphere Revitalization Test

Project Description:
Mature integrated Atmosphere Revitalization Systems and Environmental Monitoring Systems for future human missions beyond Earth orbit. Focus on key technologies that increase reliability, capability, and consumable mass recovery as well as reduce requirements for power, volume, logistics resupply, and crew involvement.

MSFC Role:
Project management (Monsi Roman); engineering design/analysis/testing

Customer: Advanced Exploration Systems

Accomplishments for 2013:

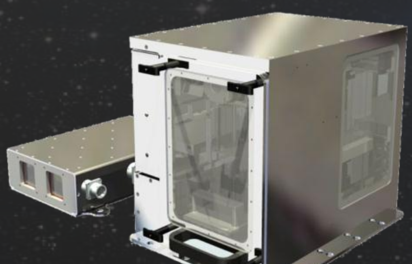
- Completed Cycle 1 closed-chamber integrated testing of Atmosphere Revitalization Systems for Exploration
- Started outfitting facility for Cycle 2 testing
- Completed ISS CDRA-4 flight-like ground unit for Cycle 2 integrated test
- Received 3rd Generation Plasma Pyrolysis Assembly from Umpqua Research (SBIR)
- Hosted Agency's Environmental Monitoring Technical Interchange Meeting (TIM)
- Participated in the NASA ECLS System Maturation Team (SMT) meeting
- Completed Agency roadmap drafts for NASA'S Microbial Monitoring, and Atmosphere Revitalization Systems

3D Printing in Zero-G (3DP)

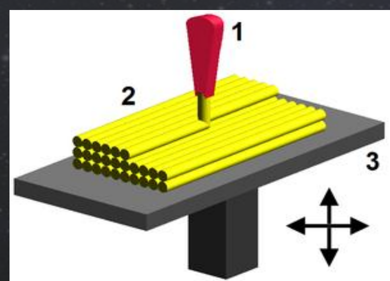
Project Description:
Partner with Made In Space, Inc. to deliver the first 3D printer to the ISS to investigate the effects of microgravity on melt deposition additive manufacturing and print parts in space. Payload will utilize Microgravity Science Glovebox, print multiple parts from polymer material, demonstrate nominal extrusion and traversing, and perform on-demand printing via CAD file uplink. Printed parts will be tested on the ground for quality and strength.

MSFC Role:
Project management (Niki Werkheiser); insight to ensure hardware meets minimum flight requirements; performance of all flight qualification and acceptance testing

Customers: Space Technology Mission Directorate (STMD) Game Changing Development, Advanced Exploration Systems (AES)/HEOMD, and ISS



Engineering Test Unit



1 – Nozzle; 2- Printed Part;
3 – Print Tray

Vibe and EMI Testing

Crew Office Assessing 3D Print

Accomplishments:
- Awarded SBIR Phase III contract to Made In Space
- Completed Systems Requirements Review (SRR) / Preliminary Design Review (PDR)
- Completed EMI/EMC, Acoustic, and Vibe Testing on Engineering Test Unit and Ground Test Unit
- Held preliminary Human Factors Interface Team (HFIT) review with crew office representatives
- Completed the Critical Design Review (CDR) with no major issues
- Held Phase 0, I, and II Safety Reviews with ISS Payload Safety Review Panel (PSRP)
- Performing detailed materials analyses and testing
- Featured in over 300 national media articles and interviews

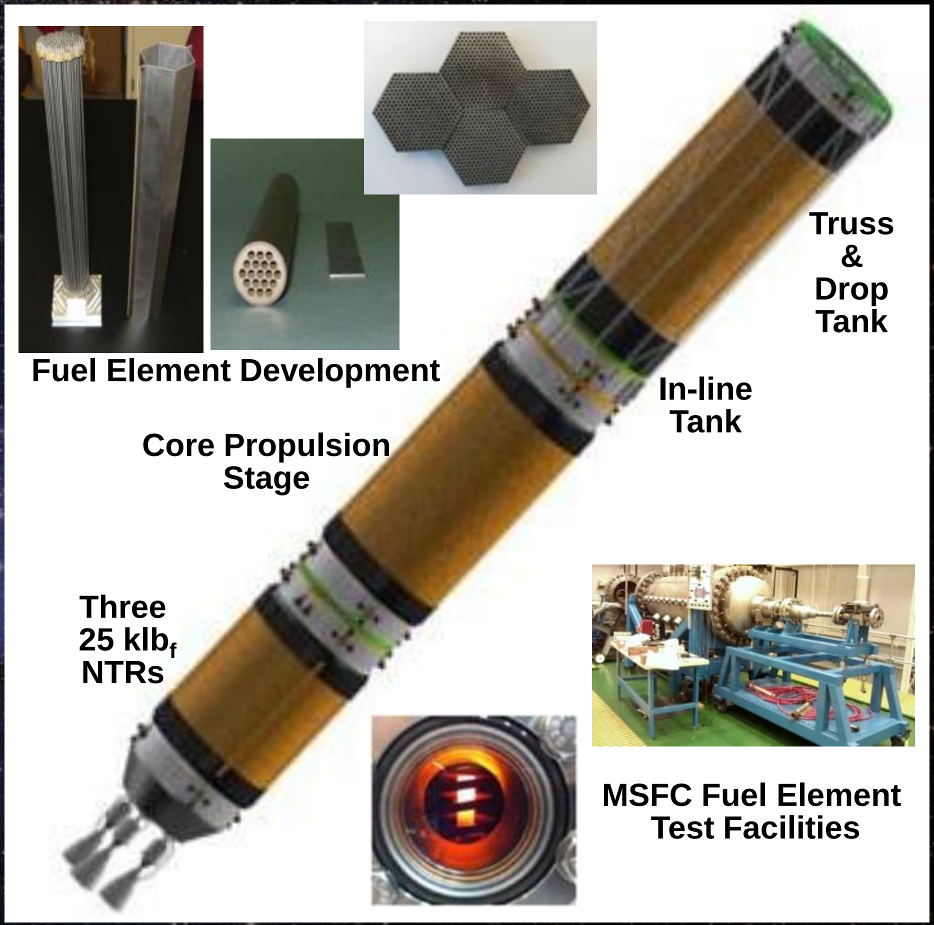
Nuclear Cryogenic Propulsion Stage (NCPS)

Project Description:
Demonstrate affordability and viability of a fully integrated NCPS. Accomplish stage design, fuel fabrication and testing, affordable development and qualification strategy. Enable NCPS to be considered a mainstream option for supporting human Mars and other missions beyond earth orbit.

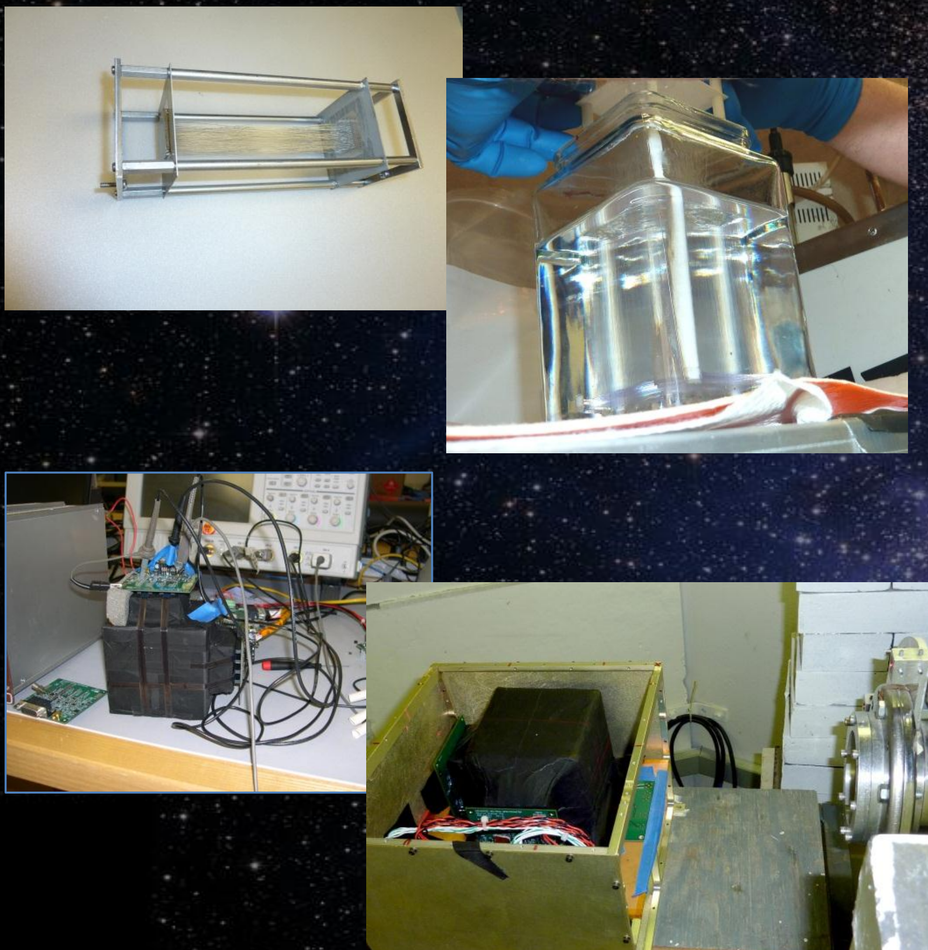
MSFC Role:
Project management (Mike Houts) and oversight; advocacy inside and outside of MSFC to help ensure project success

Customers: Advanced Exploration Systems (AES)/HEOMD, MSFC AES Project Office; NASA Human Architecture Team (HAT)

Accomplishments for 2013:
- Fabricated tungsten-based CERMET fuels with both surrogates and depleted uranium
- Completed 50 kW upgrade of Compact Fuel Element Environmental Test (CFEET)
- Achieved sample temperatures in excess of 3500 K during CFEET system checkout
- Updated NCPS vehicle concept to fully utilize SLS
- Continued NCPS fuel design/fabrication
- Started CERMET fuel element testing in CFEET system
- Completed AES Fuel Element Development Review at Oak Ridge National Laboratory



Advanced Neutron Spectrometer (ANS) for Radiation Monitoring



Photos of various stages in the development of the ANS instrument. Lower right: The fully integrated ANS prototype during test exposures to 200 MeV protons.

Project Description:

Going beyond LEO presents several new challenges for the safe execution of NASA's manned exploration plans beyond the protective layers of Earth's atmosphere and magnetic field. These challenges require advanced instrument designs to meet new requirements for monitoring radiation exposure under severe resource constraints. The Advanced Neutron Spectrometer (ANS) is being developed to address the neutron monitoring requirements and meet the future needs of exploring new destinations.

MSFC Role:

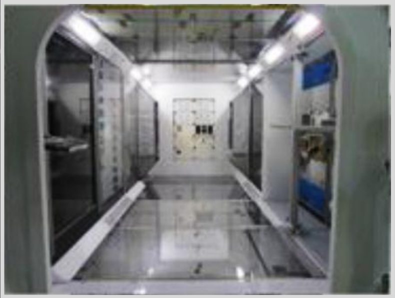
Principal Investigator (Mark Christl); ANS instrument development

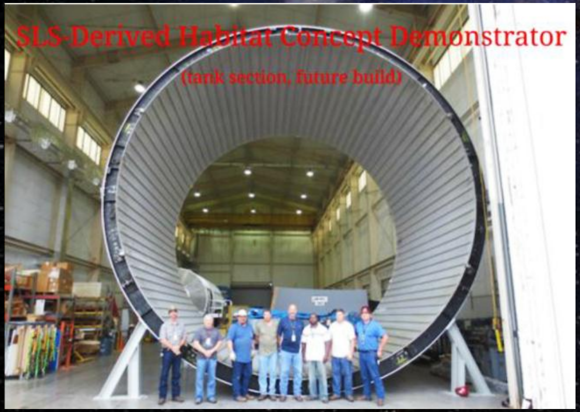
Customers: Advanced Exploration Systems (AES)/HEOMD; NASA JSC

Accomplishments for 2013:

- Completed side-by-side comparison of neutron detection techniques relevant to manned exploration
- Demonstrated advantages of the new measurement technique for fast neutrons employed in ANS
- Exposed ANS to high energy particles to demonstrate functionality in a radiation environment

Deep Space Habitat Concept Demonstrators





Project Description:
Develop, integrate, test, and evaluate Habitation Systems that will be utilized as technology testbeds and to advance NASA's understanding of alternative deep space mission architectures, requirements, and operations concepts. Utilize rapid prototyping and existing hardware to develop full-scale habitat demonstrators.

MSFC Role: Project management (Paul Bookout); assembly; engineering support

Customers: Advanced Exploration Systems (AES)/HEOMD; NASA JSC

Accomplishments for 2013:
- Integrated mockup Environmental Control and Life Support Systems (ECLSS), power, and avionics subsystems with the Multi-Purpose Logistics Module (MPLM)-based habitat demonstrator
- Accomplished additional module buildup to complete the Cis-Lunar demonstrator
- Utilized inexpensive materials and existing hardware to allow rapid prototype builds
- Discovered limitations of Cis-Lunar concept, began evaluation of SLS-derived
- Completed on-site reviews with NASA JSC project management personnel (AES)
- Provided numerous tours of habitat demonstrators, several media interviews

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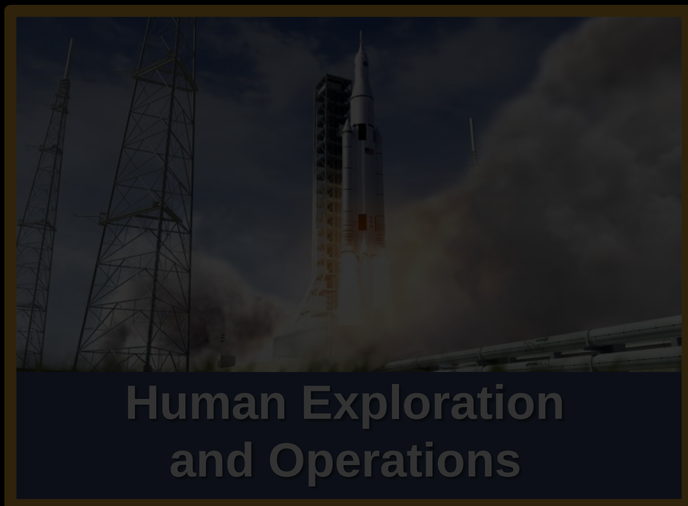
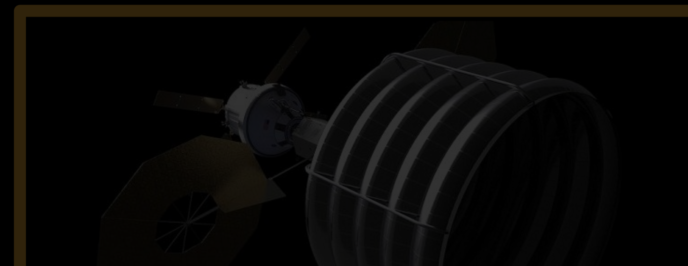




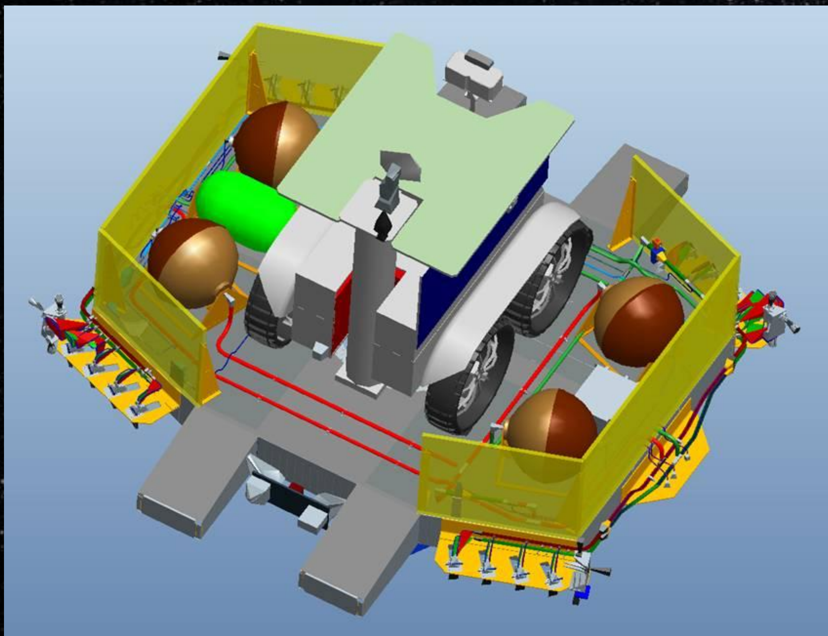
MSFC Participation in Technology Development for SMD Divisions:

- **Planetary Science Division:**
  - **Robotic Lander Development**
- **Astrophysics Division:**
  - **Advanced Mirror Technology Development**

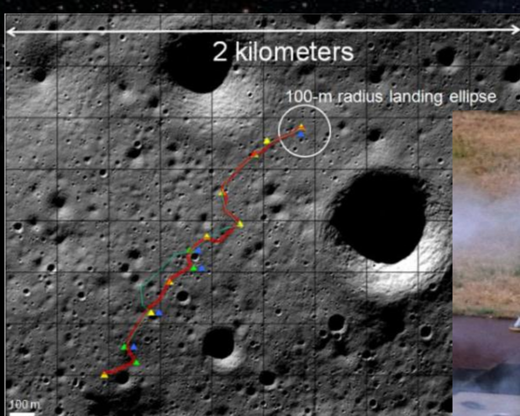
Aeronautics
Research

Marshall supports three of the NASA Mission Areas.

Robotic Lander Development



Resource Prospector Lander Concept



Mighty Eagle Testing

Project Description:
Provide robotic lunar lander development for the Resource Prospector (RP) Mission to demonstrate in-situ resource utilization (ISRU) with the Regolith and Environment Science and Oxygen and Lunar Volatiles Extraction (RESOLVE) payload. Mature the RP lander as much as possible prior to FY15 to enable NASA partnership on lunar lander.

MSFC Role:

RP Mission Lander Lead (Greg Chavers, Manager)

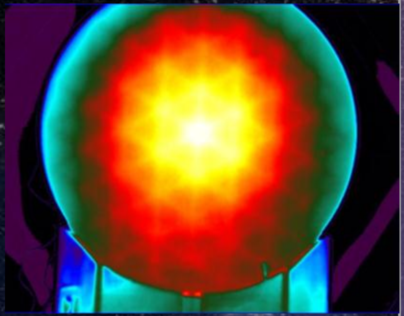
Customers: Science Mission Directorate; Advanced Exploration Systems (AES)/HEOMD (FY14); MSFC TIP (Mighty Eagle)

Accomplishments for 2013:

- Fostered MSFC/JSC lander partnership
- Completed RP lander trade studies for propulsion and avionics subsystem
- Completed RS34 module design and thruster hot-fire test prep
- Completed CDR for Pratt Whitney Rocketdyne In Space Engine 100 lb thruster
- Supplied requirements for pallet lander TIP
- Accomplished work with Mighty Eagle testbed, including hazard avoidance algorithm design and flight testing. Integrated software to allow Moon Express to fly the lander autonomously.
- Led NASA wide technical assessment of RFI seeking US industry partnership on landers

Advanced Mirror Technology Development (AMTD)

Subscale Deep Core Mirror Static Load Testing



Thermal Image of Mirror Front Surface Thermal Gradient

Subscale Deep Core Mirror at XRCF

Project Description:
Mature the TRL of 6 key technology challenges for the primary mirror of future large-aperture space telescopes. Multiple design paths include monolithic and segmented optics. Prototype development, testing, modeling, and demos. Metrics are traceable to science mission error budget.

MSFC Role:
Principal Investigator (Dr. H. Philip Stahl); Testing; Project Management

Customers: Strategic Astrophysics Technology (SAT) Program; Dr. Mario Perez, Science Mission Directorate; OCT

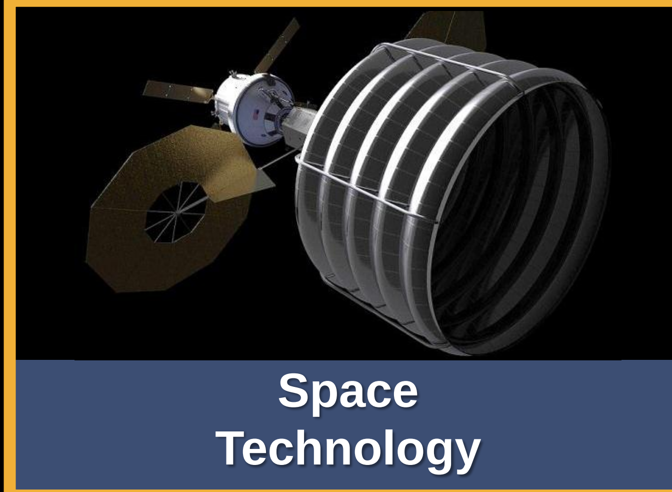
Accomplishments for 2013:

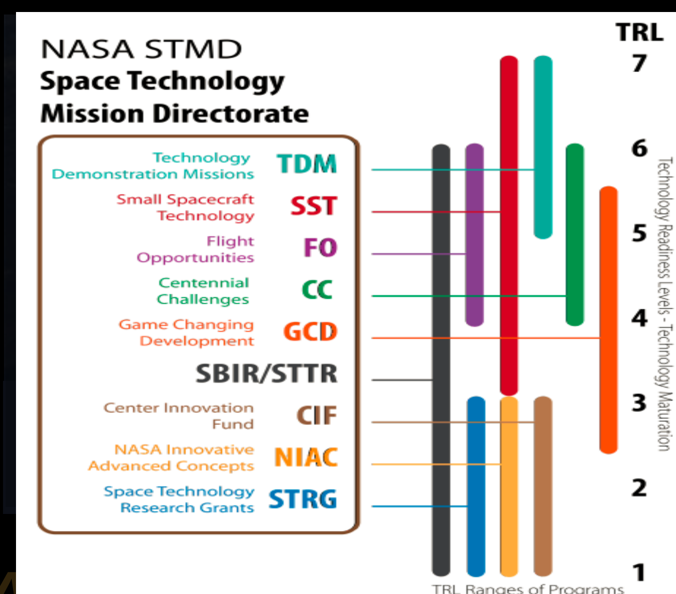
- First demonstration of the stacked-core process for making deeper, stiffer mirrors
- First demonstration of multiple replication process
- Demonstrated ability to polish deep core mirror to ultraviolet/optical (UVO) quality
- Characterized thermal performance of deep core mirror consistent with UVO performance
- Validated thermal model via test at XRCF
- Validated mechanical model via static load test
- Developing powerful design modeling and analysis tools

The National Aeronautics and Space Administration

MSFC Participation in Space Technology Programs:

- Technology Demonstration Missions (TDM)
  - Level II Program Management
  - Cryogenic Propellant Storage & Transfer (CPST)
- Centennial Challenges
  - Level II Program Management
- Game Changing Development (GCD)
  - Composite Cryotank Technologies and Demonstration (CCTD)
  - Soldier-Warfighter Operationally Responsive Deployer for Space (SWORDS)
  - Synthetic Biology and Next Generation Life Support (NGLS)
  - Programmable Ultra Lightweight Software Adaptable Radio (PULSAR)
  - Advanced Radiation Protection (ARP)
  - Manufacturing Innovation Project (MIP)
  - Fast Light Optical Gyroscopes (FLOG)
  - Nuclear Systems
- Center Innovation Fund (CIF)





Technology Demonstration Missions (TDM) Program

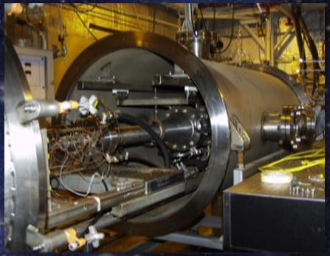
<u>Program Description:</u>
Flight projects to “bridge the gap” between development and first use by maturing crosscutting, system-level space technologies through demonstration and mission infusion

<u>MSFC Role:</u>
Level II Program Management/STMD (John McDougal)

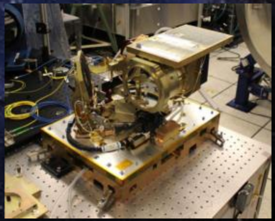
<u>Accomplishments for 2013 (CPST on separate chart):</u>
- Held TDM Program Annual Review at Gray Research in Huntsville, with 80 attendees, including STMD managers
- Met Agency Performance Goal to implement at least two TDM projects (LDSD, GPIM, SSD)
- Brought new TDM Lessons Learned database online
- <u>Deep Space Atomic Clock (DSAC)</u>: Completed system and clock PDR; obtained ride on US Air Force STP-2
- <u>Solar Sail Demo (SSD)</u>: Completed fabrication, integration, and deployment testing of Engineering Test Unit Sail
- <u>Green Propellant Infusion Mission</u> <u>(GPIM):</u> Fabricated and tested 1N & 22N thruster units; completed SRR and PDR
- <u>Low Density Supersonic Decelerator (LDSD):</u> Completed supersonic sled testing; completed ten subsystem CDRs
- <u>Laser Comm Relay Demo (LCRD):</u> Completed SRR; completed design for Control Electronics, Optical Module
- <u>Human Exploration Telerobotics (HET):</u> Completed six demos, including crew teleoperation of Robonaut 2, crew/ground control of Smart SPHERES, crew control of surface telerobotics
- <u>Mars Entry Decent and Landing Instrumentation (MEDLI):</u> Completed flight data reconstruction; released data


Atomic Clock


Solar Sail Demo


Green Prop Infusion


Supersonic Decelerator


Laser Comm Relay


Mars EDL Instrum.


Telerobotics

Cryogenic Propellant Storage and Transfer (CPST)

Project Description:
Demonstrate the capability to store, transfer, and measure cryogenic propellants both on the ground and in orbit for a duration which proves extensible to enable long term human space exploration missions beyond low Earth orbit.

MSFC Role:
Project management (Kent Chojnacki); Cryogenic Fluid System Payload design, development, fabrication, assembly, test, and delivery; Level II Program Management role also covers CPST.

Customers: **CPST Project Office (NASA GRC); Technology Demonstration Mission Level 2 Program Office; Cross-Cutting Capability Demos Office; Space Technology Mission Directorate (STMD)**

Storage Tank Assembly (STA) Engineering Development Unit (EDU)

STA EDU in Foam Spray Booth

Accomplishments for 2013:

- Completed CPST program reformulation to get within funding limits
- Completed CPST SRR/MDR milestone review and Key Decision Point (KDP)-B: Standing Review Board (SRB) concluded that CPST met all SRR/MDR success criteria and should proceed to Phase B; STMD gave approval for CPST to proceed to PDR
- Progressed with Storage Tank Assembly Engineering Development Unit (STA EDU): Completed dome-to-barrel welds, developed trimming process for Spray-On Foam Insulation (SOFI), completed tank assembly, passed acceptance testing (proof and cryogenic testing), completed NDE of welds with no anomalies, began SOFI application
- Kicked off Design Analysis Cycle 2: Initiated Preliminary Design phase for Payload System, initiated trades and systematic change process/control

Centennial Challenges Program

Program Description:
Offers incentive prizes to generate revolutionary solutions to problems of interest to NASA and the nation. The program seeks innovations from diverse and nontraditional sources of citizen inventors, private businesses and academia. Competitors are not supported by government funding, and awards are only made to successful teams when the challenges are met. NASA partners with non-profit organizations to conduct the challenges at no cost to the government.

MSFC Role:
Level II Program Management (Sam Ortega)

Customer: **Space Technology Mission Directorate (STMD)**

Sample Return Robot Challenge

Accomplishments for 2013:
- Awarded Level 1 prize money of $5000 for Sample Return Robot (SRR) Challenge at Worcester Polytechnic Institute (WPI); Touch Tomorrow science/robotics festival drew 10,000+ people
- Received Telly Award and a regional Emmy Award for NASA 360's video "Robots, Rocks & Rovers" featuring the Sample Return Robot Challenge
- Served as speaker (Level II Program Manager Sam Ortega) at New York City Maker Faire 2013; exhibited Centennial Challenges alongside NASA HQ Grand Challenge
- Toured Indiana Army base which will be the site of the Unmanned Aircraft Systems Airspace Operations Challenge in 2014, and continued planning with WPI for the 2014 SRR Challenge

Composite Cryotank Technologies and Demonstration (CCTD)

Project Description:
Mature technology readiness of composite out of autoclave (OoA) cryogenic propellant tanks at diameters that are suitable for future heavy lift vehicles and other in-space applications. Produce a major advancement to demonstrate TRL 6; successfully test a 5-meter diameter composite hydrogen fuel tank in a relevant environment, and achieve 30% weight savings and 25% cost savings compared to state-of- the-art.

MSFC Role:
Project management (John Vickers, John Fikes); engineering support from GRC, KSC, LaRC, and MSFC

Customers: STMD/Game Changing Development Program Office (Steve Gaddis/LaRC), HEOMD/Space Launch System (SLS) Office


2.4m Precursor Tank and Test Facility


5.5m Tank Tool

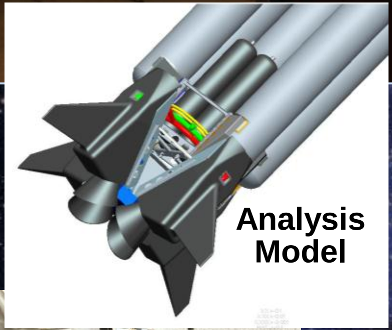

Test Stand 4699

Accomplishments:

- **2.4m Tank Status**: Completed fabrication (by Boeing) of first successful large fiber placed tank using OoA 5320-1/IM7 material and shipped to MSFC. Completed helium leak test and spray foaming of the tank. Completed the tank integration into test facility; completed TRR; successfully completed pressure tests in ambient and cryogenic (LH2) conditions. The tests met project requirements: stepwise fill with liquid hydrogen (LH2) to 90% volume capacity followed by pressurizing the tank to 135 psig. The tank was then cycled through 20 pressure/vent cycles, measuring hydrogen gas permeation on the tank dome.
- **5.5m Tank Status**: Completed the materials allowable program, optimization of the OoA Thin-Ply Prepreg and manufacture of 5.5m tool. Completed the CDR, MRR and delta CDR. Completed fabrication of four fluted core panels (288 full length flutes) and 5.5m pressure shell. Completed skirt alignment fixture installation and the automated fiber placement of the Inside Mold Line (IML) and Outer Mold Line (OML) skirt plies. Completed major refurbishment of MSFC Test Stand 4699 to accommodate CCTD 5.5m composite tank including fabrication and integration of Special Test Equipment.

Soldier-Warfighter Operationally Responsive Deployer for Space (SWORDS)

Wind Tunnel Model



Analysis Model

Test Stand 500 Mods for Horizontal Engine Testing

Project Description:
Develop an affordable, responsive, dedicated launch system for nano- and micro-satellites. Partner with US Army Space & Missile Defense Command (SMDC) to (1) develop a launch vehicle capable of lifting 25kg to 750km circular orbit, (2) target recurring production costs of ~$1.5M, and (3) reduce personnel and inventory requirements.

MSFC Role: **Project management (Benny Davis); lead four NASA centers in areas such as avionics, aerosciences, propulsion, launch services, vehicle system analysis**

Customers: **STMD Game Changing Development; Advanced Exploration Systems (AES)/HEOMD; US Army SMDC**

Accomplishments for 2013:

- Provided significant participation in second design review (PDR)
- Completed wind tunnel testing, delivered aero database
- Completed two Load Cycle reviews
- Continued Mass Properties database
- Developed models for pressurization and feed systems analysis, engine operations analysis, and engine nozzles
- Defined Flight Safety System architecture
- Prepared Test Stand 500 for horizontal engine testing

Synthetic Biology and Next Generation Life Support (NGLS)

Project Description:

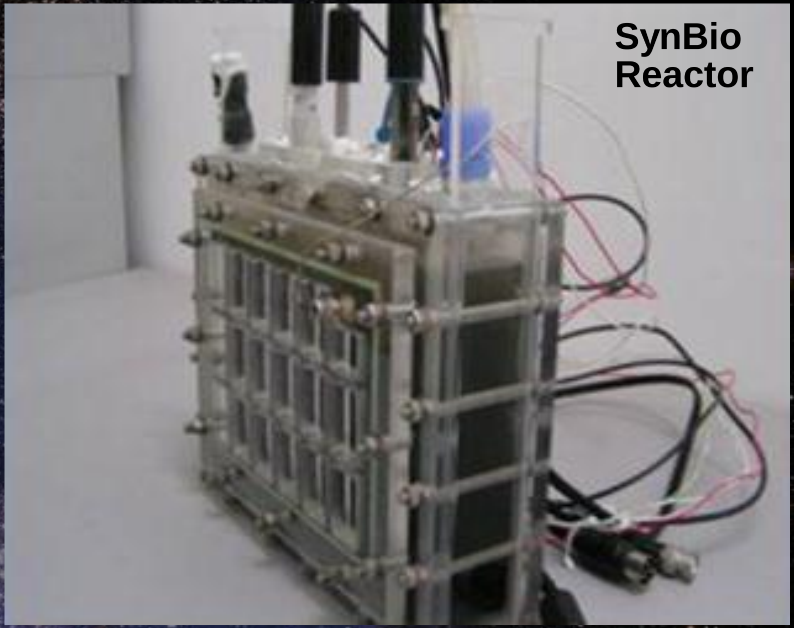
***Synthetic Biology*: Develop concept designs and collect baseline performance data on carbon dioxide removal and oxygen production using biological systems, including genetically engineered organisms**
***NGLS*: Develop and mature the Bosch CO2 reduction hardware for future integration into an atmosphere revitalization architecture**

MSFC Role: Project management (David Howard); supporting center to ARC (Synthetic Biology) and JSC (NGLS)

Customer: Game Changing Development/STMD

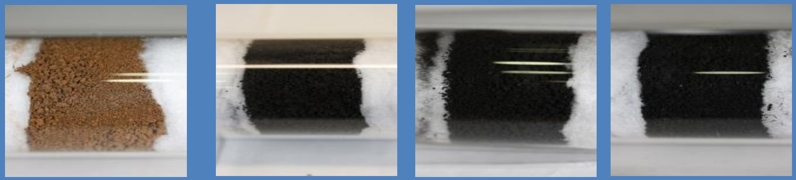
Accomplishments for 2013 include:
SynBio
- Worked with ARC to define new objectives and tasks; MSFC has role in developing test stand to evaluate SynBio reactor
- Specified components for items to test feed and separation processes ancillary to the bioreactor for testing

NGLS
- Completed Series-Bosch test stand and software package
- Completed Reverse Water-Gas Shift test stand build-up; started testing
- Completed testing of Lunar and Martian regolith as carbon formation catalysts
- Produced Lunar & Martian regolith bricks



SynBio Reactor

NGLS Results



Bosch reaction carbon formation on Martian regolith after 0hrs, 1hr, 4hrs, and 16hrs (left to right)

Programmable Ultra Lightweight System Adaptable Radio (PULSAR)

Project Description:
Continue development of software defined radio technology through ground station compatibility testing, integration into a flight relevant platform (HOPE HEROES high altitude balloon) and flight(s) of the platform

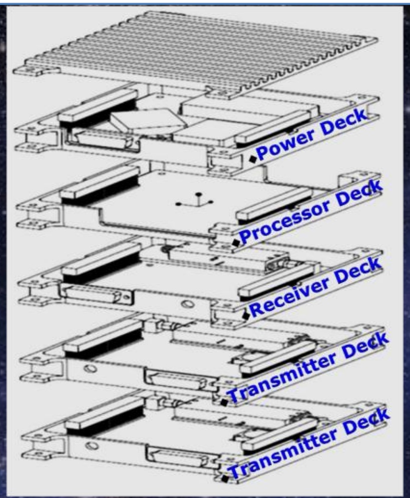
MSFC Role: Project management (Eric Eberly), engineering development/testing

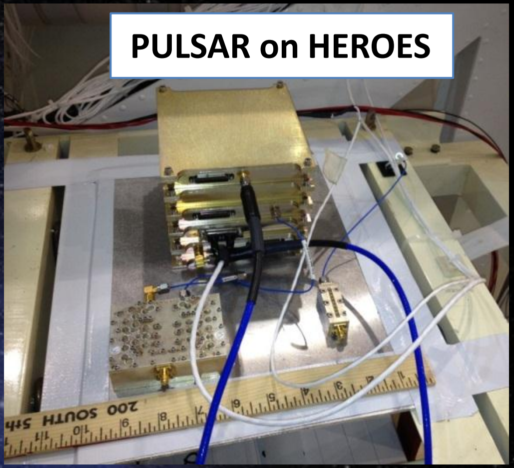
Customer: STMD Game Changing Development—Autonomous Systems

Accomplishments for 2013 include:

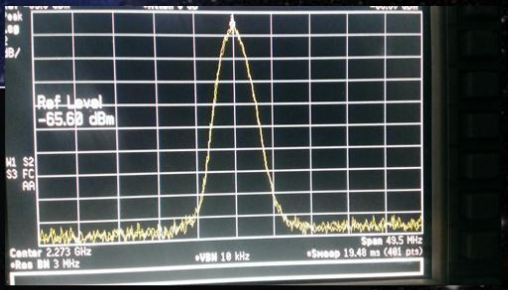
- Achieved data rates increase: 6x uplink and 150x downlink
- Validated data rates by hardware in the loop testing: system capable of 500 mega symbols per second for both S- and X-Band
- Shared ride on HEROES Balloon Flight:
  - Demonstrated data transfer during compatibility test
  - Exposed hardware to altitude over 100,000 feet for more than 15 hours
  - Confirmed flight operations with thermocouple and S-Band signal spectrum
  - Verified full functionality of hardware in post-flight test

PC104+ Connectors Permit Modular Design



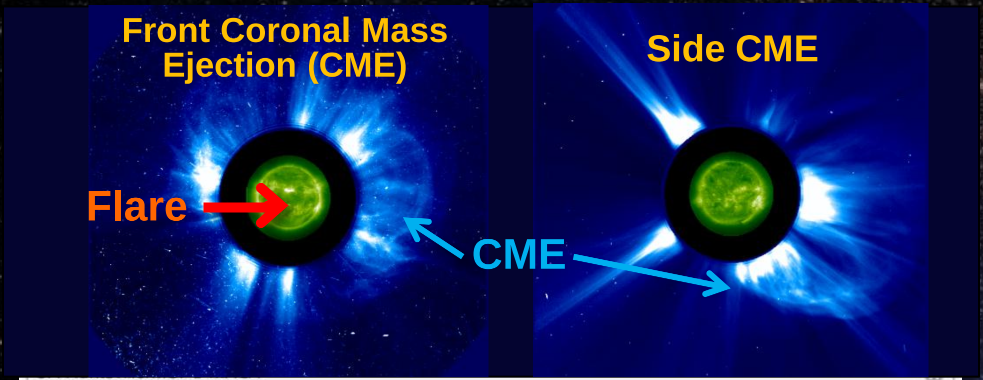


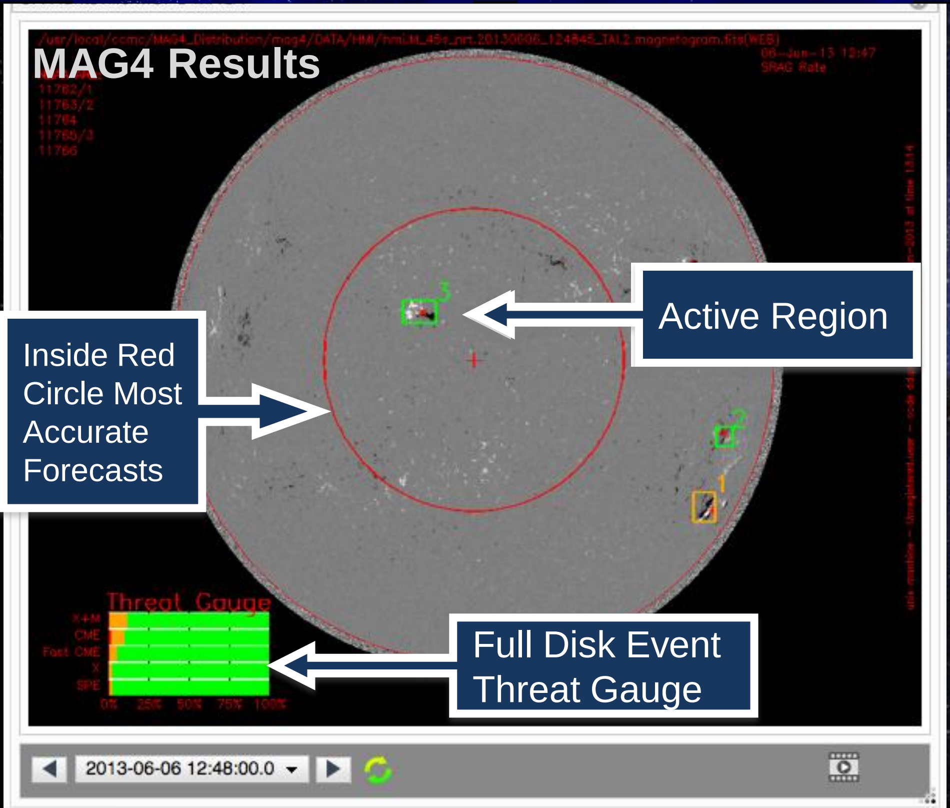
PULSAR on HEROES



HEROES Launch and PULSAR Signal

Advanced Radiation Protection (ARP)





Project Description: Assess and mature disruptive technologies that show potential to dramatically improve the radiation protection risks of future deep space exploration vehicles and habitats. Provide the capabilities to forecast major solar energetic particle events such as flares and coronal mass ejections in time for a crew to provide a secure environment during the event, i.e., to provide an alert to seek protection. Specific goal for 2013 was to develop an upgrade to the Magnetogram Forecast (MAG4) tool for improved forecasts.

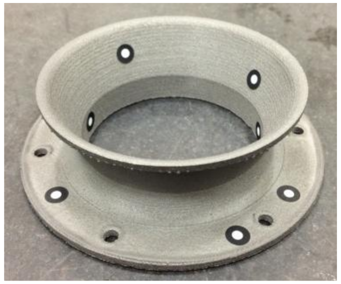
MSFC Role: Principal Investigator (Nasser Barghouty); upgrades of MAG4 space weather forecasting tool with University of Alabama in Huntsville

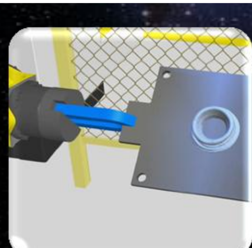
Customer: Game Changing Development/STMD

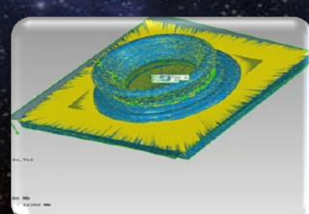
Accomplishments for 2013:

- Worked on improved version of MAG4 that uses free-energy proxy and previous flare history, to provide significantly better forecasts than present version of the tool
- Presented information on MAG4 tool to Air Force space weather forecasters
- Won Silver Snoopy for the MAG4 work
- Wrote a paper that quantifies that MAG4 present forecasts are superior to the McIntosh Active Region Class forecasts that are basis of NOAA forecasts

Manufacturing Innovation Project (MIP)







<u>Project Description:</u>
Collaborative effort between MSFC, GRC, and LaRC to advance manufacturing technologies that will enable, and reduce the risk for, NASA's future space exploration activities

<u>MSFC Role:</u> Project management (Niki Werkheiser); manufacturing engineering development

<u>Customer:</u> STMD Game Changing Development

<u>Accomplishments for 2013:</u>

- **Completed MIP Continuation and Mid-Year Reviews**
- **Participated in Advanced Manufacturing Technical Interchange Meeting at NASA HQ**
- **Developed advanced manufacturing roadmap for 2014 and beyond**
- **Completed software code for structured light scanner and robot interface, and to autonomously compare scan to CAD**
- **Achieved autonomous scanning of part, coordinated motion between scanner/robot**
- **Concluded final task to generate a mill tool path from a CAD model of a comparison as-scanned/built to as-designed data file**
- **Obtained approval from STMD for Advanced Manufacturing Technologies Project to replace MIP**

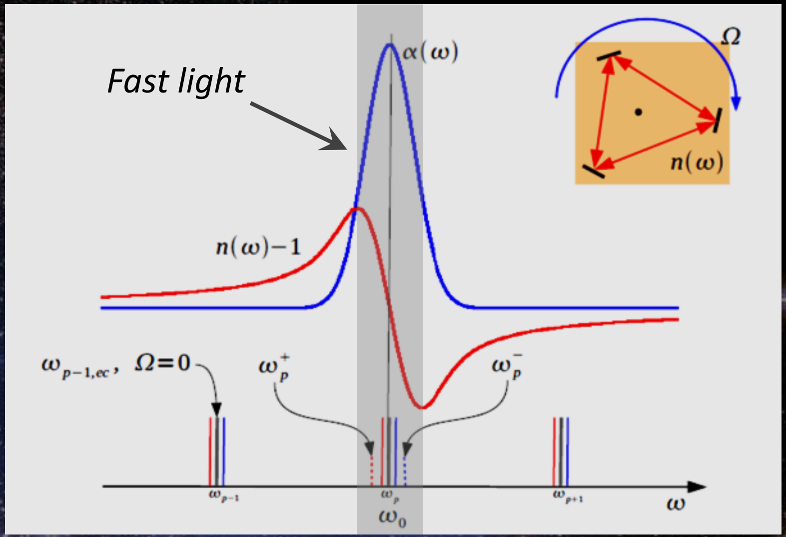
Fast Light Optical Gyroscopes for Precision Inertial Navigation (FLOG-PIN)

Project Description:
Collaborative effort between MSFC, Army and Northwestern University (NU) to explore two types of optical gyroscopes: passive cavity and active cavity (ring laser) gyros. Demonstrate field-testable, compact gyros that are at least 1,000 times more sensitive than the best current gyroscope of the same area, dramatically improving in-flight navigation capabilities.

MSFC Role: Principal Investigator (David D. Smith)

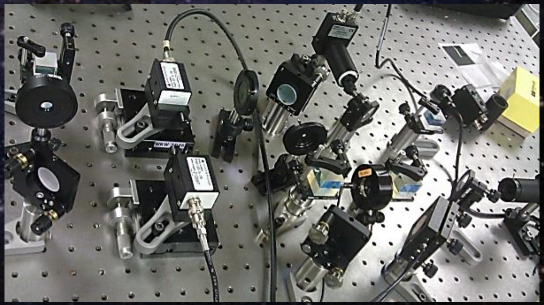
Customer: STMD Game Changing Development

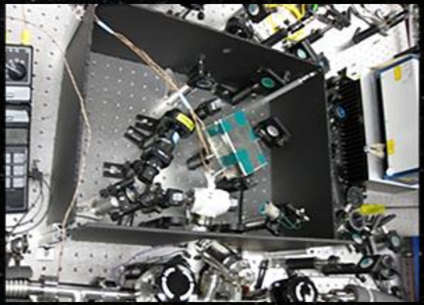
Accomplishments for 2013:
- Achieved highest scale factor enhancement ever recorded, by using polarization mode coupling in a single passive cavity
- Accomplished first ever demonstration of coherent control of the scale factor of a passive cavity
- Completed setup of a high finesse passive optical gyroscope including all control loops and simulated rotation method
- Supported Army development of compact frequency-stable laser as input for PFLOG
- Constructed a dead-band-free diode-pumped alkali ring laser gyro
- Constructed a dual pumped Raman laser that could reduce size and power required



Above: Illustration of how the response of a gyroscope is enhanced by fast light. The cavity modes are split by the rotation of the gyro. In the fast light region the refractive index *n(ω)* decreases with frequency, which pushes on the modes and further increases the splitting.

PFLOG **AFLOG**





Passive (left) and active (right) FLOG setups under development at MSFC and NU

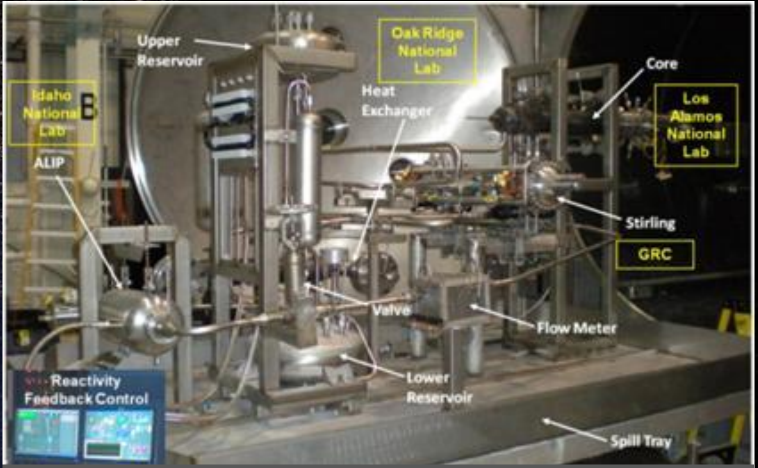
Nuclear Systems (NS)

Project Description:
Demonstrate affordability and viability of fission power systems for use on planetary surfaces or in deep space. Help enable a power rich environment anywhere in the solar system for both human and robotic missions.

MSFC Role:
Project management (Mike Houts). Provide fission reactor simulators (non-nuclear) and perform highly realistic non-nuclear testing of space fission systems. Investigate thermal, fluid, heat transport, structural, and safety aspects of space fission power systems.

Customers: **Game Changing Development/STMD; Advanced Exploration Systems (AES)/HEOMD; NASA Human Architecture Team (HAT)**

Accomplishments for 2013:
- **Completed design, development, fabrication, and checkout of Technology Demonstration Unit (TDU) reactor simulator. Reactor simulator designed to power ¼ scale TDU of 40 kWe fission surface power system designed for use anywhere on the moon or Mars.**
- **Delivered reactor simulator to GRC. In FY14 reactor simulator will be coupled to a Stirling Power Conversion subsystem, and the resulting integrated TDU will be tested at GRC.**

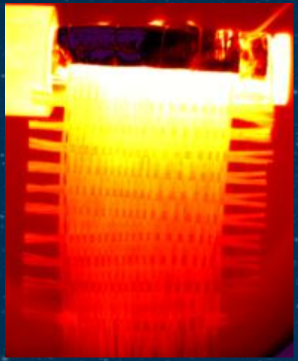


Integrated Reactor Simulator / Stirling Engine Demonstration

Reactor Simulator

Center Innovation Fund (CIF)

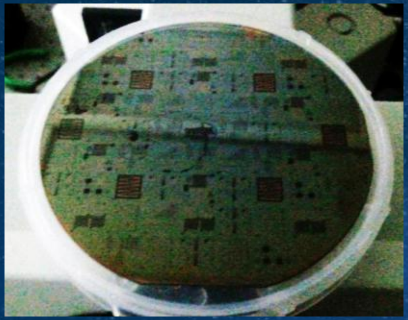
Lightweight Radiators for Nuclear Electric Propulsion: Paul Craven



Objective: Develop lightweight carbon-fin heat rejection system to operate from cryogenic to 1000ºC temperatures. Capability is enabling for game-changing power and propulsion technologies .

Accomplishments include:
- Improved radiator construction
- Demonstrated operations to 600°C
- Characterized carbon fiber fin performance

Day and Night Energy Harvesting: Angela Shields



Objective: Develop plasmonic nano-antennas to capture earth's re-emitted IR energy and convert into DC power for spacecraft. Offers major reduction in spacecraft power system weight.

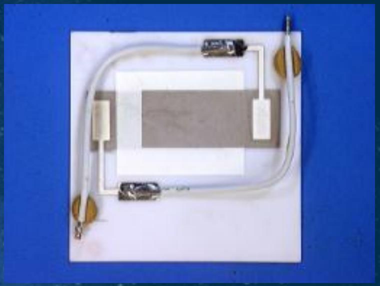
Accomplishments in FY13:
- Transitioned concept from visible to IR wavelength
- Developed lithography process for antennas
- Continued diode fabrication and testing

Electrically-Controlled Extinguishable Solid Propellant: Jeremy Rousseau

Objective: Electrically-controlled extinguishable solid propellant. Innovation could allow NASA to demonstrate throttleable, solid rocket motor that could replace multi-mode propulsion systems.

Accomplishments include:
- Static motor test firing with embedded graphite electrodes
- Based on first test results, designed second test series with fewer electrodes and GN2 purge

A Solid State Ultracapacitor to Replace Batteries: Terry Rolin

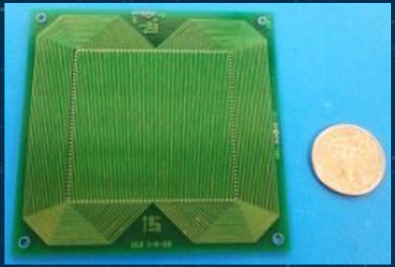


Objective: Develop internal barrier layer capacitor leading to solid-state replacement for batteries. Design offers 50X decrease in upmass and eliminates failure modes in many designs.

Accomplishments include:
- Fabricated numerous thick film ultracapacitor devices for testing
- Verified testing process by comparison to calculated values
- Established two new laboratories at MSFC

Center Innovation Fund (CIF)

Small Satellite Attitude Determination and Control: Steven Peeples



Objective: Modular attitude determination and control system (ADCS) to reduce volume by factor of five and power draw by two orders-of-magnitude. Advances CubeSat emerging science.

Accomplishments include:

- Completed magnetic torquer and ADCS PCBs design/fab/test
- Completed preliminary CubeSat proximity operations testing
- Designed adapter for ADCS IMU upgrade

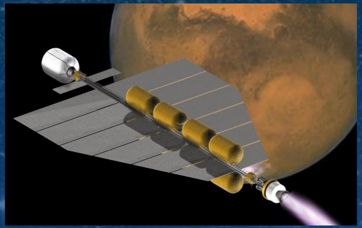
On-Orbit UV Cured Hybrid Inflatables: Alex Sobey

Objective: Develop hybrid composite inflatable structures to be cured in-orbit. Maintain advantages of inflatables, while adding the structural integrity and rigidity of a hard-shelled composite.

Accomplishments include:

- Introduced new resin and fiber; cured laminates
- Improved material consistency using Vacuum Assisted Resin Transfer Molding
- Performed impact testing of inflated articles
- Analyzed results and concluded positively on viability of material

Lighting the Fission Fragment Rocket Engine (FFRE) Afterburner: Bob Werka



Objective: Add afterburner to previously studied FFRE to achieve greater thrust while maintaining very high Isp. Innovation offers potential for 100-day Mars mission.

Accomplishments include:

- Completed analysis that predicts 1046lbf thrust at 32,000s Isp
- Synthesized FFRE-propelled spacecraft with 170mT payload to predict round trip 290 day Mars Exploration mission
- Verified FFRE modeling with independent code

Aligned Carbon Nanotube Tape for Sensors: Dennis Tucker

Objective: Demonstrate feasibility of producing piezoelectric carbon nanotube tape for use as sensing elements in small satellites. Advantages include low weight and superior mechanical/ thermal properties.

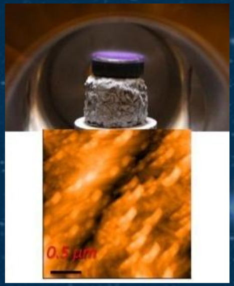
.

Accomplishments include:

- Fabricated multi-functional CNT tape and measured piezoelectric response
- Improved performance by adding barium titanate nanopowder to matrix material solution
- Designed accelerometer and gyroscope

Center Innovation Fund (CIF)

Carbon Formation for Life Support and *in situ* Fab: Morgan Abney



Objective: Investigate technologies to recover hydrogen from methane on ISS while generating useful forms of carbon using chemical vapor deposition. Potential for *in situ* fabrication using carbon.

Accomplishments:
- Processed depositions of carbon on Ni and Fe substrates
- Found that Ni and Fe substrates have different carbon forms under same conditions
- Established protocols for controlled carbon deposition from methane

Fission-Fragment Dust Experiment: Dennis Gallagher

Objective: Characterization of radioactive dust charging properties during decay and fission to enable the development of new type of fission fragment in-space rocket engine.

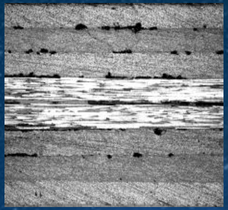
Accomplishments:
- Delivered FFDE electrostatic particle levitator apparatus and test equipment to Oak Ridge National Laboratory
- Conducted levitation tests for radioactive Californium 252 particles

Ultra-High-Resolution X-Ray Optics: Mikhail Gubarev

Objective: Improve x-ray mirror fabrication process by forming naturally-flat, thin silicon wafers through torque bending into very-lightweight, high-resolution mirrors ready to be installed in a telescope.

Accomplishments:
- Demonstrated viability in first year by building mirror bender and forming wafers into conical surface
- Designed and 3D printed second generation bender
- Demonstrated that coating stress can be measured by in-situ monitoring of wafer curvature

Boron/Graphite Hybrid Composites: John Fikes



Objective: Develop a composite laminate with 50% more compression after impact (CAI) strength by incorporating boron fibers with the carbon fibers in a laminate. Also seek to greatly reduce the cost and time needed to develop material allowables.

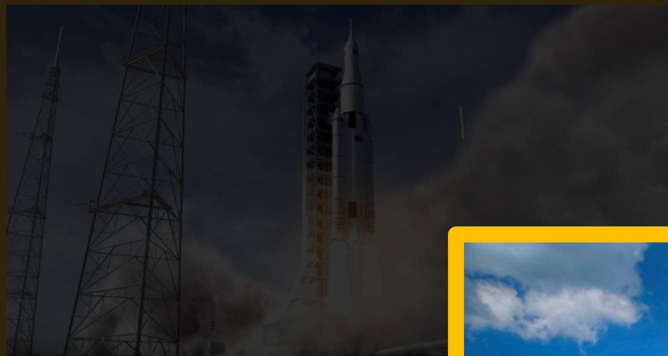
Accomplishments:
- Achieved 50 ksi CAI strength with two material plies, and 53 ksi with 3 plies (goal 61 ksi)
- Found that reduced allowable testing preliminary results were encouraging for elastic constants

Simulated Martian Exposure to Propellant: Jeremy Rousseau

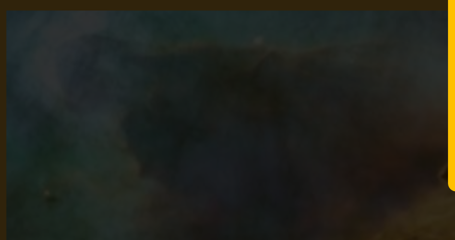
Objective: Condition a new solid propellant formulation for the Mars Ascent Vehicle. Subject propellant to space vacuum for six months, and to an atmosphere replicating the Martian environment.

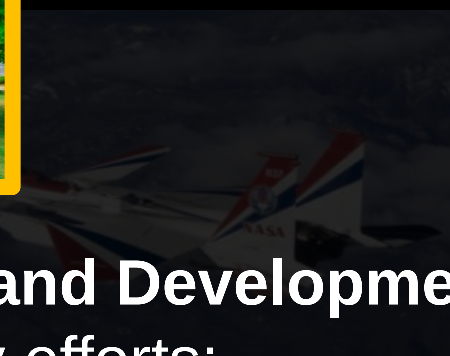
Accomplishments:
- Procured, built, assembled, and started entire test system
- Achieved savings of $250-500K through non-aerospace COTS equipment
- Started testing of 200lb of propellant

The National Aeronautics and Space Administration



Space





MSFC also expends **Internal Research and Development** (IRAD) resources on strategic technology efforts:

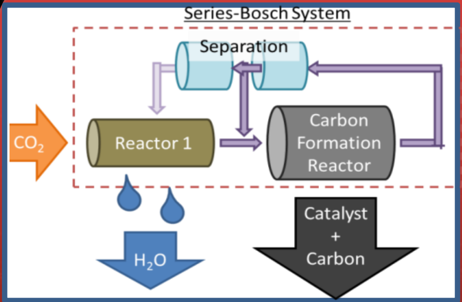
- Technology Investment Program
- Center Discretionary Funds

Aeronautics Research

Marshall supports three of the NASA Mission Areas.

Technology Investment Program (TIP)

Bosch for Space &Terrestrial Applications: Morgan Abney



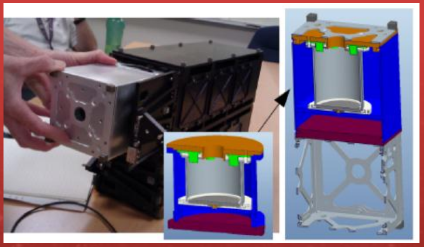
Purpose

Advance Bosch CO2 reduction technology for (1) life support systems using regolith catalyst, and (2) reduction of CO2 emissions in cement industry

Accomplishments

- Tested Martian and Lunar Regolith simulants and produced bricks
- Tested cement from two U.S.-based plants and produced bricks
- Developed concepts for regolith-based carbon formation reactor and Bosch-based CO2 reduction in a cement plant

Collimated Photoelectron Gun (CPEG): Linda Krause



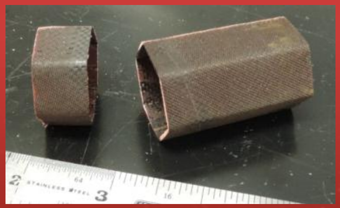
Purpose

Design, develop, and test collimated photoelectron gun, a novel electron source for spaceflight applications

Accomplishments

- Completed electrical design of system, and modified mechanical design based on vibe test results
- Completed final design and assembly of CPEG system
- Adapted design for flight as external CubeSat payload

Superior Epoxies for Cryo Composite Tanks: Richard Grugel



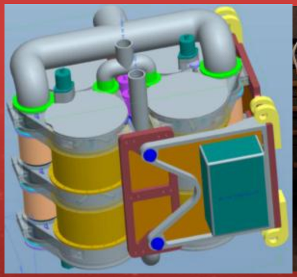
Purpose

Improve strength and fracture toughness of novel ionic-liquid-based epoxy for application in composite cryotanks. Offers potential game-changing technology.

Accomplishments

•Established procedure to mix, "cast", process, and extract ionic liquid (IL) epoxy test samples
•Incorporated nano-scale Core-Shell-Rubber (CSR) particles into IL epoxy matrix to toughen it
• Verified increased fracture toughness through impact testing; repeated cycling in LN2 showed no evidence of cracking/delamination

Bench Test of Orion Air Revitalization System: Jim Knox



Purpose

- Demonstrate viability of a MSFC approach for Orion carbon dioxide and humidity control
- Fabricate, assemble, and test modified adsorbent beds & test stand to demonstrate performance with improved vacuum conductance

Accomplishments

- Engineering Development Unit: Completed fabrication of bed components
- Seal Test: Completed housing fabrication, test stand assembly and integration, and test stand leak check
- Vacuum Characterization Test: Fabbed second-gen test article

Technology Investment Program (TIP)

Ionic Liquid Extraction of Metals from Meteorite: Laurel Karr

Purpose

Use acidic ionic liquid (IL) system to extract metals from meteorite. In year 2, scale up the process and produce material for use in additive manufacturing.

Accomplishments

- Synthesized and tested new ionic liquids
- Designed and built larger scaled-up electrolysis cell
- Produced enough metal for several gears
- Attempted additive manufacturing (AM) of parts from extracted metal; magnetic iron did not work in AM equipment
  - In future work, use meteorite with more nickel and separate out nickel for use in manufacturing

SPRITE Small Satellite HIL Testbed: Ashley Lee

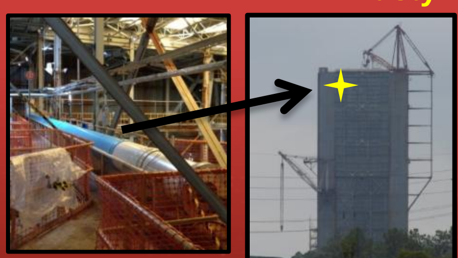
Purpose

Advance MSFC’s capabilities to support small spacecraft and payloads work by enhancing capabilities of the Small Projects Rapid Integration and Test Environment (SPRITE) Lab. Develop portable Hardware-in-the-Loop (HIL) integration and verification testbed.

Accomplishments

- Ran simulation system on portable test bed providing the ability for the SPRITE lab to test hardware at customer’s site
- Created library of both generic and specific models, ranging from physics models to hardware models
- Used ARTEMIS framework for synchronization, passing of data, and calls to hardware

Active Lateral Fluid Harmonic Absorber (AFLHA): Rusty Parks



Purpose

Apply fluid-structure coupling technology to systems such as space launch vehicles and commercial buildings. Develop active absorber to account for building frequency shifts.

Accomplishments

- Defined and used attenuation factor as ratio of un-attenuated to attenuated building response to an input at building first bending mode
- Achieved attenuation factors of 4.4 to 5.8 in as little as 160 seconds with active system (ALFHA); exceeded modern day building system attenuation factor of 2.2

Selective Laser Melting (SLM) Produced Hermetically Sealed Isolation Valve: James Richard

Purpose

Use SLM technology to achieve a hermetically sealed valve to replace expensive, difficult to handle, and potentially problematic pyrotechnic valves.

Accomplishments

- Developed valve designs to replace pyrotechnic devices near the propellant of launch or space systems; conducted trades
- Completed and built two detailed designs, using SLM techniques where possible
- Completed test plans

Technology Investment Program (TIP)

CubeSat Proximity Operations: Devon Sanders

Purpose
Accomplish autonomous rendezvous of a CubeSat prototype with another CubeSat or FASTSAT mock-up in MSFC's Flight Robotics Lab

Accomplishments
- Completed micropropulsion design and delivery (Univ. of Arkansas)
- Accomplished systems engineering t asks: ConOps analysis and trades, power budget, and card stack layout
- Completed structural design/analysis and thermal analysis
- Accomplished avionics, most of software, and GN&C tasks

Programmable Ultra-Lightweight System Adaptable Radio (PULSAR): Herb Sims & Kosta Varnavas

Purpose
Continue development of software defined radio technology through ground station compatibility testing, integration into a flight relevant platform (HOPE HEROES high altitude balloon) and flight(s) of the platform.

Accomplishments
- Completed integration of PULSAR onto HOPE/HEROES platform – achieved TRL 6
  - Completed subsystem level compatibility testing of unit on HOPE/HEROES
- Flew on HOPE/HEROES flight
  - Experienced minor problems with some loss of data

Oxygen Generator Assembly (OGA) Recombiner: Kevin Takada

Purpose
Investigate recombiner (catalytic reactor) replacement technology for existing hydrogen sensor in ISS Oxygen Generator Assembly, due to reliability issues and frequent calibration

Accomplishments
- Completed benchtop testing of two recombiner units under a variety of dew point temperatures and input mixtures. Units manufactured by Resource Systems Inc (RSI) and Precision Combustion Inc (PCI).
- Selected RSI unit for installation into OGA testbed, due to its superior performance in benchtop testing for hydrogen reaction and response time

Hazard Avoidance Demonstration for a Robotic Lander: Mike Hannan

Purpose
Demonstrate use of a low-cost, lightweight COTS stereo camera to identify landing hazards and guide Mighty Eagle to safe landing site

Accomplishments
- Completed 4 free flights over high fidelity lunar terrain field
- Integrated a secondary processing unit, COTS stereo camera, and additional networking components on the Mighty Eagle
- Gathered 22 terrain field only images with a total of 80+ images in flight
- Achieved limited success with inflight hazard avoidance
  - Image data had insufficient accuracy to process for hazard detection, due to lmited quality in the 3D stereo depth map

Technology Investment Program (TIP)

Lightweight Inflatable Solar Array: Les Johnson

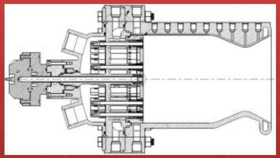
Purpose

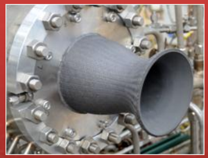
Prove feasibility and potential benefits of Lightweight Inflatable Solar Array compared to conventional spacecraft power systems

Accomplishments

- Completed three concept design studies establishing concept feasibility:
  - Kestrel Eye Demonstrator mission
  - 3U CubeSat mission
  - Saturn concept
- Designed and fabricated test article
- Conducted successful inflation test

Low-Cost 4000lb Morpheus/SWORDS Thrust Chamber: Gregg Jones





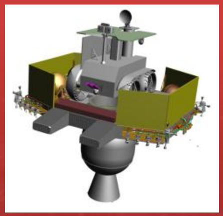
Purpose

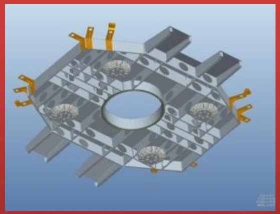
Provide high performance, 4000 lb_f thrust, LOX/CH4 injector and regeneratively cooled chamber for applications like Morpheus and SWORDS

Accomplishments

- Completed design of injector and regeneratively cooled chamber
- Completed design and initiated fabrication of uncooled iridium/rhenium chamber
- Continued work on alternate regen chamber design to provide copper liner for fuel cooling; maintains low cost fab and will be assembled into 3D printed structural jacket

"Down-in-the-Dirt" Pallet Lander: Andy Wayne





Purpose

Design and build cost efficient riveted sheet metal lunar lander structure in-house. Optimize the placement of structural members to mitigate strength and vibration concerns.

Accomplishments

- Completed work with vendor to determine most cost effective/engineering sheet metal stiffening bead/lightening hole dimensions
- Completed structural optimization for loads & frequencies
- Completed "Build-to-Print" models & issued 40 drawings

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