Appendix A: NASA Mission Directorates and Center Alignment

NASA's Mission *to pioneer the future in space exploration, scientific discovery, and aeronautics research,* draws support from four Mission Directorates and ten NASA Centers (including JPL), each with a specific responsibility.

A.1 Aeronautics Research Mission Directorate (ARMD) conducts high-quality, cutting-edge research that generates innovative concepts, tools, and technologies to enable revolutionary advances in our Nation's future aircraft, as well as in the airspace in which they will fly. ARMD programs will facilitate a safer, more environmentally friendly, and more efficient national air transportation system. Using a Strategic Implementation Plan NASA Aeronautics Research Mission Directorate (ARMD) sets forth the vision for aeronautical research aimed at the next 25 years and beyond. It encompasses a broad range of technologies to meet future needs of the aviation community, the nation, and the world for safe, efficient, flexible, and environmentally sustainable air transportation. Additional information on the Aeronautics Research Mission Directorate (ARMD) can be found at: http://www.aeronautics.nasa.gov.

Areas of Interest - POC: Tony Springer, tony.springer@nasa.gov

Researchers responding to the ARMD should propose research that is aligned with one or more of the ARMD programs. Proposers are directed to the following:

- ARMD Programs: http://www.aeronautics.nasa.gov/programs.htm
- The National Aeronautics and Space Administration (NASA), Headquarters, Aeronautics Research Mission Directorate (ARMD) Current Year version of the NASA Research Announcement (NRA) entitled, "Research Opportunities in Aeronautics (ROA)" has been posted on the NSPIRES web site at http://nspires.nasaprs.com (select "Solicitations" and then "Open Solicitations").

Detailed requirements, including proposal due dates are stated in appendices that address individual thrust areas. These appendices will be posted as amendments to the ROA NRA and will be published as requirements materialize throughout the year.

A.2 Human Exploration & Operations Mission Directorate (HEOMD) provides the Agency with leadership and management of NASA space operations related to human exploration in and beyond low-Earth orbit. HEO also oversees low-level requirements development, policy, and programmatic oversight. The International Space Station, currently orbiting the Earth with a crew of six, represents the NASA exploration activities in low-Earth orbit. Exploration activities beyond low Earth orbit include the management of Commercial Space Transportation, Exploration Systems Development, Human Space Flight Capabilities, Advanced Exploration Systems, and Space Life Sciences Research & Applications. The directorate is similarly responsible for Agency leadership and management of NASA space operations related to Launch Services, Space Transportation, and Space Communications in support of both human and robotic exploration programs. Additional information on the Human Exploration & Operations Mission Directorate (HEOMD) can be found at: (http://www.nasa.gov/directorates/heo/home/index.html)

Areas of Interest - POC: Bradley Carpenter, bcarpenter@nasa.gov

Human Research Program
The Human Research Program (HRP) is focused on investigating and mitigating the highest risks to human health and performance in order to enable safe, reliable, and productive human space exploration. The HRP budget enables NASA to resolve health risks in order for humans to safely live and work on missions in the inner solar system. HRP conducts research, develops

countermeasures, and undertakes technology development to address human health risks in space and ensure compliance with NASA's health, medical, human performance, and environmental standards.

Space Biology

The Space Biology research has three primary goals:

- Effectively use microgravity and other characteristics of the space environment to enhance our understanding of fundamental biological processes;
- Develop the scientific and technological foundations for a safe, productive human presence in space for extended periods and in preparation for exploration;
- Apply this knowledge and technology to improve our nation's competitiveness, education, and the quality of life on Earth.

These goals are achieved by sponsoring research studies in five program elements to contribute basic knowledge of biological adaptation to spaceflight to accelerate solutions to biomedical problems affecting human exploration of space as well as human health on Earth: Microbiology; Cell and Molecular Biology; Plant Biology; Animal Biology; and Developmental Biology

Current Space Biology emphases include:

- Use ground-based facilities to characterize the effects of space-like radiation on biological systems. NASA is interested in projects that will characterize how radiation exposure impacts living organisms during a single lifecycle, or over multiple generations.
- Use ground-based simulations to study how spaceflight conditions might impact plant and microbial interactions and growth. Questions of interest to NASA include, but are not limited to, whether spaceflight induces changes in the virulence of plant pathogens and/or whether spaceflight might change benign or commensal microbes on plants into pathogenic ones.
- Use ground-based facilities to simulate a range of gravitational levels on biological specimens to understand and characterize the dose-response curve between 0 and 2 G for various biological systems to determine A) if there are G-level thresholds required to trigger gravity-specific responses in living organisms, and B) the effect that exposure to levels of gravity similar to those encountered on Mars (.38 G) or the moon (0.16 G), and/or hypergravity has on living organisms.

Further details about Space Biology goals, objectives and progress can be found at the Space Biology Website.

Physical Science Research

The Physical Science Research Program, along with its predecessors, has conducted significant fundamental and applied research, both which have led to improved space systems and produced new products offering benefits on Earth. NASA's experiments in various disciplines of physical science reveal how physical systems respond to the near absence of gravity. They also reveal how other forces that on Earth are small compared to gravity, can dominate system behavior in space.

The Physical Science Research Program also benefits from collaborations with several of the International Space Station international partners—Europe, Russia, Japan, and Canada—and foreign governments with space programs, such as France, Germany and Italy. The scale of this research enterprise promises new possibilities in the physical sciences, some of which are already being realized both in the form of innovations for space exploration and in new ways to improve the quality of life on Earth.

Research in physical sciences spans from basic and applied research in the areas of:

- Biophysics: biological macromolecules, biomaterials.
- Combustion science: spacecraft fire safety, droplets, gaseous (premixed and non-premixed), solid fuels, supercritical reacting fluids.
- Complex fluids: colloidal systems, liquid crystals, foams, gels, granular flows.
- Fluid physics: adiabatic two-phase flow, boiling and condensation, capillary flow, interfacial phenomena, cryogenics storage and handling.
- Fundamental physics: space optical/atomic clocks, quantum test of equivalence principle, cold atom physics, critical point phenomena, dusty plasmas.
- Materials science: glasses and ceramics, granular materials, metals, polymers and organics, semiconductors.

Implementing Centers: NASA's Physical Sciences Research Program is carried out at the Glenn Research Center (GRC), Jet Propulsion Laboratory (JPL) and Marshall Space Flight Center (MSFC). Further information on physical sciences research is available at http://issresearchproject.nasa.gov/

Engineering Research

- Spacecraft: Guidance, navigation and control; thermal; electrical; structures; software; avionics; displays; high speed re-entry; modeling; power systems; interoperability/commonality; advanced spacecraft materials; crew/vehicle health monitoring; life support.
- Propulsion: Propulsion methods that will utilize materials found on the moon or Mars, “green” propellants, on-orbit propellant storage, motors, testing, fuels, manufacturing, soft landing, throttle-able propellants, high performance, and descent.
- Robotic Systems for Precursor Near Earth Asteroid (NEA) Missions: Navigation and proximity operations systems; hazard detection; techniques for interacting and anchoring with Near Earth Asteroids; methods of remote and interactive characterization of Near Earth Asteroid (NEA) environments, composition and structural properties; robotics (specifically environmental scouting prior to human arrival and later to assist astronauts with NEA exploration); environmental analysis; radiation protection; spacecraft autonomy, enhanced methods of NEA characterization from earth-based observation.
- Robotic Systems for Lunar Precursor Missions: Precision landing and hazard avoidance hardware and software; high-bandwidth communication; in-situ resource utilization (ISRU) and prospecting; navigation systems; robotics (specifically environmental scouting prior to human arrival, and to assist astronaut with surface exploration); environmental analysis, radiation protection.
- Data and Visualization Systems for Exploration: Area focus on turning precursor mission data into meaningful engineering knowledge for system design and mission planning of lunar surface and NEAs. Visualization and data display; interactive data manipulation and sharing; mapping and data layering including coordinate transformations for irregular shaped NEAs; modeling of lighting and thermal environments; simulation of environmental interactions including proximity operations in irregular micro-G gravity fields and physical stability of weakly bound NEAs.
- Research and technology development areas in HEOMD support launch vehicles, space communications, and the International Space Station. Examples of research and technology development areas (and the associated lead NASA Center) with great potential include:

    - *Processing and Operations*

    - Crew Health and Safety Including Medical Operations (Johnson Space Center (JSC))
    - In-helmet Speech Audio Systems and Technologies (Glenn Research Center (GRC))
    - Vehicle Integration and Ground Processing (Kennedy Space Center (KSC))
    - Mission Operations (Ames Research Center (ARC))
    - Portable Life Support Systems (JSC)
    - Pressure Garments and Gloves (JSC)
    - Air Revitalization Technologies (ARC)
    - In-Space Waste Processing Technologies (JSC)
    - Cryogenic Fluids Management Systems (GRC)
- *Space Communications and Navigation*
    - Coding, Modulation, and Compression (Goddard Spaceflight Center (GSFC)
    - Precision Spacecraft & Lunar/Planetary Surface Navigation and Tracking (GSFC)
    - Communication for Space-Based Range (GSFC)
    - Antenna Technology (Glenn Research Center (GRC))
    - Reconfigurable/Reprogrammable Communication Systems (GRC)
    - Miniaturized Digital EVA Radio (Johnson Space Center (JSC))
    - Transformational Communications Technology (GRC)
    - Long Range Optical Telecommunications (Jet Propulsion Laboratory (JPL))
    - Long Range Space RF Telecommunications (JPL)
    - Surface Networks and Orbit Access Links (GRC)
    - Software for Space Communications Infrastructure Operations (JPL)
    - TDRS transponders for launch vehicle applications that support space communication and launch services (GRC)
- *Space Transportation*
    - Optical Tracking and Image Analysis (KSC)
    - Space Transportation Propulsion System and Test Facility Requirements and Instrumentation (Stennis Space Center (SSC)
    - Automated Collection and Transfer of Launch Range Surveillance/Intrusion Data (KSC)
    - Technology tools to assess secondary payload capability with launch vehicles (KSC)
    - Spacecraft Charging/Plasma Interactions (Environment definition & arcing mitigation) (Marshall Space Flight Center (MSFC)

A.3 Science Mission Directorate (SMD) leads the Agency in four areas of research: Earth Science, Heliophysics, Planetary Science, and Astrophysics. SMD, using the vantage point of space to achieve with the science community and our partners a deep scientific understanding of our planet, other planets and solar system bodies, the interplanetary environment, the Sun and its effects on the solar system, and the universe beyond. In so doing, we lay the intellectual foundation for the robotic and human expeditions of the future while meeting today's needs for scientific information to address national concerns, such as climate change and space weather. At every step we share the journey of scientific exploration with the public and partner with others to substantially improve science, technology, engineering and mathematics (STEM) education nationwide. Additional information on the Science Mission Directorate (SMD) can be found at: (http://nasascience.nasa.gov)

Areas of Interest - POC: Kristen Erickson kristen.erickson@nasa.gov

The Science Mission Directorate (SMD) has developed science objectives and programs to answer fundamental questions in Earth and space sciences in the context of our national science agenda. The knowledge gained by researchers supporting NASA's Earth and space science program helps to unravel mysteries that intrigue us all.

- What drives variations in the Sun, and how do these changes impact the solar system and drive space weather?
- How and why are Earth's climate and environment changing?
- How did our solar system originate and change over time?
- How did the universe begin and evolve, and what will be its destiny?
- How did life originate, and are we alone?

Each of the SMD's four science divisions – Heliophysics, Earth Science, Planetary Science, and Astrophysics – makes important contributions to address national and Agency goals. The NASA 2014 Science Plan (http://science.nasa.gov/media/medialibrary/2015/06/29/2014_Science_Plan_PDF_Update_508_TAGGED.pdf) reflects the direction NASA has received from our government's executive branch and Congress, advice received from the nation's scientific community, the principles and strategies guiding the conduct of our activities, and the challenges SMD faces. Specifically,

Heliophysics Division

Heliophysics encompasses science that improves our understanding of fundamental physical processes throughout the solar system, and enables us to understand how the Sun, as the major driver of the energy throughout the solar system, impacts our technological society. The scope of heliophysics is vast, spanning from the Sum's interior to Earth's upper atmosphere, throughout interplanetary space, to the edges of the heliosphere, where the solar wind interacts with the local interstellar medium. Heliophysics incorporates studies of the interconnected elements in a single system that produces dynamic space weather and that evolves in response to solar, planetary, and interstellar conditions.

The Agency's strategic objective for heliophysics is to **understand the Sun and its interactions with Earth and the solar system, including space weather.** The heliophysics decadal survey conducted by the National Research Council (NRC), *Solar and Space Physics: A Science for a Technological Society (http://www.nap.edu/catalog/13060/solar-and-space-physics-a-science-for-a-technological-society*), articulates the scientific challenges for this field of study and recommends a slate of design reference missions to meet them, to culminate in the achievement of a predictive capability to aid human endeavors on Earth and in space. The fundamental science questions are:

- What causes the Sun to vary?
- How do the geospace, planetary space environments and the heliosphere respond?
- What are the impacts on humanity?

To answer these questions, the Heliophysics Division implements a program to achieve three overarching goals:

- Explore the physical processes in the space environment from the Sun to the Earth and throughout the solar system
- Advance our understanding of the connections that link the Sun, the Earth, planetary space environment, and the outer reaches of our solar system
- Develop the knowledge and capability to detect and predict extreme conditions in space to protect life and society and to safeguard human and robotic explorers beyond Earth

See Section 4.1 of the NASA 2014 Science Plan for specifics, including missions currently in operation, in formulation or development, and planned for the future.

Earth Science Division

Our planet is changing on all spatial and temporal scales and studying the Earth as a complex system is essential to understanding the causes and consequences of climate change and other global environmental concerns. The purpose of NASA's Earth science program is to advance our scientific understanding of Earth as a system and its response to natural and human-induced changes and to improve our ability to predict climate, weather, and natural hazards.

NASA's ability to observe global change on regional scales and conduct research on the causes and consequences of change position it to address the Agency strategic objective for Earth science, which is to advance knowledge of Earth as a system to meet the challenges of environmental change, and to improve life on our planet. NASA addresses the issues and opportunities of climate change and environmental sensitivity by answering the following key science questions through our Earth science program:

- How is the global Earth system changing?
- What causes these changes in the Earth system?
- How will the Earth system change in the future?
- How can Earth system science provide societal benefit?

These science questions translate into seven overarching science goals to guide the Earth Science Division's selection of investigations and other programmatic decisions:

- Advance the understanding of changes in the Earth's radiation balance, air quality, and the ozone layer that result from changes in atmospheric composition (Atmospheric Composition)
- Improve the capability to predict weather and extreme weather events (Weather)
- Detect and predict changes in Earth's ecosystems and biogeochemical cycles, including land cover, biodiversity, and the global carbon cycle (Carbon Cycle and Ecosystems)
- Enable better assessment and management of water quality and quantity to accurately predict how the global water cycle evolves in response to climate change (Water and Energy Cycle)
- Improve the ability to predict climate changes by better understanding the roles and interactions of the ocean, atmosphere, land and ice in the climate system (Climate Variability and Change)
- Characterize the dynamics of Earth's surface and interior, improving the capability to assess and respond to natural hazards and extreme events (Earth Surface and Interior)
- Further the use of Earth system science research to inform decisions and provide benefits to society

Two foundational documents guide the overall approach to the Earth science program: the NRC 2007 Earth science decadal survey (http://www.nap.edu/catalog/11820/earth-science-and-applications-from-space-national-imperatives-for-the) and NASA's 2010 climate-centric architecture plan (http://science.nasa.gov/media/medialibrary/2010/07/01/Climate_Architecture_Final.pdf). The former articulates the following vision for Earth science research and applications in support of society:

> Understanding the complex, changing planet on which we live, how it supports life and how human activities affect its ability to do so in the future is one of the greatest intellectual challenges facing humanity. It is also one of the most challenges for society as it seeks to achieve prosperity, health, and sustainability.

The latter addresses the need for continuity of a comprehensive set of key climate monitoring measurements, which are critical to informing policy and action, and which other agencies and international partners had not planned to continue. NASA's ability to view the Earth from a global perspective enables it to provide a broad, integrated set of uniformly high-quality data covering all parts of the planet. NASA shares this unique knowledge with the global community, including members of the science, government, industry, education, and policy-maker communities.

See Section 4.2 of the NASA 2014 Science Plan for specifics, including missions currently in operation, in formulation or development, and planned for the future.

Planetary Science Division

Planetary science is a grand human enterprise that seeks to understand the history of our solar system and the distribution of life within it. The scientific foundation for this enterprise is described in the NRC planetary science decadal survey, Vision and Voyages for Planetary Science in the Decade 2013-2022 (http://www.nap.edu/catalog/13117/vision-and-voyages-for-planetary-science-in-the-decade-2013-2022). Planetary science missions inform us about our neighborhood and our own origin and evolution; they are necessary precursors to the expansion of humanity beyond Earth. Through five decades of planetary exploration, NASA has developed the capacity to explore all of the objects in our solar system. Future missions will bring back samples from some of these destinations, allowing iterative detailed study and analysis back on Earth. In the future, humans will return to the Moon, go to asteroids, Mars, and ultimately other solar system bodies to explore them, but only after they have been explored and understood using robotic missions.

NASA's strategic objective in planetary science is to **ascertain the content, origin, and evolution of the solar system and the potential for life elsewhere**. We pursue this goal by seeking answers to fundamental science questions that guide NASA's exploration of the solar system:

- How did our solar system form and evolve?
- Is there life beyond Earth?
- What are the hazards to life on Earth?

The Planetary Science Division has translated these important questions into science goals that guide the focus of the division's science and research activities:

- Explore and observe the objects in the solar system to understand how they formed and evolve
- Advance the understanding of how the chemical and physical processes in our solar system operate, interact and evolve
- Explore and find locations where life could have existed or could exist today.
- Improve our understanding of the origin and evolution of life on Earth to guide our search for life elsewhere
- Identify and characterize objects in the solar system that pose threats to Earth, or offer resources for human exploration

In selecting new missions for development, NASA's Planetary Science Division strives for balance across mission destinations, using different mission types and sizes. Achievement of steady scientific progress requires a steady cadence of missions to multiple locations, coupled with a program that allows for a consistent progression of mission types and capabilities, from small and focused, to large and complex, as our investigations progress. The division also pursues partnerships with international partners to increase mission capabilities and cadence and to accomplish like-minded objectives.

See Section 4.3 of the NASA 2014 Science Plan for specifics, including missions currently in operation, in formulation or development, and planned for the future.

Astrophysics Division

Astrophysics is the study of phenomena occurring in the universe and of the physical principles that govern them. Astrophysics research encompasses a broad range of topics, from the birth of the universe and its evolution and composition, to the processes leading to the development of planets and stars and galaxies, to the physical conditions of matter in extreme gravitational fields, and to the search for life on planets orbiting other stars. In seeking to understand these phenomena, astrophysics science embodies some of the most enduring quests of humankind.

Through its Astrophysics Division, NASA leads the nation on a continuing journey of transformation. From the development of innovative technologies, which benefit other areas of research (e.g., medical, navigation, homeland security, etc.), to inspiring the public worldwide to pursue STEM careers through its stunning images of the cosmos taken with its Great Observatories, NASA's astrophysics programs are vital to the nation.

NASA's strategic objective in astrophysics is to **discover how the universe works, explore how it began and evolved, and search for life on planets around other stars**. Three broad scientific questions flow from this objective:

- How does the universe work?
- How did we get here?
- Are we alone?

Each of these questions is accompanied by a science goal that shapes the Astrophysics Division's efforts towards fulfilling NASA's strategic objective:

- Probe the origin and destiny of our universe, including the nature of black holes, dark energy, dark matter and gravity
- Explore the origin and evolution of the galaxies, stars and planets that make up our universe
- Discover and study planets around other stars, and explore whether they could harbor life

The scientific priorities for astrophysics are outlined in the NRC decadal survey New Worlds, New Horizons in Astronomy and Astrophysics (http://www.nap.edu/catalog/12951/new-worlds-new-horizons-in-astronomy-and-astrophysics). These priorities include understanding the scientific principles that govern how the universe works; probing cosmic dawn by searching for the first stars, galaxies, and black holes; and seeking and studying nearby habitable planets around other stars.

The multidisciplinary nature of astrophysics makes it imperative to strive for a balanced science and technology portfolio, both in terms of science goals addressed and in missions to address these goals. All the facets of astronomy and astrophysics—from cosmology to planets—are intertwined, and progress in one area hinges on progress in others. However, in times of fiscal constraints, priorities for investments must be made to optimize the use of available funding. NASA uses the prioritized recommendations and decision rules of the decadal survey to set the priorities for its investments.

NASA's Astrophysics Division has developed several strategies to advance these scientific objectives and respond to the recommendations outlined in the decadal survey on a time horizon of 5-10 years. The successful development of JWST is an Agency priority. Since its re-baseline in

2011, the project has remained on schedule and within budget for an October 2018launch. JWST and the science it will produce are foundational for many of the astronomical community's goals outlined in the 2010 decadal survey. NASA's highest priority for a new strategic astrophysics mission is the Wide

Field Infrared Survey Telescope (WFIRST), the number one priority for large-scale missions of the decadal survey. NASA plans to be prepared to start a new strategic astrophysics mission when funding becomes available. NASA also plans to identify opportunities for international partnerships, to reduce the Agency's cost of the mission concepts identified, and to advance the science objectives of the decadal survey. NASA will also augment the Astrophysics Explorer Program to the extent that the budget allows. Furthermore, NASA will continue to invest in the Astrophysics Research Program to develop the science cases and technologies for new missions and to maximize the scientific return from operating missions.

See Section 4.4 of the NASA 2014 Science Plan for specifics, including missions currently in operation, in formulation or development, and planned for the future.

A.4 The Space Technology Mission Directorate (STMD) is responsible for developing the crosscutting, pioneering, new technologies, and capabilities needed by the agency to achieve its current and future missions.

STMD rapidly develops, demonstrates, and infuses revolutionary, high-payoff technologies through transparent, collaborative partnerships, expanding the boundaries of the aerospace enterprise. STMD employs a merit-based competition model with a portfolio approach, spanning a range of discipline areas and technology readiness levels. By investing in bold, broadly applicable, disruptive technology that industry cannot tackle today, STMD seeks to mature the technology required for NASA's future missions in science and exploration while proving the capabilities and lowering the cost for other government agencies and commercial space activities.

Research and technology development takes place within NASA Centers, in academia and industry, and leverages partnerships with other government agencies and international partners. STMD engages and inspires thousands of technologists and innovators creating a community of our best and brightest working on the nation's toughest challenges. By pushing the boundaries of technology and innovation, STMD allows NASA and our nation to remain at the cutting edge. Additional information on the Space Technology Mission Directorate (STMD) can be found at: (http://www.nasa.gov/directorates/spacetech/about_us/index.html)

Areas of Interest - POC: Joseph Grant joseph.grant-1@nasa.gov

Space Technology Mission Directorate (STMD) expands the boundaries of the aerospace enterprise by rapidly developing, demonstrating, and infusing revolutionary, high-payoff technologies through collaborative partnerships. STMD employs a merit-based competition model with a portfolio approach, spanning a wide range of space technology discipline areas and technology readiness levels. Research and technology development takes place at NASA Centers, academia, and industry, and leverages partnerships with other government agencies and international partners.

STMD executes its mission according to the following tenets:

- Advancing transformative and crosscutting technologies that can be directly infused into future missions;
- Investing in a comprehensive portfolio covering low to high technology readiness levels;
- Competitively selecting research by academia, industry, and NASA Centers based on technical merit;

- Executing with lean structured projects with clear start and end dates, defined budgets and schedules, established milestones, and project level authority and accountability;
- Operating with a sense of urgency and informed risk tolerance to infuse quickly or terminate judiciously;
- Partnering with other NASA Mission Directorates, other government agencies, and the private sector to leverage resources, establish customer advocacy, and support US commercial aerospace interests;
- Delivering new inventions, enabling new capabilities and creating a pipeline of NASA and national innovators

Current space technology topics of particular interest include:

- Advanced manufacturing methods for space and in space
- Autonomous in-space assembly of structures and spacecraft
- Ultra-lightweight materials for space applications
- Materials and structures for extreme environments (high temperature, pressure)
- Extreme environment (including cryogenic) electronics for planetary exploration
- Advanced robotics for extreme environment sensing, mobility, and manipulation
- Deep space optical communication
- Extremely High Frequency microwave technologies for communication, remote sensing, and navigation
- Advanced power generation, storage, and transfer for deep space missions
- Advanced entry, decent, and landing systems for planetary exploration
- Efficient in situ resource utilization to produce items required for long-duration deep space missions including fuels, water, oxygen, food, nutritional supplements, pharmaceuticals, building materials, polymers (plastics), and various other chemicals
- Radiation mitigation for deep space crewed missions
- Biological approaches to environmental control and life support systems
- Autonomous systems for deep space missions
- Advanced telescope technologies for exoplanet imaging
- Low size, weight, and power components for small spacecraft including high-bandwidth communication from space to ground, inter-satellite communication, relative navigation and control for swarms and constellations, precise pointing systems, power generation and energy storage, thermal management, system autonomy, miniaturized instruments and sensors, robotic assembly/manufacturing, and in-space propulsion
- Enabling technologies for low-cost small spacecraft launch vehicles
- Advancements in engineering tools and models supporting Space Technology focus areas

Applicants are strongly encouraged to familiarize themselves with the roadmap document most closely aligned with their space technology interests. The individual roadmap documents may be downloaded at the following link: http://www.nasa.gov/offices/oct/home/roadmaps/index.html

The National Aeronautics and Space Administration (NASA) Space Technology Mission Directorate (STMD) current year version of the NASA Research Announcement (NRA) entitled, "Space Technology Research, Development, Demonstration, and Infusion" has been posted on the NSPIRES web site at http://nspires.nasaprs.com (select "Solicitations" and then "Open Solicitations"). The NRA provides detailed information on specific proposals being sought across STMD programs.

A.5 NASA Centers Areas of Interest

Examples of Center research interest areas include these specific areas from the following Centers. If no POC is listed or contact information is needed, please contact the POC using contact information listed in Appendix D.

A.5.1 Goddard Space Flight Center (GSFC), POC: Mablelene S Burrell, mablelene.s.burrell@nasa.gov

Applied Engineering and Technology Directorate: POC: Danielle Margiotta, Danielle.V.Margiotta@nasa.gov

- Advanced Manufacturing - facilitates the development, evaluation, and deployment of efficient and flexible additive manufacturing technologies. (ref: NAMII.org)
- **Advanced Multi-functional Systems and Structures** - novel approaches to increase spacecraft systems resource utilization
- **Micro - and Nanotechnology - Based Detector Systems** - research and application of these technologies to increase the efficiency of detector and optical systems
- **Ultra-miniature Spaceflight Systems and Instruments** - miniaturization approaches from multiple disciplines - materials, mechanical, electrical, software, and optical - to achieve substantial resource reductions
- **Systems Robust to Extreme Environments** - materials and design approaches that will preserve designed system properties and operational parameters (e.g. mechanical, electrical, thermal), and enable reliable systems operations in hostile space environments.
- **Spacecraft Navigation Technologies**
    - Spacecraft GNSS receivers, ranging crosslink transceivers, and relative navigation sensors
    - Optical navigation and satellite laser ranging
    - Deep-space autonomous navigation techniques
    - Software tools for spacecraft navigation ground operations and navigation analysis
    - Formation Flying
- **Automated Rendezvous and Docking (AR&D) techniques**
    - Algorithm development
    - Pose estimation for satellite servicing missions
    - Sensors (e.g., LiDARs, natural feature recognition)
    - Actuation (e.g., micro propulsion, electromagnetic formation flying)
- **Mission and Trajectory Design Technologies**
    - Mission design tools that will enable new mission classes (e.g., low thrust planetary missions, precision formation flying missions)
    - Mission design tools that reduce the costs and risks of current mission design methodologies
    - Trajectory design techniques that enable integrated optimal designs across multiple orbital dynamic regimes (i.e. earth orbiting, earth-moon libration point, sun-earth libration point, interplanetary)
- **Spacecraft Attitude Determination and Control Technologies**
    - Modeling, simulation, and advanced estimation algorithms
    - Advanced spacecraft attitude sensor technologies (e.g., MEMS IMU's, precision optical trackers)
    - Advanced spacecraft actuator technologies (e.g. modular and scalable momentum control devices, 'green' propulsion, micropropulsion, low power electric propulsion)

- **CubeSats** - Participating institutions will develop CubeSat/Smallsat components, technologies and systems to support NASA technology demonstration and risk reduction efforts. Student teams will develop miniature CubeSat/Smallsat systems for: power generation and distribution, navigation, communication, on-board computing, structures (fixed and deployable), orbital stabilization, pointing, and de-orbiting. These components, technologies and systems shall be made available for use by NASA for integration into NASA Cubesat/Smallsats. They may be integrated into complete off-the-shelf "CubeSat/Smallsat bus" systems, with a goal of minimizing "bus" weight/power/volume/cost and maximizing available "payload" weight/power/volume. NASA technologists will then use these components/systems to develop payloads that demonstrate key technologies to prove concepts and/or reduce risks for future Earth Science, Space Science and Exploration/Robotic Servicing missions. POC: Thomas P. Flatley (Thomas.P.Flatley@nasa.gov).
- **On-Orbit Multicore Computing** - High performance multicore processing for advanced automation and science data processing on spacecraft. There are multiple multicore processing platforms in development that are being targeted for the next generation of science and exploration missions, but there is little work in the area of software frameworks and architectures to utilize these platforms. It is proposed that research in the areas of efficient inter-core communications, software partitioning, fault detection, isolation & recovery, memory management, core power management, scheduling algorithms, and software frameworks be done to enable a transition to these newer platforms. Participating institutions can select areas to research and work with NASA technologists to develop and prototype the resulting concepts. POC: Alan Cudmore (Alan.p.cudmore@nasa.gov).
- **Integrated Photonic components and systems** - Integrated photonic components and systems for Sensors, Spectrometers, Chemical/biological sensors, Microwave, Sub-millimeter and Long-Wave Infra-Red photonics, Telecom- inter and intra satellite communications.
- **Radiation Effects and Analysis**
    - Flight validation of advanced event rate prediction techniques
    - New approaches for testing and evaluating 3-D integrated microcircuits and other advanced microelectronic devices
    - End-to-end system (e.g., integrated component level or higher) modeling of radiation effects
    - Statistical approaches to tackle radiation hardness assurance (i.e., total dose, displacement damage, and/or single-event effects) for high-risk, low-cost missions.

Sciences and Exploration Directorate POC: Blanche Meeson, Blanche.W.Meeson@nasa.gov

The Sciences and Exploration Directorate at NASA Goddard Space Flight Center (http://science.gsfc.nasa.gov) is the largest Earth and space science research organization in the world. Its scientists advance understanding of the Earth and its life-sustaining environment, the Sun, the solar system, and the wider universe beyond. All are engaged in the full life cycle of satellite missions and instruments from concept development to implementation, analysis and application of the scientific information, and community access and services.

- The **Earth Sciences Division** plans, organizes, evaluates, and implements a broad program of research on our planet's natural systems and processes. Major focus areas include climate change, severe weather, the atmosphere, the oceans, sea ice and glaciers, and the land surface. To study the planet from the unique perspective of space, the Earth Science Division develops and operates remote-sensing satellites and instruments. We analyze observational data from these spacecraft and make it available to the world's scientists and policy makers. The Division conducts extensive field campaigns to gather data from the surface and airborne platforms. The Division also develops, uses, and assimilates observations into models that simulate planetary processes involving the water, energy, and carbon cycles at multiple scales up to global. POC: Eric Brown de Colstoun (eric.c.browndecolsto@nasa.gov).

- The **Astrophysics Science Division** conducts a broad program of research in astronomy, astrophysics, and fundamental physics. Individual investigations address issues such as the nature of dark matter and dark energy, which planets outside our solar system may harbor life, and the nature of space, time, and matter at the edges of black holes. Observing photons, particles, and gravitational waves enables researchers to probe astrophysical objects and processes. Researchers develop theoretical models, design experiments and hardware to test theories, and interpret and evaluate observational data. POC: Amber Straughn (Amber.n.Straughn@nasa.gov).
- The **Heliophysics Science Division** conducts research on the Sun, its extended solar-system environment (the heliosphere), and interactions of Earth, other planets, small bodies, and interstellar gas with the heliosphere. Division research also encompasses Geospace, Earth's magnetosphere and its outer atmosphere, and Space Weather—the important effects that heliospheric disturbances have on spacecraft and terrestrial systems. Division scientists develop spacecraft missions and instruments, systems to manage and disseminate heliophysical data, and theoretical and computational models to interpret the data. Possible heliophysics-related research include: advanced software environments and data-mining strategies to collect, collate and analyze data relevant to the Sun and its effects on the solar system and the Earth ("space weather"); and advanced computational techniques, including but not limited to parallel architectures and the effective use of graphics processing units, for the simulation of magnetized and highly dynamic plasmas and neutral gases in the heliosphere. POC: Doug Rabin (Douglas.Rabin@nasa.gov).
- The **Solar System Exploration Division** builds science instruments and conducts theoretical and experimental research to explore the solar system and understand the formation and evolution of planetary systems. Laboratories within the division investigate areas as diverse as astrochemistry, planetary atmospheres, extrasolar planetary systems, earth science, planetary geodynamics, space geodesy, and comparative planetary studies. To study how planetary systems form and evolve, division scientists develop theoretical models as well as the investigations and space instruments to test them. The researchers participate in planetary and Earth science missions, and collect, interpret, and evaluate measurements. POC: Lora Bleacher (Lora.V.Bleacher@nasa.gov).

Scientists in all four divisions publish research results in the peer-reviewed literature, participate in the archiving and pubic dissemination of scientific data, and provide expert user support.

Education efforts in all science divisions seek to develop interest in and understanding of the science at GSFC by K-12 educators and students and the development of future scientist and computer scientists at the undergraduate and graduate level.

Outreach efforts in all four science divisions raise public awareness of the projects and missions in which we are involved, the research we conduct, and the associated benefits to society.

•Quantum computing

•Artificial intelligence and machine learning

•(Big) data analytics

A.5.2 Ames Research Center (ARC), POC: Danielle Carmichael (danielle.n.carmichael@nasa.gov)

Ames research Center enables exploration through selected development, innovative technologies, and interdisciplinary scientific discovery. Ames provides leadership in the following areas: astrobiology; small satellites; entry decent and landing systems; supercomputing; robotics and autonomous systems; life Sciences and environmental controls; and air traffic management.

- Entry systems: *Safely delivering spacecraft to Earth & other celestial bodies*
- Supercomputing: *Enabling NASA's advanced modeling and simulation*
- NextGen air transportation: *Transforming the way we fly*
- Airborne science: *Examining our own world & beyond from the sky*
- Low-cost missions: *Enabling high value science to low Earth orbit, the moon and the solar system*
- Biology & astrobiology: *Understanding life on Earth and in space*
- Exoplanets: *Finding worlds beyond our own*
- Autonomy & robotics: *Complementing humans in space*
- Lunar science: *Rediscovering our moon*
- Human factors: *Advancing human-technology interaction for NASA missions*
- Wind tunnels**:** *Testing on the ground before you take to the sky*

Additional Center core competencies include:

- Space Sciences
- Applied Aerospace and Information Technology
- Biotechnology
- Synthetic biology.
- Biological Sciences
- Earth Sciences
- High Performance Computing,
- Intelligent Systems
- Quantum Computing
- Nanotechnology-electronics and sensors.
- Small Spacecraft and Cubesats
- Airspace Systems
- Augmented Reality
- Digital materials

A.5.3 Glenn Research Center (GRC), POC: Mark David Kankam, Ph.D. mark.d.kankam@nasa.gov

Research and technology, and engineering engagements comprise including:

- Acoustics
- Advanced Energy (Renewable Wind and Solar, Coal Energy and Alternative Energy)
- Advanced Microwave Communications

- Aeronautical and Space Systems Analysis
- Computer Systems and Networks
- Electric (Ion) Propulsion
- Icing and Cryogenic Systems
- Instrumentation, Controls and Electronics
- Fluids, Computational Fluid Dynamics (CFD) and Turbomachinery
- Materials and Structures, including Mechanical Components and Lubrication
- Microgravity Fluid Physics, Combustion Phenomena and Bioengineering
- Nanotechnology
- Photovoltaics, Electrochemistry-Physics, and Thermal Energy Conversion
- Propulsion System Aerodynamics
- Space Power Generation, Storage, Distribution and Management
- Systems Engineering

The above engagement areas relate to the following key GRC competencies:

- Air-Breathing Propulsion
- Communications Technology and Development
- In-Space Propulsion & Cryogenic Fluids Management
- Power, Energy Storage and Conversion
- Materials and Structures for Extreme Environment
- Physical Sciences and Biomedical Technologies in Space

A.5.4Armstrong Flight Research Center (AFRC), POC: Dave Berger, dave.e.berger@nasa.gov

Autonomy (Collision Avoidance, Separation assurance, formation flight, peak seeking control)
(POC: Jack Ryan, AFRC-RC)

- Adaptive Control
  (POC: Curt Hanson, AFRC-RC)
- Hybrid Electric Propulsion
  (POC: Starr Ginn, AFRC-R)
- Control of Flexible Structures using distributed sensor feedback
  (POC: Marty Brenner, AFRC-RS; Peter Suh, AFRC-RC)
- Supersonic Research (Boom mitigation and measurement)
  (POC: Ed Haering, AFRC-RA)
- Supersonic Research (Laminar Flow)
  (POC: Dan Banks, AFRC-RA)
- Environmental Responsive Aviation
  (POC: Mark Mangelsdorf, AFRC-RS)
- Hypersonic Structures & Sensors
  (POC: Larry Hudson, AFRC-RS)
- Large Scale Technology Flight Demonstrations (Towed Glider)
  (POC: Steve Jacobson, AFRC-RC)
- Aerodynamics and Lift Distribution Optimization to Reduce Induced Drag
  (POC: Al Bowers, AFRC-R)

A.5.5 Marshall Space Flight Center (MSFC), POC: Frank Six, frank.six@nasa.gov

Propulsion Systems

- Launch Propulsion Systems, Solid & Liquid

- In Space Propulsion (Cryogenics, Green Propellants, Nuclear, Fuel Elements, Solar-Thermal, Solar Sails, Tethers)
- Propulsion Test beds and Demonstrators (Pressure Systems)
- Combustion Physics
- Cryogenic Fluid Management
- Solid Ballistics
- Rapid Affordable Manufacturing of Propulsion Components
- Materials Research (Nano Crystalline Metallics, Diamond Film Coatings)
- Materials Compatibility
- Computational Fluid Dynamics
- Unsteady Flow Environments
- Acoustics and Stability
- Solid Ballistics
- Rapid Affordable Manufacturing of Propulsion Components
- Materials Research (Nano Crystalline Metallics, Diamond Film Coatings)
- Materials Compatibility
- Computational Fluid Dynamics
- Unsteady Flow Environments
- Acoustics and Stability

Space Systems

- In Space Habitation (Life Support Systems and Nodes, 3D Printing)
- Mechanical Design & Fabrication
- Small Payloads (For International Space Station, Space Launch System)
- In-Space Asset Management (Automated Rendezvous & Capture, De-Orbit, Orbital Debris Mitigation, Proximity Operations)
- Radiation Shielding
- Thermal Protection
- Electromagnetic Interference
- Advanced Communications
- Small Satellite Systems (CubeSats)
- Structural Modeling and Analysis
- Spacecraft Design (CAD)

Space Transportation

- Mission and Architecture Analysis
- Advanced Manufacturing
- Space Environmental Effects and Space Weather
- Lander Systems and Technologies
- Small Spacecraft and Enabling Technologies (Nanolaunch Systems)
- 3D Printing/Additive Manufacturing/Rapid Prototyping
- Meteoroid Environment
- Friction Stir and Ultrasonic Welding
- Advanced Closed-Loop Life Support Systems
- Composites and Composites Manufacturing
- Wireless Systems
- Ionic Liquids
- Guidance, Navigation and Control (Autonomous, Small Launch Vehicle)
- Systems Health Management

- Martian Navigation Architecture/Systems
- Planetary Environment Modeling
- Autonomous Systems (reconfiguration, Mission Planning)

Science

- Replicated Optics
- Large Optics (IR, visible, UV, X-Ray)
- High Energy Astrophysics (X-Ray, Gamma Ray, Cosmic Ray)
- Solar, Magnetospheric and Ionospheric Physics
- Radiation Mitigation/Shielding
- Earth Science Applications
- Convective and Severe Storms Research
- Climate Dynamics
- Lightning Research
- Geochronology, Geochemistry, Atmospheres and Interiors of Planetary Bodies
- Physical Science Infomatics
- Biophysics (Protein Crystals)

A.5.6 Kennedy Space Center (KSC), by Roadmap Technical Area (TA), POC Michael Lester, gregory.m.lester@nasa.gov

- TA 4.0 Robotics and Autonomous Systems
  Barbara Brown, barbara.l.brown@nasa.gov, Ph: 321-867-1720
  - 4.1 Sensing and Perception
  - 4.1.4 Natural, Man-Made Object, and Event Recognition
  - 4.3 Manipulation
  - 4.3.6 Sample Acquisition and Handling
  - 4.5 System-Level Autonomy
  - 4.5.3 Autonomous Guidance and Control
- TA 6.0 Human Health, Life Support, and Habitation Systems
  Charlie Quincy, charles.d.quincy@nasa.gov, Ph: 321-867-8383
  - 6.1 Environmental Control and Life Support Systems and Habitation Systems
  - 6.1.1 Air Revitalization
  - 6.1.2 Water Recovery and Management
  - 6.1.3 Waste Management
- TA 7.0 Human Exploration Destination Systems
  Stanley Starr, stanley.o.starr@nasa.gov, Ph: 321-861-2262
  - 7.1 In-Situ Resource Utilization
  - 7.1.1 Destination Reconnaissance, Prospecting, and Mapping
  - 7.1.2 Resource Acquisition
  - 7.1.3 Processing and Production
  - 7.1.4 Manufacturing Products and Infrastructure Emplacement
  - 7.2 Sustainability and Supportability
  - 7.2.4 Food Production, Processing, and Preservation
- TA 13.0 Ground and Launch Systems
  Robert Johnson, robert.g.johnson@nasa.gov, Ph: 321-867-7373
  - 13.2 Environmental Protection and Green Technologies
  - 13.2.5 Curatorial Facilities, Planetary Protection, and Clean Rooms
  - 13.3 Reliability and Maintainability
  - 13.3.3 On-Site Inspection and Anomaly Detection and Identification

- 13.3.6 Repair, Mitigation, and Recovery Technologies
- KSC SBIR, **Mike Vinje**, michael.e.vinje@nasa.gov, Ph: 321-861-3874
  - Standardized Interfaces (a USB port for space)
  - A substantial portion of pre-launch processing involves the integration of spacecraft assemblies to each other or to the ground systems that supply the commodities, power or data. Each stage or payload requires an interface that connects it to the adjacent hardware which includes flight critical seals or connectors and other components. Development and adoption of simplified, standardized interfaces holds the potential of reducing the cost and complexity of future space systems, which increases the funding available for flight hardware and drives down the cost of access to space for everyone.

A.5.7 Jet Propulsion Laboratory (JPL), POC: Linda Rodgers, linda.l.rodgers@jpl.nasa.gov

- Solar System Science
  Planetary Atmospheres and Geology; Solar System characteristics and origin of life; Primitive solar systems bodies; Lunar science; Preparing for returned sample investigations
- Earth Science
  Atmospheric composition and dynamics; Land and solid earth processes; Water and carbon cycles; Ocean and ice; Earth analogs to planets; Climate Science
- Astronomy and Fundamental Physics
  Origin, evolution, and structure of the universe; Gravitational astrophysics and fundamental physics; Extra-solar planets and star and planetary formation; Solar and Space Physics; Formation and evolution of galaxies
- In-Space Propulsion Technologies
  Chemical propulsion; Non-chemical propulsion; Advanced propulsion technologies; Supporting technologies
- Space Power and Energy Storage
  Power generation; Energy storage; Power management & distribution; Cross-cutting technologies
- Robotics, Tele-Robotics and Autonomous Systems
  Sensing; Mobility; Manipulation technology; Human-systems interfaces; Autonomy; Autonomous rendezvous & docking; Systems engineering
- Communication and Navigation
  Optical communications & navigation technology; Radio frequency communications; Internetworking; Position, navigation and timing; Integrated technologies; Revolutionary concepts
- Human Exploration Destination Systems
  In-situ resource utilization and Cross-cutting systems
- Science Instruments, Observatories and Sensor Systems
  Science Mission Directorate Technology Needs; Remote Sensing instruments/sensors; Observatory technology; In-situ instruments/sensor technologies
- Entry, Descent and Landing Systems
  Aerobraking, aerocapture and entry systems; Descent; Landing; Vehicle system technology
- Nanotechnology
  Engineered materials; Energy generation and storage; Propulsion; Electronics, devices and sensors
- Modeling, Simulation, Information Technology and Processing
  Flight and ground computing; Modeling; Simulation; Information processing

- Materials, Structures, Mechanical Systems and Manufacturing
  Materials; Structures; Mechanical systems; Cross cutting
- Thermal Management Systems
  Cryogenic systems; Thermal control systems (near room temperature); Thermal protection systems

A.5.8 Johnson Space Center (JSC), POC: Kamlesh Lulla, kamlesh.p.lulla@nasa.gov

- In-space propulsion technologies
- Energy Storage technologies-Batteries, Regenerative Fuel cells
- Robotics and TeleRobotics
- Crew decision support systems
- Immersive Visualization
  - Virtual windows leading to immersive environments and telepresence systems
- Human Robotic interface
- Flight and Ground communication systems
  - Audio
    - Array Microphone Systems and processing
    - Large bandwidth (audio to ultra-sonic) MEMs Microphones
    - Front end audio noise cancellation algorithms implementable in FPGAs-example Independent Component Analysis
    - Audio Compression algorithms implementable in FPGAs.
    - COMSOL Acoustic modeling
    - Sonification Algorithms implementable in DSPs/FPGAs
  - Video
    - Ultra High Video Compressions
    - H265 Video Compression
    - Rad-Tolerant Imagers
    - Lightweight/low power/radiation tolerant displays
- Advanced habitat systems
- GN&C for descent systems
- Large body GN&C
- Human system performance modeling
- Imaging and information processing
  - Lightweight/Low power Display Technology
  - Scalable software-implementable graphics processing unit
- Simulation and modeling
- Materials and structures
- Lightweight structure
- Human Spaceflight Challenges
  - http://humanresearchroadmap.nasa.gov/explore/
- Human System Interfaces
  - OLED Technology Evaluation for Space Applications
  - Far-Field Speech Recognition in Noisy Environments
  - Radiation Hardened Graphics Processing
  - Human Computer Interaction design methods (Multi-modal and Intelligent Interaction) and apparatuses
  - Human Systems Integration, Human Factors Engineering: state of the art in Usability and performance assessment methods and apparatus.
  - Humans Systems Integration Inclusion in Systems Engineering

- ECLSS
  - Air Revitalization
    - Advanced water, O2 and CO2 monitoring and sensors
    - Advance thermally regenerated ionic fluids for CO2 and Humidity Control
  - Water Recovery and Management
    - Brine water recovery systems and wastewater treatment chemical recover for reuse or repurpose
  - Waste Management
    - Advance wastewater treatment systems (lower toxicity, recoverable)
  - Advanced trace contaminant monitoring and control technology
  - Quiet fan technologies
- Active Thermal Control
  - Lightweight heat exchangers and cold plates
  - Condensing heat exchanger coatings with robust hydrophilic, antimicrobial properties
  - Development and demonstration of wax and water-based phase change material heat exchangers
- EVA
  - Pressure Garment
  - Portable Life Support System
  - Power, Avionics and Software
- Autonomous Rendezvous and Docking
- Crew Exercise
  - Small form Equipment
  - Biomechanics
- EDL (thermal)
- Wireless and Comm Systems
  - Wireless Energy Harvesting Sensor Technologies
  - Robust, Dynamic Ad hoc Wireless Mesh Communication Networks
  - Radiation Hardened EPCglobal Radio Frequency Identification (RFID) Readers
  - Computational Electromagnetics (CEM) Fast and Multi-Scale Methods/Algorithms
  - EPCglobal-type RFID ICs at frequencies above 2 G
- Radiation and EEE Parts
  - Monitoring
  - Mitigation and Biological countermeasures
  - Protection systems
  - Space weather prediction
  - Risk assessment modeling
- Wearable Tech
  - Wearable Sensors and Controls
  - Wearable Audio Communicator
  - Wearable sensing and hands-free control
  - Tattooed Electronic Sensors
- In-Situ Resource Utilization
  - Mars atmosphere processing
    - CO2 collection, dust filtering, Solid Oxide CO2 electrolysis, Sabatier, reverse water gas shift
  - Lunar/Mars regolith processing
    - Regolith collection and drying
    - Water collection and processing, water electrolysis

- Methane/Oxygen liquefaction and storage

A.5.9 Stennis Space Center (SSC), POC: Nathan Sovik, nathan.a.sovik@nasa.gov

- Active and Passive Nonintrusive Remote Sensing of Propulsion Test Parameters
- Intelligent Integrated System Health Management (ISHM) in Rocket Test-Stands
- Advanced Non-Destructive Evaluation Technologies
- Advanced Propulsion Systems Testing
- Cryogenic Instrumentation and Cryogenic, High Pressure, and Ultrahigh Pressure Fluid Systems
- Ground Test Facilities Technology
- Propulsion System Exhaust Plume Flow Field Definition and Associated Plume Induced Acoustic & Thermal Environments
- Vehicle Health Management/Rocket Exhaust Plume Diagnostics

Propulsion Testing

Active and Passive Nonintrusive Remote Sensing of Propulsion Test Parameters
The vast amount of propulsion system test data is collected via single channel, contact, intrusive sensors and instrumentation. Future propulsion system test techniques could employ passive nonintrusive remote sensors and active nonintrusive remote sensing test measurements over wide areas instead of at a few discrete points. Opportunities exist in temperature, pressure, stress, strain, position, vibration, shock, impact, and many other measured test parameters. The use of thermal infrared, ultraviolet, and multispectral sensors, imagers, and instruments is possible through the SSC sensor laboratory.

Intelligent Integrated System Health Management (ISHM) in Rocket Test-Stands
SHM is a capability to determine the condition of every element of a system continuously. ISHM includes detection of anomalies, diagnosis of causes, and prognosis of future anomalies; as well as making available (to elements of the system and the operator) data, information, and knowledge (DIaK) to achieve optimum operation. In this context, we are interested in methodologies to embed intelligence into the various elements of rocket engine test-stands, e.g., sensors, valves, pumps, tanks, etc. Of particular interest is the extraction of qualitative interpretations from sensor data in order to develop a qualitative assessment of the operation of the various components and processes in the system. The desired outcomes of the research are: (1) to develop intelligent sensor models that are self-calibrating, self- configuring, self- diagnosing, and self- evolving (2) to develop intelligent components such as valves, tanks, etc., (3) to implement intelligent sensor fusion schemes that allow assessment, at the qualitative level, of the condition of the components and processes, (4) to develop a monitoring and diagnostic system that uses the intelligent sensor models and fusion schemes to predict future events, to document the operation of the system, and to diagnose any malfunction quickly, (5) to develop architectures/taxonomies/ontologies for integrated system health management using distributed intelligent elements, and (6) to develop visualization and operator interfaces to effectively use the ISHM capability.

Advanced Non-Destructive Technologies
Advances in non-destructive evaluation (NDE) technologies are needed for fitness-for-service evaluation of pressure vessels used in rocket propulsion systems and test facilities. NDE of ultra- high pressure vessels with wall thicknesses exceeding 10 inches require advanced techniques for the detection of flaws that may affect the safe use of the vessels.

Advanced Propulsion Systems Testing

Innovative techniques will be required to test propulsion systems such as advanced chemical engines, single- stage-to-orbit rocket plane components, nuclear thermal, nuclear electric, and hybrids rockets. New and more cost- effective approaches must be developed to test future propulsion systems. The solution may be some combination of computational- analytical technique, advanced sensors and instrumentation, predictive methodologies, and possibly subscale tests of aspects of the proposed technology.

Cryogenic Instrumentation and Cryogenic, High Pressure, and Ultrahigh Pressure Fluid Systems

Over 40 tons of liquefied gases are used annually in the conduct of propulsion system testing at the Center. Instrumentation is needed to precisely measure mass flow of cryogens starting with very low flow rates and ranging to very high flow rates under pressures up to 15,000 psi. Research, technology, and development opportunities exist in developing instruments to measure fluid properties at cryogenic conditions during ground testing of space propulsion systems. Both intrusive and nonintrusive sensors, but especially nonintrusive sensors, are desired.

Ground Test Facilities Technology

SSC is interested in new, innovative ground-test techniques to conduct a variety of required developmental and certification tests for space systems, stages/vehicles, subsystems, and components. Examples include better coupling and integration of computational fluid dynamics and heat transfer modeling tools focused on cryogenic fluids for extreme conditions of pressure and flow; advanced control strategies for non-linear multi-variable systems; structural modeling tools for ground-test programs; low-cost, variable altitude simulation techniques; and uncertainty analysis modeling of test systems.

Propulsion System Exhaust Plume Flow Field Definition and Associated Plume Induced Acoustic & Thermal Environments

Background: An accurate definition of a propulsion system exhaust plume flow field and its associated plume induced environments (PIE) are required to support the design efforts necessary to safely and optimally accomplish many phases of any space flight mission from sea level or simulated altitude testing of a propulsion system to landing on and returning from the Moon or Mars. Accurately defined PIE result in increased safety, optimized design and minimized costs associated with: 1. propulsion system and/or component testing of both the test article and test facility; 2. any launch vehicle and associated launch facility during liftoff from the Earth, Moon or Mars; 3. any launch vehicle during the ascent portion of flight including staging, effects of separation motors and associated pitch maneuvers; 4. effects of orbital maneuverings systems (including contamination) on associated vehicles and/or payloads and their contribution to space environments; 5. Any vehicle intended to land on and return from the surface of the Moon or Mars; and finally 6. The effects of a vehicle propulsion system on the surfaces of the Moon and Mars including the contaminations of those surfaces by plume constituents and associated propulsion system constituents. Current technology status and requirements to optimally accomplish NASA s mission: In general, the current plume technology used to define a propulsion system exhaust plume flow field and its associated plume induced environments is far superior to that used in support of the original Space Shuttle design. However, further improvements of this technology are required: 1. in an effort to reduce conservatism in the current technology allowing greater optimization of any vehicle and/or payload design keeping in mind crew safety through all mission phases; and 2. to support the efforts to fill current critical technology gaps discussed below. PIE areas of particular interest include: single engine and multi-engine plume flow field definition for all phases of any space flight mission, plume induced acoustic environments, plume induced radiative and convective ascent vehicle base heating, plume contamination, and direct and/or indirect plume impingement effects. Current critical technology gaps in needed PIE capabilities include: 1. An accurate analytical prediction tool to define convective ascent vehicle base heating for both single engine and multi- engine vehicle configurations. 2. An accurate analytical prediction tool to define plume induced environments associated with advanced chemical, electrical and nuclear propulsion systems. 3. A validated, user friendly free molecular flow model for defining plumes and plume induced environments for low density external environments that exist on orbit, as well as interplanetary and other planets.

Vehicle Health Management/Rocket Exhaust Plume Diagnostics
A large body of UV-Visible emission spectrometry experimentation is being performed during the 30 or more tests conducted each year on the Space Shuttle Main Engine at SSC. Research opportunities are available to quantify failure and wear mechanisms, and related plume code validation. Related topics include combustion stability, mixture ratio, and thrust/power level. Exploratory studies have been done with emission/absorption spectroscopy, absorption resonance spectroscopy, and laser induced fluorescence. Only a relatively small portion of the electromagnetic spectrum has been investigated for use in propulsion system testing and exhaust plume diagnostics/vehicle health management.

A.5.10 Langley Research Center (LaRC), POC: Gamaliel (Dan) Cherry, Gamaliel.R.Cherry@nasa.gov

- Intelligent Flight Systems – Revolutionary Air Vehicles (POC: Guy Kemmerly 757-864-5070)
- Atmospheric Characterization – Active Remote Sensing (POC: Malcolm Ko 757-864-8892)
- Systems Analysis and Concepts - Air Transportation System Architectures & Vehicle Concepts (POC: Michael Marcolini 757-864-3629)
- Advanced Materials & Structural System – Advanced Manufacturing (POC: David Dress 757-864-5126)
- Aerosciences - Trusted Autonomy (POC: Sharon Graves 757-864-5018)
- Entry, Decent & Landing - Robotic Mission Entry Vehicles (POC: Keith Woodman 757-864-7692)
- Measurement Systems - Advanced Sensors and Optical Measurement (POC: Tom Jones 757-864-4903)