National Aeronautics and Space Administration
Office of STEM Engagement

Appendix A – FY 2022 Areas of Research Interests

Established Program to Stimulate Competitive Research (EPSCoR)

FY 2022 Research Interests

NASA Headquarters
Office of STEM Engagement
Washington, DC 20546-0001

Appendix A: NASA Mission Directorates and Center Alignment

NASA's Mission *to drive advances in science, technology, aeronautics, and space exploration to enhance knowledge, education, innovation, economic vitality and stewardship of Earth*, draws support from four Mission Directorates, nine NASA Centers, and JPL, each with a specific responsibility.

A.1 Aeronautics Research Mission Directorate (ARMD)

Aeronautics Research Mission Directorate (ARMD) conducts high-quality, cutting-edge research and flight tests that generate 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.

NASA Aeronautics is partnering with industry and academia to accomplish the aviation community's aggressive carbon reduction goals. Through collective work in three areas -- advanced vehicle technologies, efficient airline operations and sustainable aviation fuels – NASA, in partnership with the aviation community, aims to reduce carbon emissions from aviation by half by 2050, compared to 2005, and potentially achieve net-zero emissions by 2060.
ARMD's current major missions include:

- Sustainable Aviation
- High Speed Commercial Flight
- Advanced Air Mobility
- Future Airspace
- Transformative Tools

Additional information on the Aeronautics Research Mission Directorate (ARMD) can be found at: https://www.nasa.gov/aeroresearch and in ARMD's Strategic Implementation plan that can be found at: https://www.nasa.gov/aeroresearch/strategy.

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Proposers are directed to the following:

- ARMD Programs: https://www.nasa.gov/aeroresearch/programs
- The ARMD current year version of the NASA Research Announcement (NRA) entitled, "Research Opportunities in Aeronautics (ROA)" is posted on the NSPIRES web site at http://nspires.nasaprs.com (*Key word:* Aeronautics). This solicitation provides a complete range of ARMD research interests.

A.2 Human Exploration & Operations Mission Directorate (HEOMD)

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, and Advanced Exploration Systems. 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: Marc Timm, marc.g.timm@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.

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 (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)

– *Commercial Space Capabilities*
  - The goal of this area is to support research, development, and commercial adoption of technologies of interest to the U.S. spaceflight industry to further their space-related capabilities.
  - These include capabilities for Moon, Mars, and Earth orbit. Such efforts are in pursuit of the goals of the National Space Policy and NASA's strategic plans, to foster developments that will lead to education and job growth in science and engineering, and spur economic growth as capabilities for new space markets are created.
  - U.S. commercial spaceflight industry interests naturally vary by company. Proposers are encouraged to determine what those interests are by engagement with such companies in various ways, and such interests may also be reflected in the efforts of various NASA partnerships.
  - Proposals should discuss how the effort aligns with U.S. commercial spaceflight company interest(s), and identify potential alignments with NASA interests.

A.2.1 Office of Chief Health and Medical Officer (OCHMO)
Areas Of Research Interest:

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POC2: Dr James D. Polk; E: james.d.polk@nasa.gov, P: 202.358.1959

- Development and elaboration of Functional aids and testing paradigms to measure activity for use by parastronauts during spaceflight. This may include egressing and exiting space capsules and donning and doffing spacesuits and other aids for parastronauts. The European Space Agency is establishing a parastronaut feasibility project. Since NASA offers its international partners access to NASA supported spacecraft and the International Space Station, NASA wants to establish appropriate functional testing measures to determine the time it takes fit astronaut-like subjects compared to fit parastronaut subjects to egress and exit simulated space capsules and simulated donning and doffing spacesuit. Research proposals are sought to establish appropriate functional testing.

- Evaluation space capsule and spacesuit activity in stable and fit lower or upper extremity amputees and compare their responses to non-amputee fit individuals. The European Space Agency is establishing a parastronaut feasibility project. Since NASA offers its international partners access to NASA supported spacecraft and the International Space Station, NASA wants to obtain research data measuring the time it takes fit astronaut-like subjects compared to fit parastronaut subject to egress and exit simulated space capsules and simulated donning and doffing spacesuit. Research proposals are sought to obtain data measuring the functional testing indicated

A.3 Science Mission Directorate (SMD)

Science Mission Directorate (SMD) leads the Agency in five areas of research: Biological and Physical Sciences (BPS), Heliophysics, Earth Science, 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. SMD's high-level strategic objectives are presented in the 2018 NASA Strategic Plan. Detailed plans by science area corresponding to the science divisions of SMD: Heliophysics, Earth Science, Planetary Science, and Astrophysics appear in *SCIENCE 2020-2024: A Vision for Scientific Excellence (the 2020 Science Plan)*", which is still available at http://science.nasa.gov/about-us/science-strategy/. The best expression of specific research topics of interest to each Division within SMD are represented in by the topics listed in SMD's "ROSES" research solicitation, see ROSES-2021 and the text in the Division research overviews of ROSES, i.e.:

Astrophysics Research Program Overview
Biological and Physical Sciences Research Overview
Cross Division Research Overview
Earth Science Research Overview
Heliophysics Research Program Overview
Planetary Science Research Program Overview
Table of ROSES-2021 program elements by Division/Topic:
https://solicitation.nasaprs.com/ROSES2021table3
Table of ROSES-2021 program elements by due date:
https://solicitation.nasaprs.com/ROSES2021table2

Please note, even if particular topic is not solicited in ROSES this year, if it was solicited via ROSES in the past, it is still a topic of interest and eligible for this solicitation. Additional information about the Science Mission Directorate may be found at: http://nasascience.nasa.gov.

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Biological and Physical Sciences (BPS)

In July 2020, NASA's biological and physical sciences research was transferred from the Space Life and Physical Sciences Research & Applications (SLPSRA) Division in the Human Exploration and Operations Mission Directorate (HEOMD) into the Biological and Physical Sciences (BPS) Division in the Science Mission Directorate (SMD).

The mission of BPS is two-pronged:

- Pioneer scientific discovery in and beyond low Earth orbit to drive advances in science, technology, and space exploration to enhance knowledge, education, innovation, and economic vitality
- Enable human spaceflight exploration to expand the frontiers of knowledge, capability, and opportunity in space

Execution of this mission requires both scientific research and technology development.

BPS administers NASA's:

- Space Biology Program, which solicits and conducts research to understand how biological systems accommodate to spaceflight environments
- Physical Sciences Program, which solicits and conducts research to understand how physical systems respond to spaceflight environments, particularly weightlessness

BPS partners with the research community and a wide range of organizations to accomplish its mission. Grants to academic, commercial and government laboratories are the core of BPS's research and technology development efforts.

Additional information on BPS can be found at: https://science.nasa.gov/biological-physical

Space Biology Program

The Space Biology Program within NASA's Biological and Physical Sciences Division focuses on pioneering scientific discovery and enabling human spaceflight exploration. Research in space biology has the following goals:

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

Research proposals are being solicited on the following topics:

- Organismal Biology – responses of whole organisms and their systems to ionizing radiation and/or other spaceflight-relevant stressors such as altered gravity simulators.
  - These will be ground-based studies.

- Ionizing radiation and altered gravity regimes (partial gravity and microgravity) are a hallmark of the deep space environment. These stressors may cause direct physiological changes in the organisms or result in indirect effects such as loss of sleep in some organisms. Studies should effectively delineate the biological effects of these factors, separately and/or in combination where possible. See information on radiation facilities below.
- Understand the mechanistic bases of the changes induced in these unique environments, preferably from a systems biology perspective, and could include genetic, cellular, or molecular biological effects.

- Advanced *in vitro* models: 3D Tissues and Tissue Chips or Microphysiological Systems – Using advanced *in vitro* models to investigate biological mechanisms associated with exposure to ionizing radiation.
    - These will be ground-based studies.
    - Ionizing radiation, specifically space radiation, is a concern for astronauts on deep space long duration missions. Understanding the mechanisms of damage induced by ionizing radiation will be important to inform risks to astronauts and develop effective countermeasures. Studies proposing ionizing radiation should use space relevant radiation exposures and doses. See information on radiation facilities below.

    Information on radiation facilities:
    - The NASA Space Radiation Laboratory (NSRL) is an irradiation facility capable of supplying particles from protons to gold with primary energies in the range of 50-2500 MeV for protons and 50-1100 MeV/n for high-mass, high-energy (HZE) particles. Selection of beam species and energies for experimental periods will be made by NASA officials in consultation with scientists proposing experiments for these beams. Activities at the NSRL are a joint effort of Brookhaven National Laboratory's Collider-Accelerator Department, providing accelerated particle beams, and the Biosciences Department, providing experimental area support, animal care, and cell and biology laboratories. The NSRL includes irradiation stations, beam controls, and laboratory facilities required for most radiobiological investigations. Additional information about NSRL may be found at https://www.bnl.gov/nsrl/.
    - Colorado State University low dose rate neutron facility is another ionizing radiation facility that provides low dose rate neutrons. Details can be found at: https://three.jsc.nasa.gov under "IN THE NEWS– JULY 2018" or by email to michael.weil@colostate.edu. Gamma-rays (Cs or Co) should be used as the reference radiation for studies. Significant justification needs to be provided to use X-rays with energies below 300 peak kilovoltage (kVp) as a reference radiation. Gamma controls must be completed at BNL for comparison with heavy charged particles, specifically for the calculation of relative biological effectiveness (RBE). Gamma ray exposures can also be performed at Colorado State University.

All proposals submitted to the EPSCoR Research Announcement are required to include a data management plan (DMP) that describes how data generated through the course of the proposed research will be shared and preserved, including timeframe, or explain why data sharing and/or preservation are not possible or scientifically appropriate, or why the data need not be made publicly available. Specifically, for this Research Announcement, award recipients are required to upload all relevant data in the GeneLab Data Systems (https://genelab.nasa.gov), as well as make all analytical models, tools, and software produced under the funded research, as well as related documentation, available to NASA. Furthermore, articles published in peer-reviewed scholarly journals and papers published in peer-reviewed conference proceedings, should be made publicly accessible via NASA's PubSpace website (Submit to PubSpace - Scientific and Technical Information Program (nasa.gov)).

Further information for the Space Biology program are available at:
https://science.nasa.gov/biological-physical/programs/space-biology
https://science.nasa.gov/biological-physical/documents

Physical Science Program

The Physical Science Research Program conducts fundamental and applied research to advance scientific knowledge, to improve space systems, and to advance technologies that may produce new products offering benefits on Earth. Space offers unique advantages for experimental research in the physical sciences. NASA supports research that uses to space environment to make significant scientific advances. Many of NASA's experiments in the physical sciences reveal how physical systems respond to the near absence of gravity. Forces that on Earth are small compared to gravity can dominate system behavior in space. Understanding the consequences is a critical aspect of space system design. Research in physical sciences spans from basic and applied research in the areas of:

- Fluid physics: two-phase flow, boiling, condensation, heat pipes, capillary and interfacial phenomena; cryogenic fluid storage and transfer
- Combustion science: spacecraft fire safety, solids, liquids and gasses, transcritical combustion, supercritical reacting fluids, and soot formation;
- Materials science: solidification in metal and alloys, crystal growth, electronic materials, glasses and ceramics, granular materials, extraction of material from regoliths;
- Complex Fluids: colloidal systems, emulsions, liquid crystals, polymer flows, foams and granular flows;
- Fundamental physics: space optical/atomic clocks, quantum test of equivalence principle, theory supporting space-based experiments in quantum entanglement, decoherence, cold atom physics, and dusty plasmas.

Areas of particular interest include:

- **Extraction of Materials from Regolith** - NASA is successfully advancing the mission of returning humans to the Lunar surface and establishing a long-term presence. Critical to success of sustaining a human presence on the Lunar surface is the utilization of natural resources. Extraction of materials (e.g. metals, glasses and water ice) from extra-terrestrial regolith and the subsequent use in manufacturing key infrastructure will enable humans to thrive on extra-terrestrial surfaces. The Physical Sciences Program requests research to develop and increase understanding of extraction techniques to generate useful materials (e.g. metals, glasses, water ice) from Lunar or Martian regolith.

  Proposed studies are expected to generate and test specific hypotheses to the extent possible in a terrestrial lab. Investigations should be proposed that would study one or more of the following topics:

- Refinement of existing techniques to extract materials from regolith.
- Development of new techniques for extraction of materials from regolith.
- Studies of the extracted material to determine its properties or to investigate novel ways of utilizing it to support NASA's exploration goals.
- Investigations to determine manufacturing processes using regolith or materials extracted from regolith to produce infrastructure and/or outfitting critical to sustaining life on extra-terrestrial surfaces.

It is expected that regolith simulant, or equivalent, will be used for the proposed experiments.

- **Metamaterials in Soft Matter -** Metamaterials have recently drawn the attention of soft-matter scientists and engineers with the possibility of designing metamaterials that have their functions governed, not by the specific substance out of which the material is constructed, but rather by its microstructure. Also, soft matter-based metamaterials possess unique physical properties, owing to their engineered structure, ranging from negative index material with regard to multitude of physical properties (e.g.- viscosity, refractive index, acoustics etc.). Some of the challenges that need to be answered are:
  - Development of novel soft-matter based metamaterials
  - Develop methodologies to encode multiple functions in soft-matter based metamaterials
  - Understand the scalability of active materials & metamaterials and how that affects multiple functionality

  In addition to laboratory experimentation of metamaterials, short duration microgravity experiments in drop towers or parabolic flights can be considered since metamaterial formation may involve phenomena such as phase separation, onset of interfacial instability, etc.

- **Oscillating Heat Pipes** - NASA has a growing need for improved passive thermal management of electronics, batteries, high capability sensors, power system heat rejection, etc. for future spacecraft and planetary habitat systems. Due to the potential to extract heat at significantly higher heat flux levels, oscillating heat pipes (OHP) offer the promise of significantly higher efficiencies compared to conventional heat pipes used on today's spacecraft. However, the underlying liquid-vapor fluid dynamics (distinct liquid plugs and vapor plugs), interfacial phenomena, and two-phase heat transfer in the pulsating flows of OHPs are not well understood. It is imperative that a physical model that can predict the performance of an OHP be developed. As a first step, NASA is seeking proposals for a highly instrumented, ground-based OHP experiment to provide insight into the mechanisms, fundamental processes and governing equations. The resulting high-fidelity data will be used for computational fluid dynamics model validation to better predict OHP performance and limits of operation. NASA is currently funding the development of an advanced OHP computer model at JPL. The experimental data from this project will be provided to the JPL OHP numerical modeling team.

Specifically, NASA is interested in fundamental experimental research to address some or all of the topics below. The list of needs is given in a somewhat prioritized order. Please note: all OHP proposals **must** include liquid film characterization.

- Liquid film characterization:
    - liquid film on the wall surrounding vapor plugs
    - dynamics and heat transfer of the liquid film trailing an advancing liquid slug in adiabatic, heated and cooled, slug plug flow. Establish a method to predict liquid film thickness in OHPs with given channel geometry and operational conditions. This may include direct or indirect measurement and theoretical modeling of the liquid film.
- Oscillation Characteristics: frequency, velocity, etc.
- Measurement of the ratio of the net heat transfer attributable to latent heat transfer as compared to that from sensible heat transfer.
- Nucleate boiling characterization, including frequency measurements, and physics in a closed isochoric system.
- Experimental research that supports or refutes the OHP operational limits published by Drolen and Smoot.[1] This includes the effect of viscous losses on OHP operation, the OHP sonic limit, the swept length limit where the amplitude of oscillation is significantly smaller than the evaporator length, the heat flux limit, and the vapor inertia limit which attempts to define the maximum flow velocity that the slug meniscus can support.
- Experimental and physical research into OHP startup including the effects of surface roughness and initial fluid distribution prior to startup

For any Physical Sciences proposal selected for award, including the three areas of particular interest ("Extraction of Materials from Regolith", "Metamaterials in Soft Matter", and "Oscillating Heat Pipes"), all data must be deposited in the Physical Sciences Informatics Database starting one year after award completion.

The two NASA GRC drop towers described below are also available to augment research investigations. These facilities are typically used to conduct combustion or fluid physics experiments. Please go to link for further information. The Points of Contact for each research area are:
Fluid Physics: John McQuillen, john.b.mcquillen@nasa.gov
Combustion Science: Dan Dietrich, daniel.l.dietrich@nasa.gov
Since there is a cost involved to use these drop towers, please contact the appropriate POC for cost estimates for your proposal.

2.2 s tower

https://www1.grc.nasa.gov/facilities/drop/

The 2.2 Second Drop Tower has been used for nearly 50 years by researchers from around the world to study the effects of microgravity on physical phenomena such as combustion

[1] B.L. Drolen and C.D. Smoot, "The Performance Limits of Oscillating Heat Pipes: Theory and Validation," Journal of Thermophysics and Heat Transfer, 31, 4, 2017, pp. 920-936.

and fluid dynamics and to develop technology for future space missions. It provides rapid turnaround testing (up to 12 drops/day) of 2.2 seconds in duration.

5..2 s tower

https://www1.grc.nasa.gov/facilities/zero-g/

The Zero Gravity Research Facility is NASA's premier facility for ground based microgravity research, and the largest facility of its kind in the world. It provides researchers with a near weightless environment for a duration of 5.18 seconds. It has been primarily used for combustion and fluid physics investigations.

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: https://science.nasa.gov/biological-physical/programs/physical-sciences

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/

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 Sun'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

Further information on the objectives and goals of NASA's Heliophysics Program may be found in the *2014 Science Plan and Our Dynamic Space Environment: Heliophysics Science and Technology Roadmap for 2014-2033* (download PDF). The Heliophysics research program is described in Chapter 4.1 of the *SMD Science Plan 2014* available at http://science.nasa.gov/about-us/science-strategy/. The program supports theory, modeling, and data analysis utilizing remote sensing and *in situ* measurements from a fleet of missions; the Heliophysics System Observatory (HSO). Frequent CubeSats, suborbital rockets, balloons, and ground-based instruments add to the observational base. Investigations that develop new observables and technologies for heliophysics science are sought.

Supported research activities include projects that address understanding of the Sun and planetary space environments, including the origin, evolution, and interactions of space plasmas and electromagnetic fields throughout the heliosphere. The program seeks to characterize these phenomena on a broad range of spatial and temporal scales, to understand the fundamental processes that drive them, to understand how these processes combine to create space weather events, and to enable a capability for predicting future space weather events.

The program supports investigations of the Sun, including processes taking place throughout the solar interior and atmosphere and the evolution and cyclic activity of the Sun. It supports investigations of the origin and behavior of the solar wind, energetic particles, and magnetic fields in the heliosphere and their interaction with the Earth and other planets, as well as with the interstellar medium.

The program also supports investigations of the physics of magnetospheres, including their formation and fundamental interactions with plasmas, fields, and particles and the physics of the terrestrial mesosphere, thermosphere, ionosphere, and auroras, including the coupling of these phenomena to the lower atmosphere and magnetosphere. Proposers may also review the information in the ROSES-21 Heliophysics Research Program Overview for further information about the Heliophysics Research Program.

Earth Science Division

The overarching goal of NASA's Earth Science program is to develop a scientific understanding of Earth as a system. The Earth Science Division of the Science Mission Directorate (https://science.nasa.gov/earth-science) contributes to NASA's mission, in particular, Strategic Objective 1.1: Understanding The Sun, Earth, Solar System, And Universe. This strategic objective is motivated by the following key questions:

- 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

In applied sciences, the ESD encourages the use of data from NASA's Earth-observing satellites and airborne missions to tackle tough challenges and develop solutions that improve our daily lives. Specific areas of interest include efforts that help institutions and individuals make better decisions about our environment, food, water, health, and safety (see http://appliedsciences.nasa.gov). In technological research, the ESD aims to foster the creation and infusion of new technologies – such as data processing, interoperability, visualization, and analysis as well as autonomy, modeling, and mission architecture design – in order to enable new scientific measurements of the Earth system or reduce the cost of current observations (see http://esto.nasa.gov). The ESD also promotes innovative development in computing and information science and engineering of direct relevance to ESD. NASA makes Earth observation data and information widely available through the Earth Science Data System program, which is responsible for the stewardship, archival and distribution of open data for all users

The Earth Science Division (ESD) places particular emphasis on the investigators' ability to promote and increase the use of space-based remote sensing through the proposed research. Proposals with objectives connected to needs identified in most recent Decadal Survey (2017-2027) from the National Academies of Science, Engineering, and Medicine, *Thriving on our Changing Planet: A Decadal Strategy for Earth Observation from Space* are welcomed. (see https://www.nap.edu/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth).

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.

Planetary Science Division

The Planetary Science Research Program, managed by the Planetary Science Division, sponsors research that addresses the broad strategic objective to "Ascertain the content, origin, and evolution of the Solar System and the potential for life elsewhere." To pursue this objective, the Planetary Science Division has five science goals that guide the focus of the division's science research and technology development activities. As described in Chapter 4.3 of the SMD 2014 Science Plan (https://science.nasa.gov/about-us/science-strategy), these are:

- 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 the 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 order to address these goals, the Planetary Research Program invites a wide range of planetary science and astrobiology investigations. Example topics include, but are not limited to:

- Investigations aimed at understanding the formation and evolution of the Solar System and (exo) planetary systems in general, and of the planetary bodies, satellites, and small bodies in these systems;
- Investigations aimed at understanding materials present, and processes occurring, in the early stages of Solar System history, including the protoplanetary disk;
- Investigations aimed at understanding planetary differentiation processes;
- Investigations of extraterrestrial materials, including meteorites, cosmic dust, presolar grains, and samples returned by the Apollo, Stardust, Genesis, and Hayabusa missions;
- Investigations of the properties of planets, satellites (including the Moon), satellite and ring systems, and smaller Solar System bodies such as asteroids and comets;
- Investigations of the coupling of a planetary body's intrinsic magnetic field, atmosphere, surface, and interior with each other, with other planetary bodies, and with the local plasma environment;
- Investigations into the origins, evolution, and properties of the atmospheres of planetary bodies (including satellites, small bodies, and exoplanets);
- Investigations that use knowledge of the history of the Earth and the life upon it as a guide for determining the processes and conditions that create and maintain habitable environments and to search for ancient and contemporary habitable environments and explore the possibility of extant life beyond the Earth;
- Investigations into the origin and early evolution of life, the potential of life to adapt to different environments, and the implications for life elsewhere;
- Investigations that provide the fundamental research and analysis necessary to characterize exoplanetary systems;
- Investigations related to understanding the chemistry, astrobiology, dynamics, and energetics of exoplanetary systems;
- Astronomical observations of our Solar System that contribute to the understanding of the nature and evolution of the Solar System and its individual constituents;
- Investigations to inventory and characterize the population of Near Earth Objects (NEOs) or mitigate the risk of NEOs impacting the Earth;
- Investigations into the potential for both forward and backward contamination during planetary exploration, methods to minimize such contamination, and standards in these areas for spacecraft preparation and operating procedures;
- Investigations which enhance the scientific return of NASA Planetary Science Division missions through the analysis of data collected by those missions;

- Advancement of laboratory- or spacecraft-based (including small satellites, e.g., CubeSats) instrument technology that shows promise for use in scientific investigations on future planetary missions; and
- Analog studies, laboratory experiments, or fieldwork to increase our understanding of Solar System bodies or processes and/or to prepare for future missions.

Proposers may also review the information in the ROSES-2021 Planetary Science Research Program Overview for further information about the Planetary Science Research Program.

Astrophysics Division

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

In order to address these Astrophysics goals, the Astrophysics Research Analysis and Technology Program invites a wide range of astrophysics science investigations from space that can be broadly placed in the following categories.

(i) The development of new technology covering all wavelengths and fundamental particles, that can be applied to future space flight missions. This includes, but is not limited to, detector development, and optical components such as primary or secondary mirrors, coatings, gratings, filters, and spectrographs.

(ii) New technologies and techniques that may be tested by flying them on suborbital platforms such as rockets and balloons that are developed and launched by commercial suborbital flight providers or from NASA's launch range facilities, or by flying them on small and innovative orbital platforms such as cubesats.

(iii) Studies in laboratory astrophysics. Examples of these studies could include atomic and molecular data and properties of plasmas explored under conditions approximating those of astrophysical environments.

(iv) Theoretical studies and simulations that advance the goals of the astrophysics program

(v) Analysis of data that could lead to original discoveries from space astrophysics missions. This could include the compilations of catalogs, statistical studies, algorithms and pattern recognition, artificial intelligence applications, development of data pipelines, etc.

(vi) Citizen Science programs, which are a form of open collaboration in which individuals or organizations participate voluntarily in the scientific process, are also invited. The current SMD Policy (https://smd-prod.s3.amazonaws.com/science-red/s3fs-public/atoms/files/SPD%2033%20Citizen%20Science.pdf) on citizen science describes standards for evaluating proposed and funded SMD citizen science projects. For more information see the https://science.nasa.gov/citizenscience webpage, that provides information about existing SMD-funded projects.

(vii) NASA astrophysics will follow recommendations of the National Academy of Sciences Decadal Survey on Astronomy and Astrophysics 2020 (Astro2020) currently in progress, which will define new directions regarding mission development, science priorities and future investments (see at: https://www.nationalacademies.org/our-work/decadal-survey-on-astronomy-and-astrophysics-2020-astro2020)

Investigations submitted to the Astrophysics research program should explicitly support past, present, or future NASA astrophysics missions. These investigations can include theory, simulation, data analysis, and technology development. The Astrophysics research program and missions are described in Chapter 4.4 of the SMD 2014 Science Plan available at https://science.nasa.gov/about-us/science-strategy

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, at JPL, 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 STMD can be found at: (http://www.nasa.gov/directorates/spacetech/about_us/index.html).

Areas of Interest – POC: Damian Taylor, Damian.Taylor@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 plans future investments to support the following strategic thrusts:

- ***Go***: *Rapid, Safe, & Efficient Space Transportation*
    - Develop nuclear technologies enabling fast in-space transits.
    - Develop cryogenic storage, transport, and fluid management technologies for surface and in-space applications.
    - Develop advanced propulsion technologies that enable future science/exploration missions.
- ***Land***: *Expanded Access to Diverse Surface Destinations*
    - Enable Lunar/Mars global access with ~20t payloads to support human missions.
    - Enable science missions entering/transiting planetary atmospheres and landing on planetary bodies.
    - Develop technologies to land payloads within 50 meters accuracy and avoid landing hazards.
- ***Live***: *Sustainable Living and Working Farther from Earth*
    - Develop exploration technologies and enable a vibrant space economy with supporting utilities and commodities.
        - Sustainable power sources and other surface utilities to enable continuous lunar and Mars surface operations.
        - Scalable ISRU production/utilization capabilities including sustainable commodities on the lunar & Mars surface.
        - Technologies that enable surviving the extreme lunar and Mars environments.
        - Autonomous excavation, construction & outfitting capabilities targeting landing pads/structures/habitable buildings utilizing in situ resources.
    - Enable long duration human exploration missions with Advanced Life Support & Human Performance technologies.
- ***Explore***: *Transformative Missions and Discoveries*
    - Develop next generation high performance computing, communications, and navigation.
    - Develop advanced robotics and spacecraft autonomy technologies to enable and augment science/exploration missions.
    - Develop technologies supporting emerging space industries including: Satellite Servicing & Assembly, In Space/Surface Manufacturing, and Small Spacecraft technologies.
    - Develop vehicle platform technologies supporting new discoveries.
    - Develop transformative technologies that enable future NASA or commercial missions and discoveries
- ***Lead***: *Ensuring American global leadership in Space Technology*
    - Lunar Exploration building to Mars and new discoveries at extreme locations
    - Robust national space technology engine to meet national needs

- U.S. economic growth for space industry
- Expanded commercial enterprise in space

Current space technology topics of particular interest include:

- Methods for space and in space manufacturing
- Autonomous in-space assembly of structures and spacecraft
- Ultra-lightweight materials for space applications
- Materials, structures and mechanisms for extreme environments (low and high temperatures, radiation, abrasive dust, etc.).
- Resource prospecting, mining, excavation, and extraction of in situ resources. 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
- High performance space computing
- Smart habitats
- Extreme environment (including cryogenic) electronics for planetary exploration
- Advanced robotics for extreme environment sensing, mobility, manipulation and repair
- Advanced power generation, storage, and distribution for deep space missions and surface operations
- Advanced entry, decent, and landing systems for planetary exploration including materials response models and parachute models
- Radiation modeling, detection and mitigation for deep space crewed missions
- Biological approaches to environmental control, life support systems and manufacturing
- Autonomous systems for deep space missions
- 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, and in-space propulsion
- Technologies that take advantage of small launch vehicles and small spacecraft to conduct more rapid and lower-cost missions
- Advancements in engineering tools and models that support Space Technology advancement and development

Applicants are strongly encouraged to familiarize themselves with the new 2020 NASA Technology Taxonomy (replaced the 2015 NASA Technology Roadmaps) and the NASA Strategic Technology Integration Framework (coming soon) that most closely aligns with their space technology interests. The new 2020 NASA Technology Taxonomy may be downloaded at the following link: https://www.nasa.gov/offices/oct/taxonomy/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 program.

A.5 NASA Centers Areas of Interest

"Engagement with Center Chief Technologists and the Agency Capability Leadership Teams is critical to value of the research and selection of proposals." Examples of Center research interest areas include these specific areas from the following Centers. If no POC is listed in the Center write-up and contact information is needed, please contact the POC listed in Appendix D for that Center and request contacts for the research area of interest.

A.5.1 Ames Research Center (ARC)

POC: Harry Partridge, harry.partridge@nasa.gov

- Entry systems: Safely delivering spacecraft to Earth & other celestial bodies
- Advanced Computing & IT Systems: Enabling NASA's advanced modeling and simulation
  - Supercomputing
  - Quantum computing, quantum sensors and quantum algorithms
  - Applied physics and Computational materials
- Aero sciences:
  - Wind Tunnels: Testing on the ground before you take to the sky
- Air Traffic Management:
  - NextGen air transportation: Transforming the way we fly
  - Airborne science: Examining our own world & beyond from the sky
  - Airspace Systems, Unmanned aerial Systems
- Astrobiology and Life Science: Understanding life on Earth - and in space
  - Biology & Astrobiology
  - Space radiation health risks
  - Biotechnology, Synthetic biology
  - Instruments
- Cost-Effective Space Missions: Enabling high value science to low Earth orbit & the moon
  - Small Satellites, Cube satellites
- Intelligent/Adaptive Systems: Complementing humans in space
  - Autonomy & Robotics: Enabling complex air and space missions, and complementing humans in space
  - Human Systems Integration: Advancing human-technology interaction for NASA missions
  - Nanotechnology-electronics and sensors, flexible electronics
- Space and Earth Science: Understanding our planet, our solar system and everything beyond
  - Exoplanets: : Finding worlds beyond our own
  - Airborne Science: Examining our own world & beyond from the sky
  - Lunar Sciences: Rediscovering our moon, searching for water

A.5.2 Armstrong Flight Research Center (AFRC)

POC: Timothy Risch, timothy.k.risch@nasa.gov

- Hybrid Electric Propulsion
  (POC: Sean Clarke, AFRC-540)

- Supersonic Research (Boom mitigation and measurement)
  (POC: Ed Haering, AFRC-520)
- Supersonic Research (Laminar Flow)
  (POC: Dan Banks, AFRC-520)
- Hypersonic Structures & Sensors
  (POC: Larry Hudson, AFRC-560)
- Control of Flexible Structures, Modeling, System Identification, Advanced Sensors
  (POC: Matt Boucher, Jeff Ouellette, AFRC-530)
- Autonomy (Collision Avoidance, Perception, and Runtime Assurance)
  (POC: Nelson Brown, AFRC-530)
- Urban Air Mobility (UAM) Vehicle Handling and Ride Qualities
  (POC: Curt Hanson, AFRC-530)
- Urban Air Mobility (UAM) Envelope Protection
  (POC: Shawn McWherter, AFRC-530)
- Aircraft Electrical Powertrain Modeling
  (POC: Peter Suh, AFRC-530)
- Un-crewed Aerial Platforms for Earth and Planetary Science Missions
  (POC: Bruce Cogan, AFRC-570)

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

Research and technology, and engineering engagements comprise including:

- Acoustics / Propulsion Acoustics
- Advanced Energy (Renewable Wind and Solar, Coal Energy and Alternative Energy)
- Advanced Microwave Communications
- Networks, Architectures and Systems Integration
- Intelligent Systems-Smart Sensors and Electronic Systems Technologies
- Aeronautical and Space Systems Analysis
- Electrified Aircraft
- Computer Systems and Networks
- Electric (Ion) Propulsion
- Fluid and Cryogenic Systems / Thermal Systems
- Growth of Ice on Aircraft
- Aviation Safety Improvements
- Instrumentation, Controls and Electronics
- Fluids, Computational Fluid Dynamics (CFD) and Turbomachinery
- Materials and Structures, including Mechanical Components and Lubrication
- Mechanical and Drive Systems (Shape Memory Alloys-Base Actuation)
- Computational Modeling
- Microgravity Fluid Physics, Combustion Phenomena and Bioengineering
- Nanotechnology
- Photovoltaics, Electrochemistry-Physics, and Thermal Energy Conversion

- Propulsion System Aerodynamics
- Power Architecture, Generation, Storage, Distribution and Management
- Urban Air Mobility (UAM)
- Systems Engineering

The above engagement areas relate to the following key Glenn Areas of Expertise:

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

A.5.4 Goddard Space Flight Center (GSFC),
POC: Heather B., gsfc-chief-technologist@mail.nasa.gov or James L. Harrington, james.l.harrington@nasa.gov

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.
- **Quantum sensors and quantum networking**
- **Artificial intelligence and machine learning**
- **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.

- **Model Based System Engineering (MBSE)**

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: Rita Samburna (Rita.m.Sambruna@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 and experimental research programs, as well as mission investigations and space instruments to test them. The researchers participate in planetary and Earth science missions, and collect, interpret, and evaluate measurements. *POC: Brook Lakew (Brook.Lakew@nasa.gov)*

- **Quantum sensors and quantum networking:** Quantum computing is based on quantum bits or qubits. Unlike traditional computers, in which bits must have a value of either zero or one, a qubit can represent a zero, a one, or both values simultaneously. Representing information in qubits allows the information to be processed in ways that have no equivalent in classical computing, taking advantage of phenomena such as quantum tunneling and quantum entanglement. As such, quantum computers may theoretically be able to solve certain problems in a few days that would take millions of years on a classical computer. *POC: Mike Little (m.m.little@nasa.gov)*

- **Artificial intelligence and machine learning**: *POCs: Mark Carroll (mark.carroll@nasa.gov) across the entire organization and in Heliophysics Barbara Thompson (Barbara.j.thompson@nasa.gov)*

- **(Big) data analytics:** Data Analytics, including Data Mining and Pattern Recognition for Science applications and with special emphasis on:
  - Quantification of uncertainty in inference from big data
  - Experiment design to create data that is AI/ML ready and robust against misleading correlations
  - Methods for prediction of new discovery spaces
  - Strength of evidence and reproducibility in inference from big data

  POC: Mark Carroll (mark.carroll@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.

A.5.5 Jet Propulsion Laboratory (JPL),

POC: Fred Y. Hadaegh, fred.y.hadaegh@jpl.nasa.gov

- Solar System Science
  Planetary Atmospheres and Geology
  Solar System characteristics and origin of life
  Primitive (1) solar systems bodies
  Lunar (9) science
  Preparing for returned sample investigations

- Earth Science
  Atmospheric composition and dynamics (Atmospheric Dynamics
  Land and solid earth processes (Solid Earth Processes
  Water and carbon cycles, Carbon Cycles, Water Cycles
  Ocean and ice
  Earth analogs to planets, Earth Analog

Climate Science

- <u>Astronomy and Fundamental Physics</u>
  Origin, evolution, and structure of the universe, Origin Universe, Evolution Universe, Structure Universe
  Gravitational astrophysics and fundamental physics
  Extra-solar planets: Exoplanets; Star formation; Planetary formation
  Solar and Space Physics
  Formation and evolution of galaxies; Formation Galaxies; Evolution Galaxies

- <u>In-Space Propulsion Technologies</u>
  Chemical propulsion
  Non-chemical propulsion
  Advanced propulsion technologies
  Supporting technologies
  Thermal Electric Propulsion
  Electric Propulsion

- <u>Space Power and Energy Storage</u>
  Power generation
  Energy storage
  Power management & distribution
  Cross-cutting technologies
  Solar power, Photovoltaic
  Tethers
  Radioisotope
  Thermoelectric

- <u>Robotics, Tele-Robotics, and Autonomous Systems</u>
  Sensing (Robotic Sensing)
  Mobility
  Manipulation technology
  Human-systems interfaces
  Autonomy
  Autonomous rendezvous & docking
  Systems engineering
  Vision
  Virtual reality
  Telepresence
  Computer Aided

- <u>Communication and Navigation</u>
  Optical communications & navigation technology
  Radio frequency communications, Radio Technologies
  Internetworking
  Position navigation and timing
  Integrated technologies
  Revolutionary concepts

Communication technology
Antennas
Radar
Remote Sensing
Optoelectronics

- 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/Remote Sensing Sensors
  Observatory technologies
  In-situ instruments, Sensor technologies
  Sensors
  In situ technologies
  Instrument technologies
  Precision frequency
  Precision timing
- Entry, Descent and Landing Systems
  Aerobraking, Aerocapture and entry system; Descent; Engineered materials; Energy generation and storage; Propulsion; Electronics, devices and sensors
  - Nanotechnology
  - Microtechnology
  - Microelectronics
  - Microdevice
  - Orbital Mechanics
  - Spectroscopy
- 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

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Other Research Areas

Small Satellite
Small Satellite Technologies
Balloons
Radio Science
MEMS
Advanced High Temperature
Spectroscopy
Magnetosphere
Plasma Physics
Ionospheres
Ground Data Systems

Laser
Drills
High Energy Astrophysics
Solar physics
Interstellar Astrophysics
Interstellar Medium
Astrobiology
Astro bio geochemistry
Life Detection
Cosmo chemistry
Adaptive Optics
Artificial Intelligence

A.5.6 Johnson Space Center (JSC)

POC: Nick Skytland, nicholas.g.skytland@nasa.gov

Active Thermal Control

- Condensing heat exchanger coatings with robust hydrophilic, antimicrobial properties
- Development and demonstration of wax and water-based phase change material heat exchangers
- Lightweight heat exchangers and cold plates

ECLSS

- Advancements in Carbon Dioxide Reduction
- Habitation systems that minimize consumables
- Human thermal modeling
- Low toxicity hygiene and cleaning products and methods

EVA

- Portable Life Support System
- Power, Avionics and Software
- Pressure Garment

Entry, Descent, and Landing

- Innovative, Groundbreaking, and High Impact Developments in Spacecraft GN&C Technologies
- Deployable Decelerator Technologies
- High-Fidelity Parachute Fluid/Structure Interaction
- Mechanical Reefing Release Mechanism for Parachutes
- Next Generation Parachute Systems & Modeling
- Precision Landing & Hazard Avoidance Technologies
- Regolith – Rocket Plume Interaction: In-situ Measurements to Enable Multiple Landings at the Same Site
- Optical / Vision-Based Navigation for EDL Applications
- Sensors, including those embedded in thermal protection systems and proximity operations and landing
- Additive Manufacturing for Thermal Protection Systems
- Advanced Materials and Instrumentation for Thermal Protection Systems

- Predictive Material Modeling

Energy Storage technologies
- Batteries, Regenerative Fuel cells

In-Situ Resource Utilization
- Lunar/Mars regolith processing (Regolith collection and drying; Water collection and processing, water electrolysis)
- Mars atmosphere processing (CO_2 collection; Dust filtering; Solid Oxide CO_2 electrolysis; Sabatier; Reverse water gas shift)
- Methane/Oxygen liquefaction and storage

In-space propulsion technologies

Autonomy and Robotics
- Biomechanics
- Crew Exercise
- Human Robotic interface
- Autonomous Vehicle Systems/Management
- Data Mining and Fusion
- Robotics and TeleRobotics
- Simulation and modeling

Autonomous Rendezvous and Docking - Next generation In-space docking systems concepts addressing challenges of mass, environments, flight operations and including long duration missions, consider:
- New Rendezvous & Docking strategies ie;, greater vehicle reliance vs kinetic energy, addressing vehicle capabilities, sensors, etc…
- Simplification of soft capture system attenuation; less complex and lighter systems
- Docking independent LRU strategies vs Integrated vehicle solution
- Seals and sealing technology
- Consumables transfer technology (power, data, water, air, fluids)
- Maintenance

Surface Docking System Concepts addressing*:*
- System design and interfaces
- Environments tolerance including long duration exposure

Computer Human Interfaces (CHI)
- *CHI - Human System Integration*
- Human Computer Interaction design methods (Multi-modal and Intelligent Interaction) and apparatuses
- Human Systems Integration, Human Factors Engineering: state of the art in Usability, workload, and performance assessment methods and apparatus.
- Inclusion of Human Readiness Level into HSI
- Humans Systems Integration Inclusion in Systems Engineering
- Human-in-the-loop system data acquisition and performance modeling
- Trust computing methodology

- *CHI - Informatics*

- Crew decision support systems
- Advanced Situation Awareness Technologies
- Intelligent Displays for Time-Critical Maneuvering of Multi-Axis Vehicles
- Intelligent Response and Interaction System
- Exploration Space Suit (xEMU) Informatics
- Graphic Displays to Facilitate Rapid Discovery, Diagnosis and Treatment of Medical Emergencies
- CHI machine learning methods and algorithms
- Imaging and information processing
- Audio system architecture for Exploration Missions

- *CHI - Audio*
- Array Microphone Systems and processing
- Machine-learning front end audio processing
- Audio Compression algorithms implementable in FPGAs.
- COMSOL Acoustic modeling
- Front end audio noise cancellation algorithms implementable in FPGAs-example Independent Component Analysis
- Large bandwidth (audio to ultra-sonic) MEMs Microphones
- Sonification Algorithms implementable in DSPs/FPGAs
- Far-Field Speech Recognition in Noisy Environments

- *CHI - Imaging and Display*
- Lightweight/low power/radiation tolerant displays
- OLED Technology Evaluation for Space Applications
- Radiation tolerant Graphics Processing Units (GPUs)
- Scalable complex electronics & software-implementable graphics processing unit
- Radiation-Tolerant Imagers
- Immersive Imagery capture and display
- H265 Video Compression
- Ultra High Video Compressions
- A Head Mounted Display Without Focus/Fixation Disparity
- EVA Heads-Up Display (HUD) Optics

Wearable Technology
- Tattooed Electronic Sensors
- Wearable Audio Communicator
- Wearable sensing and hands-free control
- Wearable Sensors and Controls
- Wearable digital twin/transformation sensor systems

Wireless and Communications Systems
- Computational Electromagnetics (CEM) Fast and Multi-Scale Methods/Algorithms
- EPCglobal-type RFID ICs at frequencies above 2 G
- Radiation Hardened EPCglobal Radio Frequency Identification (RFID) Readers
- Robust, Dynamic Ad hoc Wireless Mesh Communication Networks
- Wireless Energy Harvesting Sensor Technologies
- Flight and Ground communication systems

Radiation and EEE Parts

- Mitigation and Biological countermeasures
- Monitoring
- Protection systems
- Risk assessment modeling
- Space weather prediction

Nicholas Skytland
Deputy Chief, Exploration Technology Office
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A.5.7 Kennedy Space Center (KSC)

POC Delvin VanNorman, delvin.vannorman@nasa.gov or Jose Nunez, jose.l.nunez@nasa.gov

- HEOMD – Commercial Crew systems development and ISS payload and flight experiments
- Environmental and Green Technologies
- Health and Safety Systems for Operations
- Communications and Tracking Technologies
- Robotic, automated and autonomous systems and operations
- Payload Processing & Integration Technologies (all class payloads)
- R&T Technologies on In-Space Platforms (e.g., ISS, Gateway, Human Habitats)
- Damage-resistant and self-healing materials
- Plant Research and Production
- Water/nutrient recovery and management
- Plant habitats and Flight Systems
- Food production and waste management
- Robotic, automated and autonomous food production
- Robotic, automated and autonomous food production
- Damage-resistant and self-healing materials
- Automated and autonomous detection and repair
- Propulsion: Chemical Propulsion flight integration (human transportation)
- Space Environments Test: Right/West Altitude Chamber
- Launch technologies including propellant management, range & communications
- Vehicle, payload and flight science experiment integration and testing
- Landing & recovery operations
- Biological sciences (Plant research & production)
- Destination systems including ISRU, surface construction & dust mitigation
- Autonomous/robotic (unmanned) surface systems and operations
- Water resource utilization technologies
- Logistics reduction technologies

NOTE:

1. The above R&T Focus Areas are described in the KSC R&T Portfolio Data Dictionary

A.5.8 Langley Research Center (LaRC)

Langley Research Center (LaRC), POC: Dr. Neyda Abreu, neyda.m.abreu@nasa.gov

- Intelligent Flight Systems—autonomy and robotics." (POC: Charles "Mike" Fremaux 757-864-1193)
- Atmospheric Characterization – Active & Passive Remote and In-situ Sensing (POC: Allen Larar 757.864.5328)
- Systems Analysis and Concepts - Air Transportation System Architectures & Vehicle Concepts (POC: Phil Arcara 757.864.5978)
- Advanced Materials & Structural System – Advanced Manufacturing (POC: David Moore 757-864-9169)
- Aerosciences - Trusted Autonomy (POC: Charles "Mike" Fremaux 757-864-1193)
- Entry, Decent & Landing - Robotic Mission Entry Vehicles (POC: Ron Merski – 757-864-7539)
- Measurement Systems - Advanced Sensors and Optical Measurement (POC: Tom Jones 757-864-4903)

A.5.9 Marshall Space Flight Center (MSFC)

POC: John Dankanich, john.dankanich@nasa.gov and https://www.nasa.gov/offices/oct/center-chief-technologists-2

These Principal Technologists and System Capability Leads are available for consultation with proposers regarding the state-of-the-art, on-going activities and investments, and strategic needs in their respective areas of expertise. Proposers are encouraged to consult with the appropriate PT or SCLT early in the proposal process.

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Bo Naasz	Rendezvous & Capture	bo.j.naasz@nasa.gov
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Wes Powell	Avionics/Communications	wesley.a.powell@nasa.gov

Jerry Sanders	In Situ Resource Utilization	gerald.b.sanders@nasa.gov
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John Vickers	Advanced Manufacturing	john.h.vickers@nasa.gov
Sharada Vitalpur	Communications & Navigation	sharada.v.vitalpur@nasa.gov
Arthur Werkheiser	Cryofluid Management	arthur.wekheiser@nasa.gov
Mike Wright	Entry, Descent and Landing	michael.j.wright@nasa.gov

Propulsion Systems

- Launch Propulsion Systems, Solid & Liquid
- In Space Propulsion (Cryogenics, Green Propellants, Nuclear, Fuel Elements, Solar-Thermal, Solar Sails, Tethers)
- Propulsion Testbeds and Demonstrators (Pressure Systems)
- Combustion Physics
- Cryogenic Fluid Management
- Turbomachinery
- Rotordynamics
- Solid Propellant Chemistry
- 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
- Low Leakage Valves

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 Data & Comm. 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)
- Digital Thread / Product Lifecycle Management (for AM and/or Composites)
- Material Failure Diagnostics

Science

- Replicated Optics
- Large Optics (IR, visible, UV, X-Ray)
- High Energy Astrophysics (X-Ray, Gamma Ray, Cosmic Ray)
- Radiation Mitigation/Shielding
- Gravitational Waves and their Electromagnetic Counterparts
- Solar, Magnetospheric and Ionospheric Physics
- Planetary Geology and Seismology
- Planetary Dust, Space Physics and Remote Sensing
- Surface, Atmospheres and Interior of Planetary Bodies
- Earth Science Applications
- Convective and Severe Storms Research
- Lightning Research
- Data Informatics
- Disaster Monitoring
- Energy and Water Cycle Research
- Remote Sensing of Precipitation

A.5.10 Stennis Space Center (SSC),

POC: Dr. Ramona Travis, ramona.e.travis@nasa.gov

Intelligent Integrated System Health Management (ISHM) for Ground and Space Applications

Integrated system health management (ISHM) encompasses a unified approach of assessing the current and future state of a system's health and considers a system integrated interdependencies with other systems within a framework of available resources, concepts of operations, and operational demands.

ISHM not only considers the current health state of systems, but also the health across a system's entire life cycle. Both system health data and usage data are used to analyze and identify the behavior unique to a system, as well as help identify trends in degradation over time and estimate remaining useful life. In this context, SSC is interested in methodologies to assess the health of ground and space systems that will play a role in enabling lunar sustainability *e.g., fluid, electrical, power, thermal, propulsion, GNC (guidance, navigation, and control) and life support; required for ground facilities, spacecraft, rovers, habitats and landers.

Expected outcomes of EPSCoR research could include the following: (1) to develop monitoring and diagnostic capabilities that use intelligent models to monitor and document the operation of the system; (2) to develop monitoring and prognostics capabilities that use intelligent models to assess the life cycle of the system; (3) to develop architectures/taxonomies/ontologies for integrated system health management using distributed intelligent elements; and (4) to develop user and operator interfaces, both visual and voice, that enable ease of use for ISHM capability.

Autonomous Operations Capability for Ground and Space Applications

HEOMD has identified numerous capability gaps in the current state of the art for implementing autonomous operations. Autonomous operations are critical capabilities required for the future of NASA exploration and space missions. Autonomous operations inherently involve high levels of intricacy and cost, and these issues become exponentially compounded by increasing complexity of system design for operations in space, for operations on surfaces beyond earth, in harsh environmental conditions, and operations of systems at communication distances that limit human involvement.

Therefore, to enable sustainability for Artemis exploration and space operations, unprecedented levels of autonomy will be required to successfully accomplish planned mission objectives. Furthermore, to enabling autonomous operational capabilities, trust in these systems needs to be established.

In this context, SSC is interested in exploring challenges associated with implementing intelligent hierarchical distributed autonomous systems for Artemis capabilities required for lunar habitation and exploration; and on foundations for implementing trusted autonomous space systems.

Expected outcomes of an EPSCOR research project could include the following: (1) to develop technologies that enable trusted autonomy and autonomous space systems; (2) to develop technologies that enable hierarchical distributed autonomy; (3) to develop technologies that enable on-board autonomy whereby observation, analysis, decisions, and execution of tasks are done by the systems themselves; and (4) to develop technologies for user interfaces with autonomous systems.

Advanced Propulsion Test Technology Development

Rocket propulsion development is enabled by rigorous ground testing to mitigate the propulsion system risks that are inherent in spaceflight. This is true for virtually all propulsive devices of a space vehicle including liquid and solid rocket propulsion, chemical and nonchemical propulsion, boost stage, in-space propulsion, and so forth. This area of interest seeks to develop advanced ground test technology components and system level ground test systems that enhance chemical and advanced propulsion technology development and certification while substantially reducing the costs and improving safety/reliability of NASA's test and launch operations. At present, focal areas of interest are:

- Tools using computational methods to accurately model and predict system performance, that integrate simple interfaces with detailed design and/or analysis software, are required. Stennis Space Center (SSC) is interested in improving capabilities and methods to accurately predict and model the transient fluid structure interaction between cryogenic fluids and immersed components to predict the dynamic loads and frequency response of facilities.
- Improved capabilities to predict and model the behavior of components (valves, check valves, chokes, etc.) during the facility design process are needed. These capabilities are required for modeling components in high pressure (to 12,000 psi), with flow rates up to several thousand lb/sec, in cryogenic environments and must address two-phase flows. Challenges include: accurate, efficient, thermodynamic state models; cavitation models for propellant tanks, valve flows, and run lines; reduction in solution time; improved stability; acoustic interactions; and fluid-structure interactions in internal flows.

Advanced Rocket Propulsion Test Instrumentation

Rocket propulsion system development is enabled by rigorous ground testing to mitigate the propulsion system risks inherent in spaceflight. Test articles and facilities are highly instrumented to enable a comprehensive analysis of propulsion system performance. Advanced instrumentation has the potential for substantial reduction in time and cost of propulsion systems development, with substantially reduced operational costs and improvements in ground, launch, and flight system operational robustness.

Advanced instrumentation should provide a wireless, highly flexible instrumentation solution capable of multiple measurements (e.g., heat flux, temperature, pressure, strain, and/or near-field acoustics). These advanced instruments should function as a modular node in a sensor network, capable of performing some processing, gathering sensory information, and communicating with other connected nodes in the network. The collected sensor network must be capable of integration with data from conventional data acquisition systems adhering to strict calibration and timing standards (e.g., Synchronization with Inter-Range Instrumentation Group—Time Code Format B (IRIG-B) and National Institute of Standards and Technology (NIST) traceability is critical to propulsion test data analysis.)

Rocket propulsion test facilities also provide excellent testbeds for testing and using the innovative technologies for possible application beyond the static propulsion testing environment. These sensors would be capable of addressing multiple mission requirements for remote monitoring such as vehicle health monitoring in flight systems, autonomous vehicle operation, or instrumenting inaccessible measurement locations, all while eliminating cabling and auxiliary power. Advanced instrumentation could support sensing and control applications beyond those of propulsion testing. For example, inclusion of expert system or artificial intelligence technologies might provide great benefits for autonomous operations, health monitoring, or self-maintaining systems.