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.

Areas of Interest - POC: Dave Berger, dave.e.berger@nasa.gov

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 Exploration Systems Development and Space Operations Mission Directorates (ESDMD and SOMD)

The Exploration Systems Development and Space Operations Mission Directorates (ESDMD and SOMD) provides the Agency with leadership and management of NASA space operations related to human exploration in and beyond low-Earth orbit. Through the Artemis missions, NASA will land the first woman and first person of color on the Moon, using innovative technologies to explore more of the lunar surface than ever before. NASA is collaborating with commercial and international partners to establish the first long-term human-robotic presence on and around the Moon. Then, we will use what we learn on and at the Moon to take the next giant leap: sending the first astronauts to Mars.

The Exploration Systems Development Mission Directorate (ESDMD) defines and manages systems development for programs critical to the NASA's Artemis program and planning for NASA's Moon to Mars exploration approach in an integrated manner. ESDMD manages the human exploration system development for lunar orbital, lunar surface, and Mars exploration. ESDMD leads the human aspects of the Artemis activities as well as the integration of science into the human system elements. ESDMD is responsible for development of the lunar and Mars architectures. Programs in the mission directorate include Orion, Space Launch System, Exploration Ground Systems, Gateway, Human Landing System, and Extravehicular Activity (xEVA) and Human Surface Mobility. Additional information about the Exploration Systems Development Mission Directorate can be found at: https://www.nasa.gov/directorates/exploration-systems-development.

The Space Operations Mission Directorate (SOMD) manages NASA's current and future space operations in and beyond low-Earth orbit (LEO), including commercial launch services to the International Space Station. SOMD operates and maintains exploration systems, develops and operates space transportation systems, and performs broad scientific research on orbit. In addition, SOMD is responsible for managing the space transportation services for NASA and NASA-sponsored payloads that require orbital launch, and the agency's space communications and navigation services supporting all NASA's space systems currently in orbit. Additional information on the Space Operations Mission Directorate can be found at: https://www.nasa.gov/directorates/space-operations-mission-directorate .

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 to enable safe, reliable, and productive human space exploration. The HRP budget enables NASA to resolve health risks 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 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; small payloads to accomplish science and research objectives, as well as for risk reduction for human-rated systems
- 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 and

Mars surfaces; visualization and data display; interactive data manipulation and sharing; modeling of lighting and thermal environments; simulation of environmental interactions for pressurized and unpressurized vehicles, and

- Research and technology development areas in ESDMD and SOMD support exploration systems development including in-space vehicles, space communications, commercial space, and the International Space Station. Examples of research and technology development areas (and the associated lead NASA Center) with great potential include:

- Research and technology development areas in ESDMD and SOMD support exploration systems development including in-space vehicles, space communications, commercial space, 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 (JSC)
    - Vehicle Integration and Ground Processing (Kennedy Space Center (KSC))
    - Mission Operations (JSC)
    - Portable Life Support Systems (JSC)
    - Pressure Garments and Gloves (JSC)
    - Air Revitalization Technologies (ARC)
    - In-Space Waste Processing Technologies (JSC)
    - Cryogenic Fluids Management Systems (MSFC)
  - *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~~ GSFC
    - 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. (KSC)
  - 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. (KSC)
  - 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. (KSC)
  - Proposals should discuss how the effort aligns with U.S. commercial spaceflight company interest(s) and identify potential alignments with NASA interests. (KSC)

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

POC: Dr Victor Schneider, vschneider@nasa.gov P: 202.258.3645
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.2.2 Human Research Program/Space Radiation Element
POC: Elgart, S Robin (JSC-SK4) [IPA] <shona.elgart@nasa.gov>, (281)244-0596

Research Overview:

Space radiation exposure is one of numerous hazards astronauts encounter during spaceflight that impact human health. High priority health outcomes associated with space radiation exposure are carcinogenesis, cardiovascular disease (CVD), and central nervous sytem (CNS) changes that impact astronaut health and performance.

Areas of Research Interest:

1. Research proposals are sought to **accelerate risk characterization for high priority radiation health risks and inform mitigation strategies the NASA Human Research Program (HRP) Space Radiation Element (SRE) by sharing animal tissue samples and data.** The proposed work should focus is on translational studies that support priority risk characterization (cancer, CVD, CNS), development of relative biological effectiveness (RBE) values, identification of actionable biomarkers, and evaluation of dose thresholds for relevant radiation-associated disease endpoints. Cross-species comparative analyses of rodent data/samples with higher order species (including human archival data and tissue banks) are highly encouraged.
    - Data can include but is not limited to behavioral tasks, tumor data, physiological measurements, imaging, omics', etc. that has already been, or is in the process of being, collected.
    - Tissue samples can include, but are not limited to, samples that have already been, or are in the process of, being collected and stored as well as tissues from other external archived banks (e.g., http://janus.northwestern.edu/janus2/index.php).
    - Relevant tissue samples and data from other externally funded (e.g., non-NASA) programs and tissue repositories/archives for comparison with high linear energy transfer (LET), medical proton, neutron and other exposures can be proposed.
    - A more detailed list of samples and tissues available from SRE can be found at our tissue sharing websites:
        - https://lsda.jsc.nasa.gov/Document/doc_detail/Doc13726
        - https://lsda.jsc.nasa.gov/Document/doc_detail/Doc13766
        - https://lsda.jsc.nasa.gov/Biospecimen by searching "NASA Space Radiation Laboratory (NSRL)" in the payloads field.
        - Instructions for accessing the tissue sharing information are posted at: https://spaceradiation.jsc.nasa.gov/tissue-sharing/.

2. **Research proposals are sought to define the mechanisms underlying sexual dimorphism following exposure to space radiation.** Research should focus on translational biomarkers relevant to changes in cognitive and/or behavioral performance, cardiovascular function, and the development of carcinogenesis **in non-sex-specific organs**. Due to limited time and budget, researchers are encouraged to utilize radiation sources located at home institutions at space relevant doses (0-5 Gy of photons or proton irradiation). A successful proposal will not necessitate the use of the NASA Space Radiation Laboratory (NSRL) at Brookhaven National Laboratory at this phase. Collaborations between investigators and institutions for the sharing of data and tissue samples are highly encouraged. Samples available for use by SRE, can be found at https://lsda.jsc.nasa.gov/Biospecimen by searching "NASA Space Radiation Laboratory (NSRL)" in

the payloads field (SRE approval required). Instructions for accessing the tissue sharing information are posted at: https://spaceradiation.jsc.nasa.gov/tissue-sharing/. Other topics include:

- Individual sensitivity
- Early disease detection (Cancer, CVD, neurological/behavioral conditions)
- Biomarker identification
- High-throughput countermeasure screening
- Sex-specific risk assessment
- Radiation quality and/or dose-rate effects

3. **Research proposals are sought to establish screening techniques for compound-based countermeasures to assess their efficacy in modulating biological responses to radiation exposure relevant to the high priority health risks of cancer, CVD, and/or CNS.** Techniques that can be translated into high-throughput screening protocols are highly desired, however high-content protocols will also be considered responsive.

4. **Research proposals are sought to evaluate the role of the inflammasome in the pathogenesis of radiation-associated cardiovascular disease (CVD), carcinogenesis, and/or central nervous system changes that impact behavioral and cognitive function.** Although innate inflammatory immune responses are necessary for survival from infections and injury, dysregulated and persistent inflammation is thought to contribute to the pathogenesis of various acute and chronic conditions in humans, including CVD. A main contributor to the development of inflammatory diseases involves activation of inflammasomes. Recently, inflammasome activation has been increasingly linked to an increased risk and greater severity of CVD. Characterization of the role of inflammasome-mediated pathogenesis of disease after space-like chronic radiation exposure can provide evidence to better quantify space radiation risks as well as identify high value for countermeasure development.

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 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-2022 and the text in the Division research overviews of ROSES, i.e.:

Astrophysics Research Program Overview

Biological and Physical Sciences Research Overview
Earth Science Research Overview
Heliophysics Research Program Overview
Planetary Science Research Program Overview and
Cross Division Research Overview.
Proposers may find a list of all of the currently solicited topics in Table 3 of ROSES-2022 at https://solicitation.nasaprs.com/ROSES2022table3

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

SMD POC: Kristen Erickson kristen.erickson@nasa.gov

A.3.1 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.

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. 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;
- Soft Condensed Matter: colloidal systems, emulsions, liquid crystals, polymer flows, foams and granular flows, and complex plasmas;
- Fundamental physics: space optical/atomic clocks, quantum test of equivalence principle, theory supporting space-based experiments in quantum entanglement, decoherence, cold atom physics.

A.3.2 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.

A.3.3 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.

A.3.4 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.

Additional information on technologies needed to support NASA Planetary Science Division missions may be found on the Planetary Exploration Science Technology Office website.

Proposers may also review the information in the ROSES-2021 Planetary Science Research Program Overview for further information about the Planetary Science Research Program. The use of NASA Research Facilities is available to supported investigators (see Appendix C section 4.3). If their use is anticipated, this use must be discussed and justified in the submitted proposals and include a letter of support from the facility (or resource) confirming that it is available for the proposed use during the proposed period.

A.3.5 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

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

STMD looks to engage new and diverse partners in order to garner different perspectives and approaches to our biggest technology challenges. An overarching principle guiding STMD's work is our commitment to inspiring and developing a diverse and powerful US aerospace technology community. As part of our strategic approach, STMD is committed to empowering innovators by expanding our work with and supported for underrepresented communities. Furthermore, we are focused on demonstrating engaging practices for underserved and underrepresented communities through the R&D process that strengthens and supports economic growth for a diverse technology community.

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.
- ***<u>Explore</u>****:* *<u>Transformative Missions and Discoveries</u>*
    - 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
- ***<u>Lead</u>***: *<u>Ensuring American global leadership in Space Technology</u>*
    - Advance US space technology innovation and competitiveness in a global context
    - Encourage technology driven economic growth with an emphasis on the expanding space economy
    - Inspire and develop a diverse and powerful US aerospace technology community

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, descent, and landing systems for planetary exploration including modeling with uncertainty quantification
- 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
- Lunar dust –mitigation techniques and dust behavior modeling
- High temperature radiators
- High temperature coatings
- Excavation, construction, and outfitting for the lunar surface, particularly methodologies and technologies to provide site clearing, roads with autonomous navigation aids, landing pads/berms, plume surface interaction mitigations and assembly of structures such as towers or buildings.

In recognition of NASA's leadership in developing advanced technologies for the benefit of all, research topics related to advancing national capabilities in the following climate-related technology areas are of interest:

- Clean Energy and Emissions Technologies: Clean energy and emissions mitigation technology projects focusing on the research and development, demonstration, or deployment of systems, processes, best practices, and sources that reduce the amount of greenhouse gas emitted to, or concentrated in, the atmosphere.

- U.S. Climate Change Research Program: Earth-observing capabilities to support breakthrough science and National efforts to address climate change.
  - Specific topic areas could include:
    - Reductions in greenhouse gas emissions (including CO2, CH4, N2O, HFCs)
      - Fuel Cells
      - Batteries and Energy Storage
      - Carbon Capture, Utilization, and Storage
      - Processes that enhance industrial efficiency and reduce emissions
      - Production of clean energy including solar, hydrogen, nuclear, or other clean energy sources
    - Enabling platforms and early-stage instruments for climate-relevant science observations

  - POCs for additional information:

- Clean energy: John Scott (john.h.scott@nasa.gov)
- Nuclear systems: Anthony Calomino (anthony.m.calomino@nasa.gov)
- Hydrogen: Jerry Sanders (gerald.b.sanders@nasa.gov)
- Earth-observing capabilities: Chris Baker (christopher.e.baker@nasa.gov), Justin Treptow (justin.treptow@nasa.gov)
- Carbon capture and utilization: James Broyan (james.l.broyan@nasa.gov)
- Harnessing data for improved visualization: Lawrence Friedl (SMD) (lfriedl@nasa.gov)

Applicants are strongly encouraged to familiarize themselves with the 2020 NASA Technology Taxonomy (replaced the 2015 NASA Technology Roadmaps) and the NASA Strategic Technology Integration Framework (https://techport.nasa.gov/framework) that most closely aligns with their space technology interests. The 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. Specifically, STMD supports research from universities through a number of other solicitations from early stage programs such as NASA Innovations Advanced Concepts, Space Technology Research Grants, and Small Business Technology Transfer. Additionally, here's a link to other STMD program opportunities that potentially could benefit from university research ideas.

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, Kurt Kloesel, AFRC-520)
- 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 public 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

- Astronomy and Fundamental Physics
  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

- In-Space Propulsion Technologies
  Chemical propulsion
  Non-chemical propulsion
  Advanced propulsion technologies
  Supporting technologies
  Thermal Electric Propulsion
  Electric Propulsion

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

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

- Communication and Navigation
  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: Linda Ham, linda.j.ham@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

Power Distribution and Control
- Lightweight, radiation tolerant cables and spools for Lunar/Mars surface power
- Dust tolerant electrical connectors
- Radiation hard power convertors.

Energy Storage technologies
- Batteries, Regenerative Fuel cells
- High energy, long-life fuel cell membranes

In-Situ Resource Utilization
- Lunar/Mars regolith processing and water-ice mining (Regolith collection, delivery, regolith processing, and drying; Water separation and capture, water cleanup ~~collection~~ and processing, water electrolysis)
- Mars atmosphere processing (CO2 collection; Dust filtering; Solid Oxide CO2 electrolysis; Sabatier; Reverse water gas shift)
- Methane/Oxygen liquefaction and storage
- ISRU regolith processing simulation and modeling

In-space propulsion technologies
- Human rated in-space propulsion systems (storable and cryogenic)
- EVA-IVA compatible miniature propulsion systems (including CubeSat)
- Propellant transfer and refueling
- Propellant gauging

Pyrotechnic device development and test
- Miniature pyrovalves
- Low energy, long duration pyrotechnic devices

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
- Environment's 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
- Radiation robust 3GPP network technologies
- 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

Linda Ham
Exploration Integration and Science Directorate
NASA Johnson Space Center
https://eto.jsc.nasa.gov/

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: Neyda Abreu, neyda.m.abreu@nasa.gov

Topic 1: Intelligent Flight Systems & Trusted Autonomy: (POC: "Mike" Fremaux - c.m.fremaux@nasa.gov)
Research in areas of advanced air mobility, increasingly automated and autonomous systems, robotics, and "smart cities" to enable current and future NASA missions and maintain U.S. aerospace preeminence. Development and validation of new architectures, technologies, and operations for increasingly complex and increasingly autonomous aerospace systems is accomplished by:

- Enabling robust control, vehicle performance, and mission management under nominal and off-nominal conditions
- Ensuring robust and flexible human-machine integration and teaming
- Advancing technologies for vehicle and system-autonomy, robotics, and flight vehicle environment awareness
- Developing new methods and tools for the verification, validation, and safety assurance of complex and autonomous systems
- Developing, maintaining, and utilizing experimental ground and flight test facilities and labs

Topic 2: Advanced Materials, Manufacturing Technologies & Structural Systems: (POC: Chris Wohl - c.j.wohl@nasa.gov)

- Rapid, scalable additive manufacturing
- Materials for extreme environments
- Materials manufacturing and characterization in extreme environments
- Computational modeling of the manufacturing process influence on metallic microscale and bulk properties
- Computational modeling of polymer synthesis, processing, and additive manufacturing
- Multifunctional materials supporting electric aircraft
- Composite materials supporting green aviation
- Process monitoring during composites fabrication
- Materials systems supporting Human Landing System (HLS) and Environmental Control and Life Support System (ECLSS) objectives

Topic 3: Measurement Systems - Advanced Sensors and Optical Diagnostics (POC: "Tony" Humphreys - william.m.humphreys@nasa.gov)

- Detectors and focal planes for Low Earth Orbit observing platforms
- Electronics for both flight platforms and ground test facilities
- Optical components including adaptive optics based on phase change materials
- Microwave, millimeter, and sub-millimeter wave detection systems
- Weather sensors for Advanced Air Mobility (AAM) applications

- Custom laser designs (wavelengths, pulse durations, etc.) for remote sensing and ground facility test applications
- Flow visualization methods for high-speed ground test facilities (supersonic to hypersonic)
- High spatial and temporal resolution velocimetry measurements, both seeded and seedless
- Cryogenic and thermal sensors for ground test facilities
- Non-destructive evaluation (NDE) methods for crewed vehicle structural health
- Automated non-destructive evaluation (NDE) methods and systems utilizing machine learning

Topic 4: Entry, Descent & Landing (POC: Ron Merski – n.r.merski@nasa.gov)
- Advanced EDL architecture approaches
- Advanced EDL vehicle concepts – small spacecraft
- EDL systems analysis (empirical performance assessment tools, packaging)
- Aero-assist technologies -- Aerocapture concepts
- Aero maneuvering technologies – trim tabs, morphing, RCS, magneto-hydrodynamics (MHD)
- Decelerator technologies – ballutes, parachutes, supersonic retro-propulsion, hypersonic inflatable aerodecelerators (HIADs)
- High end computing for EDL modeling -- GPUs
- Flight mechanics and GNC methods
- Atmospheric model development
- Computational fluid dynamics methods and modeling
- Rarefied flow computations -- DSMC
- Complex fluid dynamics characterization -- plume surface interaction, supersonic retro-propulsion, RCS
- Unsteady aerodynamics measurement approaches
- Wind tunnel (subsonic, transonic, supersonic, hypersonic) aero and aeroheating instrumentation, flow characterization methods (MDOE), and testing approaches
- Entry systems structures, composites manufacturing and testing methods
- Landing system concepts
- Ultra-precise velocity and ranging methods -- lidar
- Flight test instrumentation and low-cost data acquisition
- Flight data reconstruction
- Uncertainty quantification

Topic 5: Terrestrial and Planetary Atmospheric Sciences: (POC: Allen Larar - allen.m.larar@nasa.gov)
- Measurements of aerosols, water vapor, trace gases, cloud properties, and winds,
- Addressing air quality, chemistry,
- Radiation budget
- Climate change

Topic 6: Innovative Concepts for Earth and Space Science Measurements: (POC: Allen Larar -

allen.m.larar@nasa.gov)

- Advanced active and passive remote sensing and in-situ sensors including LiDAR, radiometers, spectrometers, and interferometers

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.

STMD POC	Technology Area	NASA Email
Danette Allen	Autonomous Systems	danette.allen@nasa.gov
Shaun Azimi	Robotics	shaun.m.azimi@nasa.gov
Jim Broyan	ECLSS[1] Deputy	james.l.broyan@nasa.gov
John Carson	EDL Precision Landing; HPSC[2]	john.m.carson@nasa.gov
Scott Cryan	Rendezvous & Capture	scott.p.cryan@nasa.gov
John Dankanich	In Space Transportation	john.dankanich@nasa.gov
Terry Fong	Autonomous Systems	terry.fong@nasa.gov
Robyn Gatens	ECLSS Lead	robyn.gatens@nasa.gov
Julie Grantier	In Space Transportation	julie.a.grantier@nasa.gov
Mark Hilburger	Structures/Materials	mark.w.hilburger@nasa.gov
Michael Johansen	Dust Mitigation	michael.r.johansen@nasa.gov
Julie Kleinhenz	In Situ Resource Utilization	julie.e.kleinhenz@nasa.gov
Angela Krenn	Thermal Technologies	angela.g.krenn@nasa.gov
Ron Litchford	Propulsion Systems	ron.litchford@nasa.gov
Jason Mitchell	Communications & Navigation	jason.w.mitchell@nasa.gov
Michelle Munk	Entry, Descent and Landing (EDL)	michelle.m.munk@nasa.gov
Bo Naasz	Rendezvous & Capture	bo.j.naasz@nasa.gov
Denise Podolski	Sensors/Radiation/Comm.	denise.a.podolski@nasa.gov
Wes Powell	Avionics/Communications	wesley.a.powell@nasa.gov
Jerry Sanders	In Situ Resource Utilization	gerald.b.sanders@nasa.gov
John Scott	Space Power & Energy Storage	john.h.scott@nasa.gov
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.

Appendix B: NASA Strategic Approach

B.1 NASA Strategic Plan

The NASA 2018 Strategic Plan focuses on the development of science, technology, engineering, and mathematics (STEM) disciplines along with the engagement of academic institutions and students in accomplishing the vision and mission of NASA. NASA contributes to national efforts for achieving excellence in STEM education through a comprehensive education portfolio implemented by the Office of STEM Engagement, the Mission Directorates, and the NASA Centers. NASA will continue the Agency's tradition of investing in the Nation's education programs and supporting the country's educators who play a key role in preparing, inspiring, exciting, encouraging, and nurturing the young minds of today that will manage and lead the Nation's laboratories and research centers of tomorrow.

<u>NASA Mission:</u>
Drive advances in science, technology, aeronautics, and space exploration to enhance knowledge, education, innovation, economic vitality, and stewardship of Earth.

<u>NASA Strategic Goals:</u>

1. Expand the frontiers of knowledge, capability, and opportunity in space.
2. Advance understanding of Earth and develop technologies to improve the quality of life on our home planet.
3. Serve the American public and accomplish our Mission by effectively managing our people, technical capabilities, and infrastructure.

<u>NASA Strategic Goals and Objectives Relevant to Education</u>
Objective 1.2: *Conduct research on the International Space Station (ISS) to enable future space exploration, facilitate a commercial space economy, and advance the fundamental biological and physical sciences for the benefit of humanity*.
Objective 2.4: *Advance the Nation's STEM education and workforce pipeline by working collaboratively with other agencies to engage students, teachers, and faculty in NASA's missions and unique assets.*
Objective 3.1: *Attract and advance a highly skilled, competent, and diverse workforce, cultivate an innovative work environment, and provide the facilities, tools, and services.*

B.2 NASA Education Strategic Coordination Framework

NASA will continue the Agency's tradition of investing in the nation's education programs and supporting the country's educators who play a key role in preparing, inspiring, exciting, encouraging, and nurturing the young minds of today who will be the workforce of tomorrow.

<u>NASA will continue to pursue three major education goals</u>:

- Strengthening NASA and the Nation's future workforce
- Attracting and retaining students in science, technology, engineering and mathematics, or STEM, disciplines

- Engaging Americans in NASA's mission. The plan encompasses all education efforts undertaken by NASA and guides the Agency’s relationships with external education partners.

Appendix C: Definitions

- Center – Refers to one of the nine NASA Centers plus the Jet Propulsion Laboratory (JPL). For purposes of collaboration in NASA EPSCoR, JPL is included in the NASA Center category.
- Cooperative Agreement – An award of federal assistance used to carry out a public purpose of support or stimulation authorized by a law. A cooperative agreement is similar to a grant with the exception that NASA and the award recipient are each expected to substantially involved for the performance of the project. Cooperative agreements are managed pursuant to the policies set forth in 2 CFR Part 200, 2 CFR Part 1800, and the NASA Grant and Cooperative Agreement Manual.
- Directorate – One of NASA's Mission Directorates—Aeronautics Research (ARMD), Space Operations (SOMD), Exploration Systems Development (ESDMD), Space Technology (STMD), and Science (SMD).
- Jurisdiction – States or commonwealths eligible to submit proposals in response to this NOFO.
- NASA Research Contact – The NASA Research Contact is the primary NASA point of contact during the proposal writing stage for the proposed research area. If the proposer has contacted and received permission from a NASA scientific or technical person, that individual may be listed in the proposal as the NASA Research Contact. Otherwise the NASA Research Contact is the University Affairs Officer at the Center, or the NASA Mission Directorate contact at NASA Headquarters. (See Appendix D.)
- Partnership – A reciprocal and voluntary relationship between the project personnel and NASA, industry, or other partners, to cooperatively achieve the goals of the proposed research.
- Principal Investigator (PI) – For this EPSCoR NOFO, the Principal Investigator is the jurisdiction's EPSCoR director. The Principal Investigator has an appropriate level of authority and is responsible for proper conduct of the research, including appropriate use of funds and administrative requirements such as the submission of the scientific progress reports to the Agency. The PI is the administrator for the proposal.
    - Science-I – For this NOFO, one Co-I shall be designated as the Science-I for those cases where the person leading the scientific direction of the proposed work is not the PI. The formally stated PI will still be held responsible for the overall direction of the effort and use of funds.
    - Co-Investigator (Co-I) – A Co-I is a member of the proposal's investigation team who is a critical "partner" for the conduct of the investigation through the contribution of unique expertise and/or capabilities.
    - Co-I/Institutional-PI – A Co-I at an organization other than that of the PI's institution, who is making a major contribution to the proposal and serves as the point of contact at the Co-I's institution, may also be designated as the Co-I/Institutional-PI. For this NOFO, the Science-I may also serve as a Co-

I/Institutional-PI. In these cases, the individual shall be identified as the Science- I in the proposal cover page.

- Research area – One of the areas of research interest for the NASA Mission Directorate(s).
- Research Group – A group of researchers that undertakes one of the specific research areas proposed.
- Research Assistant – A student (undergraduate, graduate, or postdoctoral) who receives a research appointment in direct support of the NASA EPSCoR research in the research proposals.
- Technical Monitor – A NASA scientific or technical person designated by the NASA EPSCoR office to monitor the research project.

Appendix D: NASA Points of Contact

D.1 Additional information regarding NASA EPSCoR can be obtained from the following:

Mr. Jeppie R. Compton
Project Manager, NASA EPSCoR Office of STEM Engagement
Bldg. M6-0399, PX-E Kennedy Space Center, FL 32899-0001
Phone: (321) 867-6988
Cell: (321) 360-6443
E-mail: Jeppie.R.Compton@nasa.gov

Dr. Mitch Krell
Deputy Project Manager, NASA EPSCoR, Office of STEM Engagement
Bldg. 1100, Rm 108
Stennis Space Center, MS 39529
Phone: (228) 688-1821
Cell: (228) 342-7462
Email: Mitch.Krell@nasa.gov

D.2 NASA Research Contacts

Technical and scientific questions about research opportunities in this announcement may be directed to the appropriate contact below. Discussions of research with appropriate NASA Center or JPL personnel are strongly encouraged.

D. 3 NASA Mission Directorate Liaisons

NASA Mission Directorate Contacts **Aeronautics Research Mission Directorate** *Dave Berger* OSTEM Embed for Aeronautics P: 661.276.5712 M**:** 661.810.8429 E: dave.e.berger@nasa.gov	**Science Mission Directorate** *Kristen Erickson* Director, Science Engagement & Partnerships NASA Headquarters P: (202) 358-1017 E: kristen.erickson@nasa.gov
Exploration Systems Development Mission Directorate *Greg Chavers* DAA for HEO System Engineering & Integration NASA Headquarters P: (256) 544-0494 E: greg.chavers@nasa.gov	**Space Technology Mission Directorate** *Damian Taylor* SBIR and STTR Mission Directorate Liaison NASA Headquarters P: (202) 358-1432 E: damian.taylor@nasa.gov

Space Operations Mission Directorate *Marc Timm* Program Executive NASA HQ/Rm 7A77 Email: marc.g.timm@nasa.gov P: (202) 358-0373 M: (202)372-5931	

D.4 NASA Center Liaisons

Johnson Space Center *Nick Skytland* Office of Chief Technologist P: (281) 792-7792 M: (832) 388-4226 E: nicholas.g.skytland@nasa.gov	**Stennis Space Center** *Ramona Pelletier Travis* Office of Chief Technologist P: (228) 688-3832 M: (228) 342-5295 E: ramona.e.travis@nasa.gov
Ames Research Center *Harry Partridge* Office of Chief Technologist P: (650) 604-5236 E: harry.partridge@nasa.gov	**Glenn Research Center** *Kurt Sacksteder* Office of Chief Technologist P: (216) 849-8549 M: (216) 849-8549 E: **kurt.sacksteder@nasa.gov** *Mark David Kankam* Technical Resources Management Office P: (216) 433-6143 M: (216) 308-0619 E: **Mark.D.Kankam@nasa.gov**
Armstrong Flight Research Center *Timothy Risch* Associate Director for Research P: (661) 276-6720 M: (661) 857-3721 E: timothy.k.risch@nasa.gov	**Langley Research Center** *Neyda Abreu* Science Technology Utilization & Communication (LARC-A) P: (757) 864-4319 E: neyda.m.abreu@nasa.gov
Goddard Space Flight Center *Heather Bradshaw* Office of Chief Technologist P: (301) 286-4913 E: gsfc-chief-technologist@mail.nasa.gov *James Harrington* Computer Research & Development P: (301) 286-4063 M: (301) 806-2382 E: james.l.harrington@nasa.gov	**Kennedy Space Center** *Delvin van Norman* Technology Transfer Program P: (321) 867-6927 E: delvin.vannorman@nasa.gov *Jose Nunez* Engineering Project Management Office P: (321) 867-5922 M: (321) 289-2479 E: jose.l.nunez@nasa.gov
Jet Propulsion Laboratory *Fred Y. Hadaegh* Office of Chief Technologist Senior Research Scientist and Technical Fellow P: (818) 354-8777 E: fred.y.hadaegh@jpl.nasa.gov	**Marshall Space Flight Center** *John Dankanich* Office of Chief Technologist In-Space Transportation Capability Lead (SCLT) P: (256) 544-3441 M: (256) 425-405 E: john.dankanich@nasa.gov

Appendix E: Proposal and Submission Information

E.1 Proposal Instructions and Requirements

All information needed to respond to this solicitation is contained in this Notice of Funding Opportunity (NOFO) and in the companion *NASA Guidebook for Proposers* located at https://www.nasa.gov/sites/default/files/atoms/files/nasa_guidebook_for_proposers-feb_2022_tagged.pdf

Proposers are responsible for understanding and complying with the *NASA Guidebook for Proposers*' procedures for the successful, timely preparation and submission of their proposals. Proposals that do not conform to its standards may be declared noncompliant and rejected without review.

The introductory material, as well as the appendices, of the *NASA Guidebook for Proposers* provide additional information about the entire NOFO process, including NASA policies for the solicitation of proposals, guidelines for writing complete and effective proposals, and NASA's general policies and procedures for the review and selection of proposals and for issuing and managing the awards to the institutions that submitted selected proposals.

E.2 Content and Form of the Proposal Submission

- Electronic Proposal Submission

  All proposals submitted in response to this NOFO must be submitted in a fully electronic form. **No hard copy proposals will be accepted.** Electronic proposals shall be submitted by the authorized organization representative (AOR) at the proposal Principal Investigator's (PI) institution. Electronic submission by the AOR serves as the required original signature by an authorized official of the proposing institution.

  Proposers shall submit proposals in response to this NOFO via electronic proposal submission through NSPIRES, located at http://nspires.nasaprs.com (see below). NASA plans to use the NSPIRES system to facilitate the review process.

  Carefully note the following requirements for submission of an electronic proposal via NSPIRES:

  - Every institution intending to submit a proposal to NASA in response to this NOFO shall be registered in NSPIRES. Registration for the proposal data system shall be performed by an institution's electronic business point-of-contact (EBPOC) having a valid registration with the System for Award Management (SAM) [formerly known as the Central Contractor Registry (CCR)].
  - Any institution requesting NASA funds through the proposed investigation shall be listed on the Proposal Cover Page. NASA will not fund institutions that are not included on the Proposal Cover Page.
  - Each individual team member named on the proposal's electronic cover page shall be individually registered in NSPIRES.

- Each individual team member named on the proposal's electronic cover page shall specify an institutional affiliation. The institutional affiliation specified shall be the institution through which the team member is participating in the proposed investigation. If the individual has multiple affiliations, then this institution may be different from the individual's primary employer or preferred mailing address.

  Generally, an electronic proposal consists of one or more electronic forms, including an electronic cover page and one or more attachments. The attachments contain all sections of the proposal, including the project description as well as all required and allowed appendices; see the "Proposal Format and Contents" section below for further requirements.

Submission of electronic proposals via NSPIRES requires several coordinated actions from the proposing institution. In particular, when the PI has completed entry of the data requested in the required electronic forms and attachment of the allowed PDF attachments, including the project description section, an official at the PI's institution who is authorized to make such a submission, referred to as the AOR, shall submit the electronic proposal (forms plus attachments). Coordination between the PI and his/her AOR on the final editing and submission of the proposal materials is facilitated through their accounts in NSPIRES. Note that if one individual is acting in both the PI and AOR roles, he/she shall ensure that all steps in the process are taken, including submitting the institution's proposal.

- Proposal Format and Contents

  All proposals submitted in response to this NOFO shall include the appropriate required electronic forms available through NSPIRES.

  The project description and other required sections of the proposal shall be submitted as *SEARCHABLE*, unlocked PDF files that are attached to the electronic submission in NSPIRES. Proposers shall comply with any format requirements specified in this NOFO and in the *NASA Guidebook for Proposers*, Section 3. Only appendices/attachments that are specifically requested in either this NOFO or in the NASA *Guidebook for Proposers* for Proposers will be permitted; proposals containing additional appendices/attachments may be declared noncompliant. The *NASA Guidebook for Proposers*, Section 3, provides detailed guidelines on the content of proposals applicable to this NOFO. Additionally, this NOFO's Section 7.0. on Proposal Preparation provides a listing of required content elements.

  In the event the information in this NOFO is different from or contradicts the information in the *NASA Guidebook for Proposers*, the information in this NOFO takes precedence.

  <u>Important note on creating PDF files for upload</u>: It is essential that all PDF files generated and submitted meet the NASA requirements below. This will ensure that the submitted files can be transferred into NSPIRES. At a minimum, it is the proposer's responsibility to: (1) ensure that all PDF files are unlocked and that edit permission is enabled – this is necessary to allow NSPIRES to concatenate submitted files into a single PDF document; and (2) ensure that all fonts are embedded in the PDF file and that only Type 1 or

TrueType fonts are used. In addition, any proposer who creates files using TeX or LaTeX is required to first create a DVI file and then convert the DVI file to Postscript and then to PDF. See http://nspires.nasaprs.com/tutorials/PDF_Guidelines.pdf for more information on creating PDF documents that are compliant with NSPIRES. PDF files that do not meet the NASA requirements may be declared noncompliant and not submitted to peer review for evaluation.

- Additional Requirement for Budget Format

In addition to the budget summary information provided in NSPIRES:

Cover Page forms: all proposers shall include more detailed budgets and budget justifications, including detailed subcontract/subaward budgets, in a format of their own choosing in the *Budget Justification*. For this NOFO, this additional budget must be divided into two parts, the "*Budget Justification: Narrative*" and the "*Budget Justification: Details*," both as described in the *NASA Guidebook for Proposers,* Section 3.18.

The *Budget Justification: Narrative* includes the *Table of Proposed Work Effort* and the description of facilities and equipment, as well as the rationale and basis of estimate for all components of cost including procurements, travel (destination, purpose and number of travelers), publication costs, and all subawards/subcontracts. The *Table of Proposed Work Effort* shall include the names and/or titles of all personnel (including postdoctoral fellows and graduate students, where known) necessary to perform the proposed investigation, regardless of whether these individuals require funding from the current proposal. The number of person-months each person is expected to devote to the project must be given for each year.

The *Budget Justification: Details* shall include the detailed proposed budget including all of the Other Direct Costs, Total Cost Share/Match and Other Applicable Costs specified in the *NASA Guidebook for Proposers*.

A proposer's failure to provide sufficient budget justification and data in the *Budget Justification: Narrative* (including the *Table of Proposed Work Effort*) and the *Budget Justification: Details* will prevent the peer review from appropriately evaluating the cost realism of the proposed effort. A finding by the peer review of "insufficient information to properly evaluate cost realism" shall be considered a proposal weakness. Inconsistent information between these budget descriptions and the proposal text shall also be considered a proposal weakness.

- Submission of Proposals via NSPIRES, the NASA Proposal Data System

In order to submit a proposal via NSPIRES, this NOFO requires that the proposer register key data concerning the intended submission with NSPIRES; NSPIRES is accessed at http://nspires.nasaprs.com. Potential applicants are strongly urged to access this site well in advance of the proposal due date(s) of interest to familiarize themselves with its structure and enter the requested identifier information.

It is especially important to note that every individual named on the proposal's electronic *Cover Page* form (see below) as a proposing team member in any role, including Co-Investigators (Co-I's), shall be registered in NSPIRES and that such individuals shall perform this registration themselves; no one may register a second party, even the Principal Investigator of a proposal in which that person is committed to participate. This data site is secure and all information entered is strictly for NASA's use only.

All proposals submitted via NSPIRES in response to this NOFO shall include a required electronic *Cover Page* form that is accessed at http://nspires.nasaprs.com. This form comprises several distinct sections: a *Cover Page* that contains the identifier information for the proposing institution and personnel; a *Proposal Summary* that provides an overview of the proposed investigation that is suitable for release through a publicly accessible archive if the proposal is selected; and a *Budget Summary* of the proposed research effort. Unless specified in the program description itself, no other forms are required for proposal submission via NSPIRES. See the *NASA Guidebook for Proposers* for further details.

The required elements of the proposal, including the project description, shall be submitted as one PDF document that is attached to the *Cover Page* using the tools in NSPIRES. The complete proposal is submitted as a single, *SEARCHABLE*, unlocked PDF document that contains the complete proposal, including the project description section and budget justification, assembled in the order provided in this NOFO and uploaded using the tools in NSPIRES. One advantage of submitting the proposal as one PDF document is that it is easy to upload.

NSPIRES will provide a list of all elements that make up an electronic proposal, and the system will conduct an element check to identify any item(s) that is (are) apparently missing or incomplete. The element check may produce warnings and/or identify errors. Uploading the proposal in one PDF file is likely to create warnings as part of the element check. Please ignore these warnings since such warnings do not prevent proposal submission.

Proposers are encouraged to begin their submission process early. Tutorials and other NSPIRES help topics may be accessed through the NSPIRES online help site at http://nspires.nasaprs.com/external/help.do. For any questions that cannot be resolved with the available on-line help menus, requests for assistance may be directed by e-mail to nspires- help@nasaprs.com or by telephone to (202) 479-9376, Monday through Friday (except Federal holidays), 8:00 a.m. – 6:00 p.m. Eastern Time.

E.3 Notice of Intent to Propose

A brief Notice of Intent (NOI) to propose is suggested for the submission of proposals to this NOFO. The information contained in an NOI is used for planning purposes and to help expedite the proposal review activities and, therefore, is of considerable value to both NASA and the proposer. NOIs shall be submitted by the jurisdiction NASA EPSCoR Director through NSPIRES (http://nspires.nasaprs.com). Grants.gov does not support NOI submittal. Note that NOIs may be submitted within NSPIRES directly by the proposal's PI; no action by an organization's AOR is required to submit an NOI. The NOI, at a minimum, shall include a clear descriptive title and/or a scientific/technical summary of the anticipated research. The NOI shall:

- Identify the Mission Directorate(s)/Centers with which the proposal will be aligned (if known)

- Identify the areas of expertise required for the research
- Identify the Science-I

E.4 Certifications, Assurances, and Representations

The AOR's signature on the Proposal Cover Page automatically certifies that the proposing organization has read and is in compliance with all certifications, assurances, and representations as detailed in NASA Grant and Cooperative Agreement Manual (GCAM).

Appendix F: Useful Web Sites

- NASA http://www.nasa.gov
- NASA Office of STEM Engagement http://stem.nasa.gov
- NASA EPSCoR https://www.nasa.gov/stem/epscor/home/index.html
- Vision for Space Exploration https://www.nasa.gov/pdf/55583main_vision_space_exploration2.pdf
- NASA Centers & Facilities https://www.nasa.gov/about/sites/index.html
- Guidebook for Proposers Responding to a NASA Research Announcement https://www.nasa.gov/sites/default/files/atoms/files/nasa_guidebook_for_proposers-feb_2022_tagged.pdf
- NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES) http://nspires.nasaprs.com
- NASA Grants and Cooperative Agreement Manual (GCAM) https://www.nasa.gov/sites/default/files/atoms/files/grant_and_cooperative_agreement_manual_-_jan_2022.pdf.
- NPR 5810.1A, Standard Format for NASA Research Announcement and Other Announcements for Grants and Cooperative Agreements https://nodis3.gsfc.nasa.gov/npg_img/N_PR_5810_001A_/N_PR_5810_001A_.pdf
- Electronic Code of Federal Regulations (2 CFR 200, 2 CFR 1800) https://ecfr.federalregister.gov/current/title-2
- NASA EPSCoR Director's Contact Information https://www.nasa.gov/stem/epscor/home/EPSCoR_Directors.html

Appendix G: Research Interests from the Rapid Response Research (R3) solicitation

Research Focus Areas

Aeronautic Research Mission Directorate / Advanced Air Vehicles Program / Revolutionary Vertical Lift Technology Project

Aeronautic Research Mission Directorate
NASA Glenn Research Center

POC: Timothy Krantz, timothy.l.krantz@nasa.gov

Research Focus Area: Safety of Electro-mechanical Powertrains for Electrified Vertical Takeoff and Landing (eVTOL) Vehicles
Research Identifier: **A-001**

Research Focus Area: **H**igh power density power grids, power electronics, motors, and electro-mechanical powertrains
Research Identifier: **A-002**

Research Focus Area: High reliability and robustness for safety-critical propulsion systems including but not limited to a) arc fault protection; b) EMI/filtering; c) fault tolerant architectures; d) power management.
Research Identifier: **A-003**

Research Focus Area: Novel thermal management of the propulsion components and/or of the propulsion system.
Research Identifier: **A-004**

Research Focus Area: Application of advanced materials and manufacturing to achieve above
Research Identifier: **A-005**

Research Overview:

With their unique ability to take off and land from any spot, as well as hover in place, vertical lift vehicles are increasingly being contemplated for use in new ways that go far beyond those considered when thinking of traditional helicopters. NASA's Revolutionary Vertical Lift Technology (RVLT) project is working with partners in government, industry, and academia to develop critical technologies that enable revolutionary new air travel options, especially those associated with Advanced Air Mobility (AAM) such as large cargo-carrying vehicles and passenger-carrying air taxis.

These new markets are forecast to rapidly grow during the next ten years, and the vertical lift industry's ability to safely develop and certify innovative new technologies, lower operating costs, and meet acceptable community noise standards will be critical in opening these new markets.

NASA is conducting research and investigations in Advanced Air Mobility (AAM) aircraft and operations. AAM missions are characterized by ranges below 300 nm, including rural and urban operations, passenger carrying as well as cargo delivery. Such vehicles will require increased automation and innovative propulsion systems, likely electric or hybrid-electric that may need advanced electro-mechanical powertrain technology.

Research Focus: Analytical and/or experimental fundamental research is sought for power grids and electro–mechanical powertrains for electrified vertical takeoff and landing (eVTOL) vehicles. The focus is safety, and overall goals are to obtain high power-to-weight with long life and higher reliability than the current state of the art. The scope of interest includes high-voltage (>540 V) bus and high-voltage DC protection devices, electric motors and associated power electronics, and mechanical or magnetically-geared powertrains and the associated sub-components and materials technologies. Research topics of particular interest are those that focus on:

1) high power density power grids, power electronics, motors, and electro-mechanical powertrains.
2) high reliability and robustness for safety-critical propulsion systems including but not limited to a) arc fault protection; b) EMI/filtering; c) fault tolerant architectures; d) power management.
3) novel thermal management of the propulsion components and/or of the propulsion system.
4) application of advanced materials and manufacturing to achieve items 1), 2) or 3).

The target application is eVTOL vehicles sized to carry four to six passengers with missions as described in References 1-6.

Reference 7 discusses Urban Air Mobility Electric Motor Winding Insulation Reliability Challenges.

This research opportunity is relevant to aerospace propulsion and is of mutual interest to NASA, FAA, DoD, and the US vertical lift vehicle industry.

References:

1) Silva, C.; Johnson, W.; and Solis, E. "Multidisciplinary Conceptual Design for Reduced-Emission Rotorcraft." American Helicopter Society Technical Conference on Aeromechanics Design for Transformative Vertical Flight, San Francisco, CA, January 2018.
2) Johnson, W.; Silva, C.; and Solis, E. "Concept Vehicles for VTOL Air Taxi Operations." American Helicopter Society Technical Conference on Aeromechanics Design for Transformative Vertical Flight, San Francisco, CA, January 2018.
3) Patterson, M.D.; Antcliff, K.R.; and Kohlman, L.W. "A Proposed Approach to Studying Urban Air Mobility Missions Including an Initial Exploration of Mission Requirements." American Helicopter Society 74th Annual Forum, Phoenix, AZ, May 2018.
4) Silva, C.; Johnson, W.; Antcliff, K.R.; and Patterson, M.D. "VTOL Urban Air Mobility Concept Vehicles for Technology Development." AIAA Paper No. 2018-3847, June 2018.
5) Antcliff, K. Whiteside, S., Silva, C. and Kohlman, L. "Baseline Assumptions and Future Research Areas for Urban Air Mobility Vehicles," AIAA Paper No. 2019-0528, January 2019.
6) Silva, C., and Johnson, W. "Practical Conceptual Design of Quieter Urban VTOL Aircraft." Vertical Flight Society 77th Annual Forum, May 2021.
7) Tallerico, T., Salem, J., Krantz, T. and Valco, M., "Urban Air Mobility Electric Motor Winding Insulation Reliability: Challenges in the Design and Qualification of High Reliability Electric Motors and NASA's Research Plan." NASA TM-20220004926, 2022.

Intellectual Property Rights: All data and analysis methods will be publicly available and no intellectual property rights will be assigned to any of the parties involved in this research.

Research Focus Area:	Development of Characterization Techniques to Determine Key Composite Material Properties for the LS-DYNA MAT213 Model
Research Identifier**:**	**A-006**
POC:	Robert Goldberg robert.goldberg@nasa.gov

Justin Littell justin.d.littell@nasa.gov
Mike Pereira mike.pereira@nasa.gov

Research Overview: Overview of MAT213 - MAT213 is an orthotropic macroscopic three-dimensional material model designed to simulate the impact response of composites which has been implemented in the commercial transient dynamic finite element code LS-DYNA [1-5]. The material model is a combined plasticity, damage and failure model suitable for use with both solid and shell elements. The deformation/plasticity portion of the model utilizes an orthotropic yield function and flow rule. A key feature of the material model is that the evolution of the deformation response is computed based on input tabulated stress-strain curves in the various coordinate directions.
The damage model employs a semi-coupled formulation in which applied plastic strains in one coordinate direction are assumed to lead to stiffness reductions in multiple coordinate directions. The evolution of the damage is also based on tabulated input from a series of load-unload tests. A tabulated failure model has also been implemented in which a failure surface is represented by tabulated single valued functions. While not explicitly part of MAT213, when using the model, interlaminar failure is modeled using either tie-break contacts or cohesive elements.

There are several key material parameters required for input to the MAT 213 material model that are challenging to obtain via traditional coupon level testing techniques. Specifically, due to the fact that the plasticity flow law in the deformation portion of the material model is not coupled to the yield function, determining the coefficients required for the flow rule function requires the measurement of complex parameters such as the plastic Poisson's ratio. Developing a more straightforward and reproduceable approach to determining these flow rule coefficients would significantly improve the usability of the material model. Furthermore, to appropriate capture the full response of a composite under dynamic loading conditions, the ability to account for stress degradation after peak loading conditions are reached is required. Currently, however, the parameters required to characterize this post-peak stress degradation response are determined based on correlation with structural level impact and/or crush tests. Research is required to develop a methodology to characterize this stress-degradation response based on lower scale experiments such as coupon level tests.

For this task we are focused on developing techniques and recommended approaches to characterize the material parameters described above using tests at the coupon scale or similar fundamental types of tests. To carry out this task, we are interested in having a composite material or materials that will defined and supplied by NASA tested. The focus of the effort is to develop test methods and conduct detailed tests to characterize the flow rule coefficients and the post-peak stress degradation response. Fundamental characterization data obtained from standard tension, compression and shear tests should be available for the chosen material. The primary focus of this task will be to characterize the material to a sufficient degree to allow for simulations of the material to be conducted using shell elements.

Required Tests

Specific tests will have to be developed and carried out to appropriately characterize the flow rule coefficients and the post-peak stress degradation response. However, it is expected that the following standard set of tests could provide a baseline from which the needed parameters can be determined. For the shell element version of MAT213, at a minimum, seven fundamental tests are required to appropriately characterize the material response. The loading directions are as follows:

a. Tension in the 1-direction

b. Compression in the 1-direction

c. Tension in the 2-direction

d. Compression in the 2-direction

e. Shear in the 12-direction

f. Shear in the 21-direction

g. 45 degree off axis tension

While some or all of the tests listed above could form the basis of determining the flow rule coefficients and the post-peak stress degradation response, it is acknowledged that additional tests to be determined over the course of the research will likely be required to characterize the specified parameters.

Test Requirements

i. Test coupons will be machined by the grant recipient from flat panels supplied by NASA.
ii. For all tests the tabulated full stress-strain curve, all the way to failure, must be recorded and supplied in electronic tabular format. Raw data such as loads must also be supplied.
iii. All specimens must be measured and weighed prior to testing
iv. Testing is to be conducted at nominal room temperature conditions
v. The test environmental conditions must be recorded and documented
vi. A minimum of three repeats for each loading condition must be conducted
vii. Full Field Digital Image Correlation (DIC) must be used to measure deformations and strains
viii. The tests should be based on ASTM Standard Test Methods if possible, but it is acknowledged that modifications to the standard methods may be required to obtain the specific data required to characterize the flow rule coefficients and the post-peak stress degradation response.
ix. Testing at different strain rates is encouraged but not required

Deliverables

b. Full tabulated stress strain data to failure supplied in electronic tabular format
c. All DIC images and associated calibration files
d. A proposed approach to characterize the plasticity flow rule coefficients based on coupon or similar low scale test data.
e. A proposed approach to characterize the post-peak stress degradation based on coupon level or similar low scale test data

References:

1. Khaled, B., Shyamsunder, L., Schmidt, N. Hoffarth, C. and Rajan, S., "Development of a Tabulated Material Model for Composite Material Failure, MAT213. Part 2: Experimental Tests to Characterize the Behavior and Properties of T800-F3900 Toray Composite", DOT/FAA/TC-19/51, Nov. 2018
2. T. Achstetter, "Development of a composite material shell-element model for impact applications", *PhD Dissertation,* George Mason University, 2019
3. Goldberg, R.K.; Carney, K.S.; DuBois, P.; Hoffarth, C.; Harrington, J; Rajan, S.; and Blankenhorn, G.: "Development of an Orthotropic Elasto-Plastic Generalized Composite Material Model Suitable for Impact Problems", *Journal of Aerospace Engineering*, Vol. 29, no. 4, 04015083, 2016.
4. Goldberg, R.K.; Carney, K.S.; DuBois, P.; Hoffarth, C.; Khaled, B.; Rajan, S.; and Blankenhorn, G.: "Analysis and Characterization of Damage Utilizing a Generalized Composite Material Model Suitable for Impact

Problems", *Journal of Aerospace Engineering*, Volume 31, Issue 4, 10.1061/(ASCE)AS.1943-5525.0000854, 04018025, 2018.
5. Goldberg, R.K.; Carney, K.S.; DuBois, P.; Hoffarth, C.; Khaled, B.; Shyamsunder, L.; Rajan, S.; and Blankenhorn, G.: "Implementation of a tabulated failure model into a generalized composite material model", *Journal of Composite Materials*, Vol. 52, Issue 25, pp. 3445-3460.

Intellectual Property Rights: All data and analysis methods will be publicly available and no intellectual property rights will be assigned to any of the parties involved in this research.

Astrophysics

Research Focus Area: Astrophysics Technology Development
Research Identifier**:** **A-007**

POCs: Dr. Hashima Hasan, hhasan@nasa.gov, (202) 358-0692
Dr. Mario Perez, mario.perez@nasa.gov, 202.358.1535

TECHNOLOGY:
- Astrophysics Technology Development: https://apd440.gsfc.nasa.gov/technology.html
- Technology Highlights: https://science.nasa.gov/technology/technology-highlights?topic=11
- Astrophysics Technology Database: http://www.astrostrategictech.us/

ASTROPHYSICS DATA CENTERS:
- https://science.nasa.gov/astrophysics/astrophysics-data-centers

DOCUMENTS:
- strophysics Documents: https://science.nasa.gov/astrophysics/documents

DECADAL SURVEY 2020:
- Decadal Survey on Astronomy and Astrophysics 2020 (Astro 2020): https://www.nationalacademies.org/our-work/decadal-survey-on-astronomy-and-astrophysics-2020-astro2020

CITIZEN SCIENCE PROJECTS:
- Current projects: https://science.nasa.gov/citizenscience

RESEARCH SOLICITATIONS:
- Omnibus NASA Research Announcement (NRA): https://science.nasa.gov/researchers/sara/grant-solicitations/roses-2021/schedule-research-opportunities-space-and-earth-sciences-roses-2021

NASA Biological and Physical Sciences (BPS)

NASA Headquarters Biological and Physical Sciences Division

Research Focus Area: Fundamental Physics - Quantum Science
Research Identifier**:** **B-001**

POC: Brad Carpenter bcarpenter@nasa.gov (202) 358-0826

Research Overview: Quantum mechanics is one of the most successful theories in physics. It describes the very small, such as atoms and their formation into the complex molecules necessary for life, to structures as large as cosmic strings. The behavior of exotic matter such as superfluids and neutron stars is explained by quantum mechanics, as are everyday phenomena such as the transmission of electricity and heat by metals.

The frontline of modern quantum science involves cross-cutting fundamental and applied research. For example, world-wide efforts concentrate on harnessing quantum coherence and entanglement for applications such as the enhanced sensing of electromagnetic fields, secure communications, and the exponential speed-up of quantum computing. This area is tightly coupled to research on the foundations of quantum mechanics, which involves exotica such as many-worlds theory and the interface between classical and quantum behavior. Another frontier encompasses understanding how novel quantum matter—such as high-temperature superconductivity and topological states—emerges from the interactions between many quantum particles. Quantum science is also central to the field of precision measurement, which seeks to expand our knowledge of the underlying principles and symmetries of the universe by testing ideas such as the equivalence between gravitational and inertial mass.

Research Focus: Quantum physics is a cornerstone of our understanding of the universe. The importance of quantum mechanics is extraordinarily wide ranging, from explaining emergent phenomena such as superconductivity, to underpinning next-generation technologies such as quantum computers, quantum communication networks, and sensor technologies. Laser-cooled cold atoms are a versatile platform for quantum physics on Earth, and one that can greatly benefit from space-based research. The virtual elimination of gravity in the reference frame of a free-flying space vehicle enables cold atom experiments to achieve longer observation times and colder temperatures than are possible on Earth. The NASA Fundamental Physics program plans to support research in quantum physics that will lead to transformational outcomes, such as the discovery of phenomena at the intersection of quantum mechanics and general relativity that inform a unified theory, the direct detection of dark matter via atom inte **ion Sciences** rferometry or atomic clocks, and the creation of exotic quantum matter than cannot exist on Earth. Proposals are sought for ground-based theory and experimental research that may help to develop concepts for future flight experiments. Research in field effects in quantum superposition and entanglement are of particular interest.
Additional information on BPS can be found at: https://science.nasa.gov/biological-physical

NASA Biological and Physical Sciences (BPS)

NASA Headquarters Biological and Physical Sciences Division

Research Focus Area: Complex Fluids/Soft Matter - Soft Matter-Based Materials
Research Identifier: **B-002**

POC: Brad Carpenter bcarpenter@nasa.gov (202) 358-0826

Research Overview: Soft matter research examines materials with properties governed by relatively weak (compared to atomic bonds) interactions between the constituent particles. Classic soft matter systems include colloids, granular materials, polymers, and liquid crystals. Newer developments in soft matter physics include studies of cooperativity and self-assembly in non-equilibrium systems.

Research Focus: The focus of soft matter research in the Biological and Physical Sciences Division is the development and execution of concepts that use the unique characteristics of the space environment, in this case, near-absence of perceived gravity, to achieve results of transformative significance for science and technology. Research supported by the program must clearly identify how the work is related to past, current, or potential future space experiments.
Additional information on BPS can be found at: https://science.nasa.gov/biological-physical

Additional Information: All publications that result from an awarded EPSCOR study shall acknowledge NASA Biological and Physical Sciences (BPS).

NASA Biological and Physical Sciences (BPS)
NASA Glenn Research Center, Low-Gravity Exploration Technology Branch

Research Focus Area: Fluid Physics - Oscillating Heat Pipes (OHP)
Research Identifier**:** **B-003**

POC: John McQuillen john.b.mcquillen@nasa.gov 216-433-2876

Research Overview: 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.

Research Focus: 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 an 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

All publications that result from an awarded EPSCOR study shall acknowledge NASA Biological and Physical Sciences (BPS).
Additional information on BPS can be found at: https://science.nasa.gov/biological-physical

NASA Biological and Physical Sciences (BPS)
NASA Glenn Research Center

Research Focus Area: Combustion Science - High Pressure Transcritical Combustion (HPTC)
Research Identifier**:** **B-004**

POC: Daniel L. Dietrich Daniel.L.Dietrich@nasa.gov, (216) 433-8759

Research Overview: Fundamental discoveries made by NASA researchers over the last 50 years has helped enable advances in fundamental combustion including low-temperature hydrocarbon oxidation, soot formation and flame stability, to name a few. Two areas of fundamental research that NASA wishes to emphasize in the future are high pressure, transcritical combustion (HPTC) and the combustion of carbon-neutral and/or bio-derived fuels. These topics include transformative research to enable the design of future internal combustion engines that are moving to higher operating pressures (increasing efficiency while simultaneously reducing pollutant emissions) and using more environmental friendly fuels. It also includes novel applications such as supercritical water oxidation (SCWO) for waste incineration.

The microgravity environment provides an ideal experimental backdrop for probing many of the questions raised in high pressure supercritical research and providing fundamental data on renewable, carbon-neutral fuels. Since the buoyant force scales with pressure squared, fundamental combustion studies in terrestrial laboratories are increasingly difficult because of the dominance of the buoyant force. The microgravity environment allows for extended length and/or time scales without the intrusion of a dominant buoyant flow. This in turn enables diagnostic techniques, that otherwise prove intractable in 1-g environments, to obtain transformative insights into supercritical phenomena. Using well designed experiments the aforementioned research topics can successfully be explored in microgravity and will serve to greatly enhance the developmental pace of a number of important technologies for both terrestrial and extraterrestrial application.

Research Focus: This Combustion Science Emphasis requests proposals for hypothesis-driven experiments and/or

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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.

analysis that that will help determine: 1) fundamental phase change and transport processes in the injection of a subcritical fluid into an environment in which it is supercritical; 2) ignition and combustion of hydrocarbons under these conditions; 3) ignition and combustion characteristics of bio-derived or carbon neutral fuels and 4) how to optimize SCWO systems for waste management in extraterrestrial habitats.

Additional Information: Proposers are encouraged to include the use of drop tower facilities in their proposals. For more information about these facilities, they can contact Eric Neumann (eric.s.neumann@nasa.gov ; 216-433-2608). These facilities provide either 2.2 or 5.2 seconds of low-gravity. The possibility exists (and proposals encouraged) that investigators could take advantage of an existing experimental apparatus for the 5.2 second drop tower. Additional information on BPS can be found at: https://science.nasa.gov/biological-physical

All publications that result from an awarded EPSCOR study shall acknowledge NASA Biological and Physical Sciences Division

NASA Biological and Physical Sciences (BPS)
NASA Marshall Space Flight Center (MSFC) / EM41

Research Focus Area: Materials Science - Extraction and Utilization of Materials from Regolith
Research Identifier: **B-005**

POC: Michael SanSoucie michael.p.sansoucie@nasa.gov 256-544-5269

Research Overview: 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 extracted materials could be used as feedstock for additive manufacturing processes to produce outfitting for habitats, to build infrastructure, for example, habitats, roads, walls, and landing pads, or to fabricate tools or other hardware. The water ice from regolith material could be used to augment life support systems for extended stay missions or produce liquid hydrogen and liquid oxygen for propellant production.

Research Focus: The goal of this NASA Physical Sciences Program research emphasis is 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:

a) Refinement of existing techniques to extract materials from regolith.
b) Development of new techniques for extraction of materials from regolith.
c) Studies of the extracted material to determine its properties or to investigate novel ways of utilizing it to support NASA's exploration goals.
d) 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. For example, crushed basalt could potentially be used in lieu of Lunar regolith simulant. Proposals are encouraged to use existing hardware.

More information on NASA's exploration goals can be found in the Decadal Survey (http://www.nap.edu/catalog/13048.html), specifically Translation to Space Exploration Systems (TSES) number 16 (TSES16). Additional information on BPS can be found at: https://science.nasa.gov/biological-physical

Additional Information: All publications that result from an awarded EPSCOR study shall acknowledge NASA Biological and Physical Sciences (BPS).

NASA Biological and Physical Sciences (BPS)
NASA Head Quarters, Space Biology Program

Research Focus Area: Effects of Regolith Simulant on Growth, Survival, and Fitness of Animal Models
Research Identifier**:** **B-006**

POC: Sharmila Bhattacharya SpaceBiology@nasaprs.com

Research Overview: As human exploration prepares to go beyond Earth Orbit, Space Biology is advancing its research priorities towards work that will enable organisms to Thrive In DEep Space (TIDES). These efforts will focus on determining the effects of deep-space stressors, including exposure to regolith, ionizing radiation, and reduced gravity, on multiple organisms. Space Biology-supported animal research will enable the study of the effects of environmental stressors in spaceflight on model animal systems, that will both inform future basic science work, as well as provide valuable information that will better enable human exploration of deep space. The ultimate goal of the TIDES initiative is to enable long-duration space missions and improve life on Earth through innovative research.

While some of the of the stressors associated with spaceflight in Low Earth Orbit, such as microgravity, are also found in deep space, stressors such as increased levels of space radiation and potentially toxic regolith are exclusive to deep space. The focus of this research element, therefore, is to gain a better understanding of how these deep space stressors, specifically regolith, impact the survival and fitness of animal models.

Research Focus: This Space Biology Research Emphasis requests proposals for hypothesis-driven experiments that will determine the effects of regolith (simulant) exposure on invertebrate or vertebrate animal model systems or cellular systems derived from such models. Studies may use lunar or Martian regolith simulant, or both. Proposed studies may be conducted over multiple generations but are not required to do so, and both acute and long/term consequences of regolith exposure will be characterized at the molecular and/or physiological levels.

Proposers can incorporate other deep space stressors into their experimental design if they choose, including the use of simulated micro/partial gravity and/or ionizing radiation, if feasible. While not required, applicants may propose to examine the effect that regolith exposure has on host/microbe interactions. Additional information on BPS can be found at: https://science.nasa.gov/biological-physical

Additional Information: All publications that result from an awarded EPSCOR study shall acknowledge NASA Space Biology Program. If the NASA GeneLab Data Systems (genelab.nasa.gov) is used, GeneLab shall be referenced in the resulting publication and included in the keyword list. All omics data obtained from this study shall be uploaded to the NASA GeneLab (https://genelab.nasa.gov).

NASA Biological and Physical Sciences (BPS)
NASA Head Quarters, Space Biology Program

Research Focus Area: Effects of Space-Associated Stressors on Plant and Microbial Interactions
Research Identifier: **B-007**

POC: Sharmila Bhattacharya SpaceBiology@nasaprs.com

Research Overview: Fundamental discoveries made by NASA researchers over the last 50 years has helped enable successful growth of plants in spacecraft, as is demonstrated through current work being done on the ISS. Despite these advances, additional fundamental plant biology research is still needed. There is still much to learn about how plants respond to the spaceflight environments both in Low Earth Orbit (LEO) and in deep space, and what it will take to support long-duration, multiple generation plant growth and cultivation during extended space exploration missions. To fully support NASA's goals of conducting extended lunar and planetary exploration missions, it will be necessary to utilize the resources found within these environments, including regolith, to grow and cultivate plants.

One area of fundamental research that NASA wishes to focus on is the impact of the spaceflight environment on plant and microbial interactions. While the microbial contamination of plants grown in the closed environment of a spacecraft is always a potential concern, the interactions of these plants with beneficial microbes, may also be altered in the spaceflight-environment. Additionally, the impact of spacecraft-associated stressors on plant/microbial interactions, coupled with the use of regolith as a growth substrate, are topics of major interest to NASA.

The goal of this NASA Space Biology Program research emphasis, therefore, is to build a better understanding of the effects of spaceflight on microbial and plant ecosystems found both on spacecraft such as the ISS, and in deep space environments, which in turn will help us prepare for future exploration missions far from Earth.

Research Focus: This Space Biology Research Emphasis requests proposals for hypothesis-driven experiments that will help determine: 1) the effects of space-associated stressors on plant-microbial interactions; 2) the long-term, multigenerational effects of space-associated stressors on plant-microbial population dynamics; and 3) how to optimize plant-microbial systems for growing and sustaining plants in spacecraft and in deep space, including the lunar and Martian surfaces. Fundamental plant-microbial biology research is needed to specifically identity the driving space environmental factors or combination of factors that impact plant-microbial interactions.

Proposers are encouraged incorporate at least one of the following space-associated stressors in their experimental design: growth in regolith simulant, the use of microgravity analogs that simulate the effects of spaceflight (or partial gravity), and/or exposure to ionizing radiation. Investigators may also characterize the long terms effects of other spaceflight relevant stressors, including increased levels of CO_2 concentrations (e.g., 4000ppm) as experienced in enclosed space habitats etc.

The intention of the Space Biology Program is that awarded projects produce preliminary data for an application to future NASA Life Sciences funding opportunities. Additional information on BPS can be found at: https://science.nasa.gov/biological-physical

Additional Information: All publications that result from an awarded EPSCOR study shall acknowledge NASA

Space Biology Program. If the NASA GeneLab Data Systems (genelab.nasa.gov) is used, GeneLab shall be referenced in the resulting publication and included in the keyword list. All omics data obtained from this study shall be uploaded to the NASA GeneLab (https://genelab.nasa.gov).

Center for Design and Space Architecture

Center for Design and Space Architecture
NASA Johnson Space Center

Missions beyond LEO are challenging for traditional survivability paradigms such as redundancy management, reliability, sparing, orbital replacement, and mission aborts. Distances, transit durations, crew time limitations, onboard expertise, vehicle capabilities, and other factors significantly limit the ability of human spaceflight crews to respond to in-flight anomalies. There is a need for a Repair, Manufacturing, and Fabrication (RMAF) facility to increase the capability of the crew to recover from spacecraft component failures by combing aspects of machine shop, soft goods lab, and repair shop into an IVA capability for both microgravity and surface spacecraft. An RMAF is responsible for restoring damaged components to working order (repair), keeping components in service or properly functioning (maintenance), and creating new components from raw or scavenged materials (fabrication). This responsibility extends not only to the habitat, but to all other elements sharing the same destination environment (e.g., landers, rovers, robots, power systems, science instruments, etc.). The RMAF serves both the physical operability needs of the architectural systems and contributes in two ways to the psychological well-being of the crew: one the peace of mind from understanding the capacity to respond to failures, and two, the capacity to fabricate items that serve recreational or relaxation purposes. The RMAF has potential applicability to a wide variety of in-space habitation needs.

NASA is exploring space architectures that can serve as next steps to build upon the current Artemis program. The Common Habitat Architecture Study is based on a suite of common spacecraft elements that can be used for long-duration human spaceflight in multiple destinations, including the Moon, Mars, and deep space. NASA is seeking engineering and architectural research to aid in the development of an RMAF facility capable of packaging within mid deck of the Common Habitat, a Skylab-like habitat that uses the Space Launch System (SLS) core stage liquid oxygen tank as the primary structure, with a horizontal orientation. Because most habitats intended for use beyond LEO do not return to Earth, yet may operate for decades, it can be assumed that even low probability failures will eventually occur and there must be a way to recover from them and continue the mission. Thus, the Common Habitat must include the RMAF capability. The RMAF speaks to an overarching gap of inability to mitigate spacecraft component failures. Limited in-space experiments have been conducted with 3D printing, welding, soldering, and other RMAF tools, but they have yet to be integrated into an operable spacecraft facility. The RMAF goes beyond the replacement of failed components with spares and focuses on the capabilities to restore failed components to working order, making them effectively the new spare.

Research Focus Area:	Repair, Manufacturing, And Fabrication (RMAF) Facility for the Common Habitat Architecture
Research Identifier:	**C-001**
POC:	Robert Howard robert.l.howard@nasa.gov

Research Focus: Proposed studies will assess the needs of an RMAF system for long-duration, deep space habitation and create one design solution to increase crew and vehicle survivability. Prior research has identified a list of 53 component-level critical failures that could render a subsystem or element inoperable. Fourteen repair, maintenance, and fabrication functions have been identified as collectively being able to recover a system from any of these failures. This establishes the target capability of the RMAF. Proposers will design a workspace within the volume limitations of the Common Habitat, while still accommodating these fourteen functions and will determine the associated mass impacts.

Critical Failures Requiring RMAF Capability

1. Actuator FOD
2. Actuator overpressure
3. Actuator underpressure
4. Adhesive failure
5. Bad wireless connection
6. Belt break
7. Broken cables
8. Broken electrical connection
9. Broken physical structure
10. Bulb burnout
11. Bulb shatter
12. C&W software failure
13. Connector overtorque
14. Connector pin/connection failure
15. Connector under torque
16. Consumable depletion
17. Cracked housing
18. Cracked screen
19. Debris clog
20. Debris impact damage
21. Debris in motor
22. Diaphragm damage (digital)
23. Electrical lead failure
24. Electrical short
25. Fabric erosion
26. Fabric tear
27. Failed electrical connection
28. Fin breakage / bending/ding
29. Fluid line rupture
30. Fuse blown
31. Kinked line
32. Material abrasion / erosion
33. Material corrosion
34. Material delamination
35. Material stretching
36. Motor failure
37. Physical obstruction
38. Potting failure
39. Power surge
40. Pressure bladder puncture, tear, or rip
41. Spring too weak or too stiff
42. Structural bending
43. Structural buckling
44. Structural burst
45. Structural crack/fracture
46. Structural deformation
47. Structural gouge
48. Structural membrane disjoin
49. Structural rupture / puncture
50. Structural seal failure
51. Structural shear
52. Surface chemical contamination
53. Wire detach, split, tear, rip, or break

Generic RMAF Functions to Repair Critical Failures

1. Soldering
2. Drilling
3. Metal cutting and bending
4. Metallurgical analysis
5. Bonding metal, composite, and other surfaces
6. Electronics analysis and repair
7. Computer/Avionics inspection/testing and repair

8. CAD Modeling / Software Coding / Computer Analysis
9. Material Handling (inclusive of the range from large ORUs and small fasteners)
10. Precision Maintenance (manipulation, inspection, repair of small/delicate components)
11. 3D Printing (metal, plastic, and printed circuit board)
12. Soft goods (including thermoplastics, sewing, cutting, and patching)
13. Dust/Particle/Fume Mitigation
14. Welding

A design solution should include a mass equipment list (MEL), CAD model, and Concept of Operations document. CAD models must be in a format capable of being opened by Rhino 7 and must also be suitable for incorporation in Virtual Reality using the Unreal Engine 5. Physical prototyping and iterative human-in-the-loop (HITL) testing are encouraged but are not required.

References:

[1] Howard, Robert, "Opportunities and Challenges of a Common Habitat for Transit and Surface Operations," in 2019 IEEE Aerospace, Big Sky, MT, 2019.
[2] Howard, Robert, "Stowage Assessment of the Common Habitat Baseline Variants," in 2020 AIAA ASCEND, Virtual Conference, 2020.
[3] Howard, Robert, "Design Variants of a Common Habitat for Moon and Mars Exploration," 2020 AIAA ASCEND, AIAA, Virtual Conference, 2020.
[4] Howard, Robert, "A Multi-Gravity Docking and Utilities Transfer System for a Common Habitat Architecture," in 2021 AIAA ASCEND, Las Vegas, NV + Virtual, 2021.
[5] Howard, Robert, "A Two-Chamber Multi-Functional Airlock for a Common Habitat Architecture," in 2021 AIAA ASCEND, Las Vegas, NV + Virtual, 2021.
[6] Howard, Robert, "A Common Habitat Base camp for Moon and Mars Surface Operations," in 2021 AIAA ASCEND, Las Vegas, NV + Virtual, 2021.
[7] Howard, Robert, "A Common Habitat Deep Space Exploration Vehicle for Transit and Orbital Operations," in 2021 AIAA ASCEND, Las Vegas, NV + Virtual, 2021.
[8] Howard, Robert. "A Safe Haven Concept for the Common Habitat in Moon, Mars, and Transit Environments." 2021 AIAA ASCEND. Las Vegas, NV + Virtual. November 8-17, 2021.
[9] Howard, Robert, "Down-Selection of Four Common Habitat Variants," in 2022 IEEE Aerospace, Big Sky, MT, 2022.
[10] Howard, Robert, "Internal Architecture of the Common Habitat," in 2022 IEEE Aerospace Conference, Big Sky, Montana, 2022.

Proposer-Coordinated Contributions to Proposed Work: Proposer to indicate any contributions to the proposed work that the Proposer has arranged, in the event of a NASA award, and that would be in addition to NASA EPSCoR awarded funding. This may include funding or other in-kind contributions such as materials or services (Proposal should indicate the estimated value of the latter)

a. **From Jurisdiction or Organization that would partner with the Jurisdiction**
Encouraged but None are required. Proposer shall indicate if any has been arranged for the proposed work.

Intellectual Property Rights: All technologies developed through this research will be submitted through NASA's New Technology Reporting System prior to any public dissemination. Unless otherwise determined by the NASA New Technology Office, all data and analysis methods will be publicly available and no intellectual property rights will be assigned to any of the parties involved in this research. Proposer to indicate any specific intellectual property considerations in the Proposal.

Additional Information: NASA will support a telecon with the Proposer prior to the submission of Proposals, to answer Proposer's questions and discuss Proposers anticipated approach towards this Research Request. Contact information is provided in section (5). NASA welcomes opportunities to co-publish results proposed by EPSCoR awardee. NASA goal is for widest possible eventual dissemination of the results from this work when other restrictions allow.

Commercial Space Capabilities (CSC)

NASA Johnson Space Center
Commercial Space Capabilities Office

The Commercial Space Capabilities (CSC) Research Interest area supports the Commercial Low Earth Orbit Development Program of NASA's Space Operations Mission Directorate (SOMD). This area's purpose is to harness the capabilities of the U.S. research community to advance research and perform initial proofs / validations, that improve technologies of interest to the U.S. commercial spaceflight industry. The intent is to address the commercially riskiest portion of implementing new and improved technologies ("Innovation Valley of Death") to advance science and technologies from TRL1 through to TRL4. U.S. commercial spaceflight industry can then assess and determine implementation. The overall goal of this area is to encourage and facilitate a robust and competitive U.S. low Earth orbit economy. Efforts that primarily benefit near-Earth commercial activities but that may also be extensible Moon and/or Mars are also in scope.

Research Focus Area: In-Space Welding
Research Identifier**:** **C-002**

POC: Warren Ruemmele warren.p.ruemmele@nasa.gov

Research Overview: Research and initially demonstrate (in 1g) metal welding suitable for being directly exposed to space vacuum/0g. Metals of interest are those typically used for spacecraft structures and plumbing. (Extensibility to being used while exposed to Moon vac/g, and/or Mars atm/g environments could be a secondary interest.) Potential applications include the in-space assembly of very large structures that are too bulky or heavy to launch in one piece, and insitu repair or modifications. Consider weld processes suitable for incorporation into a robotic or EVA crew tool. A related secondary interest is for a metal cutting operation suitable for incorporation into a robotic or EVA crew tool. For cutting operations consider debris generation and how to control.

Research Focus Area: Materials and Processes Improvements for Chemical Propulsion State of Art (SoA)
Research Identifier**:** **C-003**

POC: Warren Ruemmele warren.p.ruemmele@nasa.gov

Research Overview: Propose and demonstrate improvements for launch, entry, and/or in-space chemical propulsion (of any type), to improve performance, reduce cost, enable new capabilities, and/or improve/simplify manufacturing. For this topic, when a current SoA exists, identify the shortcoming in the current SoA that the

improvement addresses. NASA is specifically interested in proposed work in two subtopics:
Increase the knowledgebase of methane/natural gas/oxygen/air characteristics and combustion, pertinent to spaceflight applications. For this subtopic the Proposer should identify any current knowledge gaps that the work would try to address.
Develop new computational simulation tool(s) for Methane / Natural Gas Plume Combustibility modelling specifically for spaceflight applications. Tool would use inputs for: vehicle/storage tank dimensions/ shape (e.g. IGES file), vent locations / separation distance, venting rate, species (Methane and Natural Gas mixtures, Oxygen, air) characteristics, and total propellant masses. Tool would then perform thermophysical calculations to estimate potential of developing combustible / explosive mixtures and the potential explosive force / quantity distance, and considering the effects of: ambient wind and atmospheric condition. Petroleum Industry and Governmental standards / procedures should also be considered. Scenarios to assess are:
Launch vehicle boiloff of cryogenic propellants while on pad prior to launch.
Launch site storage tank boiloff of liquified methane/natural gas and oxygen.

Research Focus Area: Materials and Processes Improvements for Electric Propulsion State of Art (SoA)
Research Identifier**:** **C-004**

POC: Warren Ruemmele warren.p.ruemmele@nasa.gov

Research Overview: Propose and demonstrate improvements for solar powered electric propulsion suitable for cislunar application, to improve performance, reduce cost, enable new capabilities, and/or improve/simplify manufacturing. For this topic; i) Proposer may contact NASA to schedule a pre-proposal telecon to discuss approach and understand details. ii) Proposer must describe the existing personnel skill and expertise, and facility capabilities to perform the work such as material finishing/processing, testing, inspection, and failure analysis.

NASA is specifically interested in proposed work to any of these three subtopics:

1) Material Properties: An evaluation of the bulk mechanical, thermal, and electrical properties of several common commercially available grades of material in environments relevant to thruster designs.
    a. Specific grades and in some cases samples can be provided by NASA and may include graphite, ceramics, refractories, aluminum, titanium, stainless steel, Inconel, Kovar, and other materials commonly used in thruster designs.
    b. Properties of interest include mechanical strength (flexural and compressive), low cycle fatigue, high cycle fatigue, toughness, slow crack growth, elastic modulus, Poisson's ratio, thermal conductivity, electrical conductivity, emissivity, thermal expansion, and outgas properties.
    c. Environments of interest include ambient temperature, low temperature (-40ºC), thruster temperature (600ºC), and cathode temperature (1100ºC).
    d. This work is intended to help fill gaps in open literature for common properties and materials used by the electric propulsion community to aid in design and analysis.

2) Material Deposition: An evaluation of material deposition resulting from ion beam sputtering of commonly used EP materials onto common spacecraft materials. Data shall include the following:
    a. Phase of the material deposited
    b. Whether the deposits are conductive or insulating
    c. Deposition rate compared to sputter yield based predictions,
    d. When/if spalling of the deposition occur.

3) Krypton Sputter Erosion: An evaluation of the sputter erosion of common thruster, spacecraft, and related materials from Krypton ion bombardment. The materials will be exposed to Krypton ion beams and the following will be determined:
    a. The dependence of the total yield with ion energies in the general range of tens to volts up to 1 kV
    b. Dependence of the total yield with ion incidence angles from normal to near grazing, and/or
    c. Differential yield profiles at various energies and incidence angles.

Materials of interest include graphite, ceramics, coverglass, kapton, composites, and/or anodized coatings. This effort may be combined with the Material Deposition effort as appropriate including possibly measurement of sticking coefficients of the sputtered products

Research Focus Area: Improvements to Space Solar Power State of Art (SoA)
Research Identifier: **C-005**

POC: Warren Ruemmele warren.p.ruemmele@nasa.gov

Research Overview: Propose and demonstrate improvements for solar power generation (of any type) suitable for cis-lunar in-space application (e.g. space stations, satellites, power beaming), to improve performance, reduce cost, enable new capabilities, and/or improve/simplify manufacturing. NASA is especially interested in these two subtopics:

1) Improvements for in-space photovoltaics compared to current spaceflight solar array SoA.
2) Engineering trade studies of other solar power production methods (e.g. concentrators, thermodynamic cycles, etc) compared to current SoA space photovoltaic systems. Considerations would include: Technology readiness and gaps, launch volume and mass with respect to current US launch vehicles, peak/steady state power and characteristics, efficiency, operational considerations, in-space lifetime/performance degradation, energy storage, orbit and distance, and identifying break points and sweet spots.

Research Focus Area: Small Reentry Systems
Research Identifier: **C-006**

POC: Warren Ruemmele warren.p.ruemmele@nasa.gov

Research Overview: Design and demonstrate reentry systems that can be deployed from low Earth orbit to perform a self-guided intact reentry to return small cargo contained inside them intact to Earth. Cargo might include science samples, space-manufactured items, etc. An alternate use is to recover flight data recorders from destructively reentering technology demonstrators to allow retrieving large amounts of telemetry without the use of communications satellites. Passively guided systems are preferred. Such reentry systems might need to be safely storable inside crewed in-space platforms so preference is to not use hazardous materials. Hazards for people/property on the Earth resulting from reentry must be considered. Landing on ground is preferred to simplify and expedite recovery.

Research Focus Area: Other Commercial Space Topic
Research Identifier: **C-007**

POC: Warren Ruemmele warren.p.ruemmele@nasa.gov

NASA is receptive to topics in this Research Interest Area that it may not have already identified if a strong case can be made for these. The Proposer may therefore propose other topics as follows:

1) The proposed Topic must be consistent with the Intent and goal of this CSC area.
2) The proposal must include a strong letter of support from a U.S. commercial company that describes the company's need for the work and any arrangements with the Proposer.
3) Before submitting the proposal for such a topic the Proposer must discuss with NASA per CSC NASA Contact listed in the following page.

Additional Instructions for Proposals in this CSC Interest Area (C-002 through C-007):

A. Content

1. Proposals should discuss how the effort is anticipated to align with U.S. commercial spaceflight company interest(s). Proposers are encouraged to contact U.S. commercial spaceflight companies to understand current research challenges.
2. Proposals should identify the estimated starting and end point of the currently proposed effort in terms of Technology Readiness Level (TRL) https://www.nasa.gov/pdf/458490main_TRL_Definitions.pdf), and what subsequent work might be anticipated to achieve TRL5.
3. If there is an existing SoA, state how proposed work would address an identified need/shortcoming (not just a "nice to have").
4. Describe proposing Institution's and Co-I/Sci-I's relevant capabilities and prior work. Compare and contrast proposed work against prior and existing work by others. (Weblinks preferred. Does not count against the Technical page limit.)
5. Work must produce a final report and delivery of developed design concept and data (as applicable).
6. Proposers can assume that technically knowledgeable NASA engineers and scientists will be reviewing the Proposal – so Proposer should focus on technical/scientific specifics.
7. NASA anticipates that depending on the specifics of the proposed work, the Proposer *may* need to implement Export Controls (e.g. EAR or ITAR). Proposer should identify in their proposal whether they believe Export Control would apply, and identify (e.g. weblink) institutional export control methods/policy in the proposal's Data Management Plan. Proposer may contact NASA PoC to discuss prior to submitting proposal.
8. For Rapid Response Research (R3) proposals to this CSC interest area, the Technical portion of the proposal may be up to five (5) pages.

B. Contributions to Proposed Work other than NASA EPSCoR

Proposer-coordinated contributions from Jurisdiction, or Organizations (especially US commercial entities) that would partner with the Jurisdiction, are welcomed but not required. If there are such contributions then the Proposer must state what has been arranged, include funding or other in-kind contributions such as materials or services and indicate the estimated value of these.

C. Intellectual Property

Proposer to indicate any intellectual property considerations in the Proposal.

D. Publishing of Results

NASA welcomes opportunities to co-publish results as proposed by EPSCoR awardee, and its goal is for widest possible eventual dissemination of the results of the Researcher(s) work, to the extent other restrictions (e.g. Export Control) allow. For results that must be controlled, NASA will work with Researcher to present accordingly, and make data available in access controlled databases such as MAPTIS database https://maptis.nasa.gov/ .

E. NASA Contact

The CSC NASA Contact will support a telecon with the Proposer prior to the submission of their Proposal, to answer questions and discuss anticipated approach towards this Research Request. NASA Contact will coordinate support from within NASA as needed to provide subject matter expertise/limited consultation in event of award. (If Proposer has already discussed with and NASA or JPL personnel please identify so they might be able to support telecon.)

NASA SMD Computational and Information Sciences and Technology Office (CISTO)

NASA Goddard Space Flight Center
Ethical/Inclusive AI Research Opportunity
James Harrington james.l.harrington@nasa.gov 301-286-4063

Research Overview: Computational and Information Sciences and Technology Office (CISTO) Computational and Technological Advances for Scientific Discovery via AI/ML Modeling and Development implementing an open science approach.

NASA open science promotes the availability of original source code and data to be available on the public domain to be repurposed for easier collaborations to be born among different groups or teams to work towards solving scientific problems that can benefit society.

NASA SMD communicates a VISION via the SMD Big Data Working Group (Strategy for Data Management and Computing for Groundbreaking Science 2019-2024 Report) to enable transformational open science through continuous evolution of science data and computing systems for NASA's Science Mission Directorate. SMD requests that NASA EPSCoR include research opportunities for data analysis that provide tools and training to diverse communities to be better able to collaborate with all types of computational and computer scientists that enables the funding of successful collaborations, including Artificial Intelligence and Machine Learning (AI/ML).

Artificial intelligence technology is rapidly growing in capability, impact and influence. As designers and developers of AI systems, it is an imperative to understand the ethical considerations of our work. A tech-centric focus that solely revolves around improving the capabilities of an intelligent system doesn't sufficiently consider human needs. (credit: IBM everyday ethics)

In 2019, a representative poll across NASA revealed over one hundred agency applications of AI in the past three years, with hundreds of AI projects planned across various missions, centers, and mission support activities from 2020 to 2022 and beyond. In November and December of 2020, the White House and Office of Management and Budget (OMB) published guidance3 regarding AI principles, policy, and governance. As an enthusiastic and forward leaning AI adopter, NASA must create and apply an evolving, living set of AI policies, principles, and guidelines to provide AI practitioners an ethical framework for their work.

NASA Framework for the Ethical Use of Artificial Intelligence (AI) TM RDP Fillable 298.pdf (nasa.gov).

The executive summary from the NASA Framework for the Ethical Use of AI guides the focus of this research opportunity:

The initial framework for NASA's ethical use of AI includes considerations applicable to today's simple Artificial Narrow Intelligence (ANI), as well as future human-level Artificial General Intelligence (AGI), and beyond to Artificial Super Intelligence (ASI). Considerations also include the ways humans may interact with machines, from using them as tools to augmenting humans with implants, to more speculative further-term topics such as the merging or melding of human and machine. This NASA framework draws from principles and frameworks of many other leading organizations, relating them to NASA's specific needs to provide an initial set of six ethical AI principles:

Fair. AI systems must include considerations of how to treat people, including scrubbing solutions to mitigate discrimination and bias, preventing covert manipulation, and supporting diversity and inclusion.

Explainable and Transparent. Solutions must clearly state if, when, and how an AI system is involved, and AI logic and decisions must be explainable. AI solutions must protect intellectual property and include risk management in their construction and use. AI systems must be documented.

Accountable. Organizations and individuals must be accountable for the systems they create, and organizations must implement AI governance structures to provide oversight.

Secure and Safe. AI systems must respect privacy and do no harm. Humans must monitor and guide machine learning processes. AI system risk tradeoffs must be considered when determining benefit of use.

Human-Centric and Societally Beneficial. AI systems must obey human legal systems and must provide benefits to society. At the current state of AI humans must remain in charge, though future advancements may cause reconsideration of this requirement.

Scientifically and Technically Robust. AI systems must adhere to the scientific method NASA applies to all problems, be informed by scientific theory and data, robustly tested in implementation, well-documented, and peer reviewed in the scientific community.

Need for involvement of underrepresented communities

A common issue of interest is the need for direct involvement of underrepresented communities in building, using, and testing datasets for bias and AI applications for fairness and disparate impact. Some specific questions noted include the following:

- How do we reach underrepresented communities?
- Can we involve underrepresented communities into user-centered design at every stage of data collection and AI design and usage?
- How do we support the need for creativity in identifying potential biases?
- How do we keep data secure so that people will trust data collection?
- Can we involve underrepresented communities to correct bias in AI apps and use "human-in-the-loop?

Supporting increasing diversity

Methods and suggestions for involving underserved communities in STEM and development of technical skills to increase diversity of AI developers:

- Include / recruit from diverse institutions - HBCUs, HSIs, and MSIs
- Involve Subject Matters Experts (e.g., social scientists, not just technologists) for diversity of thought

Increasing awareness of inequitable impact and use of review/testing

- Adopt equity impact assessments
- Educate developers in testing for inclusive AI
- Involve acquisition in training to spot inclusive AI
- Assign dedicated roles for reviewing AI applications for equity (e.g, scientific review officers)

Today's markets, including NASA missions, are relying every more increasingly on highly automated and autonomous systems for the wide range of benefits they provide. Many of these systems have or will be taking over some of roles that human previously were responsible for. Some of those key roles include independent decision-making and learning. Independent, autonomous decision-making & learning carry with them significant implications, both of which include ensuring ethical behavior and beliefs.

At this time, there are no formal ethics standards with detailed parameters highly automated and autonomous systems to use. Executive Order 13960 and the Federal Data Strategy Action Plan provide a starter set of Federal AI ethics principles, and direct Federal organizations to begin taking action to guide responsible use of AI. This current gap in ethical standards for highly automated and autonomous system means that industry and agencies need interim approaches to provide the best possible means of ensuring ethical behaviors and learning from our advanced systems until standards have been adopted. The goal of the research is to help provide key information to support formulation of such interim approached. Exploration of ethics challenges in designing, testing, implementing, and maintaining highly automated and autonomous systems.

Note: While holistic research across all the above topics is encouraged, applicants may propose research into focused subsets of the overall AI ethics solution space. NASA seeks both depth and breadth of research into this emerging area.

In all cases a report should be provided that documents the findings; identifies key risks and possible mitigations; and proposes possible next steps.

Research Focus Area: Document the Current State-of-the-Art/Practice of Ethical Decision Making by Humans in Operational Systems

Research Identifier: **C-008**

POC: James Harrington james.l.harrington@nasa.gov 301-286-4063
Edward McLarney Edward.l.mclarney@nasa.gov
Yuri Gawdiak yuri.o.gawdiak@nasa.gov
Nikunj Oza nikunj.c.oza@nasa.gov

Document the Current State-of-the-Art/Practice of Ethical Decision Making by Humans in Operational Systems:

1. Document the historical evolution of operations ethical decision scenarios
    a. World and Cultural Views on Ethics and their possible impacts on values and priorities
    b. Evolution of operator and regulator responsibilities and ethical considerations as systems have gotten more complex and more automated.
2. Document current approaches to ethical decision-making training for professional operators:
    a. Pilots
    b. Ship Captains
    c. Train Engineers
    d. Truck Drivers
    e. Doctors
    f. Fire & Rescue
    g. Others as appropriate

Research Focus Area: Explore and document the parameters in play in the transition of ethical decision making from humans to autonomous systems

Research Identifier: **C-009**

POC: James Harrington james.l.harrington@nasa.gov 301-286-4063
Edward McLarney Edward.l.mclarney@nasa.gov

Yuri Gawdiak yuri.o.gawdiak@nasa.gov
Nikunj Oza nikunj.c.oza@nasa.gov

Explore and document the parameters in play in the transition of ethical decision making from humans to autonomous systems. Human performance capabilities and limitations:

a. Situational Awareness
b. Context/Lessons Learned
c. Training
d. Biological Characterizations
    i. Cognitive Processing Power & Speed (decisions per second)
    ii. Physical Performance Capabilities & Limitations (i.e. reflexes)
    iii. Learning Capabilities
    iv. Social Characteristics

Research Focus Area: Current & projected autonomous performance capabilities and limitations
Research Identifier: **C-010**

POC: James Harrington james.l.harrington@nasa.gov 301-286-4063
Edward McLarney Edward.l.mclarney@nasa.gov
Yuri Gawdiak yuri.o.gawdiak@nasa.gov
Nikunj Oza nikunj.c.oza@nasa.gov

Current & projected autonomous performance capabilities and limitations

a. Situational Awareness
b. Context Assessment/Lesson Learning Capabilities
c. Design/Implementation Characterizations
    i. Roles & Responsibilities
    ii. Training
    iii. Processing Power Capabilities & Limitations
    iv. Physical Performance Capabilities & Limitations
    v. Learning Capabilities
    vi. Distributed Network Characteristics

Research Focus Area: Document legal ecosphere of ethical decision making in off-nominal scenarios
Research Identifier: **C-011**

POC: James Harrington james.l.harrington@nasa.gov 301-286-4063
Edward McLarney Edward.l.mclarney@nasa.gov
Yuri Gawdiak yuri.o.gawdiak@nasa.gov
Nikunj Oza nikunj.c.oza@nasa.gov

Document legal ecosphere of ethical decision making in off-nominal scenarios:

a. Multi-Culture/Tradition/Industry Domains
b. Precedents
c. Statutes
d. Laws, Regulations, Guidelines
e. Methods for: Tests, Certifications, Verification & Validations
f. Current Society Performance/Challenges on Ethical Decision Making
    i. Ability to make explicit historically implicit roles and responsibilities in ethical decision making to explicit parameters
    ii. Ability to get consensus on (why do we have 40 million lawsuits a year in the US?):
        1. Values
        2. Beliefs
        3. Fairness
        4. Equitable
        5. Unbiased
        6. Trade-offs/Priorities
        7. Etc.

Research Focus Area: Policy/Standards/Law Making Assessment
Research Identifier: **C-012**

POC: James Harrington james.l.harrington@nasa.gov 301-286-4063
Edward McLarney Edward.l.mclarney@nasa.gov
Yuri Gawdiak yuri.o.gawdiak@nasa.gov
Nikunj Oza nikunj.c.oza@nasa.gov

Policy/Standards/Law Making Assessment

a. Explore where policy, standards, and laws for Ethical Decision Making for Operations should considered/developed.
b. Requirements for each venue
c. Challenges for each venue
d. Estimated ability of development and schedule for each venue

Research Focus Area: Design, Development, & Implementation of Highly Automated / Autonomous Systems to abide by ethical decision making policy, standards, guidelines, and laws
Research Identifier: **C-013**

POC: James Harrington james.l.harrington@nasa.gov 301-286-4063
Edward McLarney Edward.l.mclarney@nasa.gov
Yuri Gawdiak yuri.o.gawdiak@nasa.gov
Nikunj Oza nikunj.c.oza@nasa.gov

Design, Development, & Implementation of Highly Automated/Autonomous Systems to abide by ethical decision making policy, standards, guidelines, and laws

a. Availability & challenges of appropriate (certified) data sets
b. Abstraction & modeling of policy, standards, guidelines, and laws
    i. Roles, Responsibilities, Liabilities
    ii. Cross Domain/Industry: Commonalities, Inter-operabilities, Hierarchies, Dependencies, etc..
    iii. Testing
    iv. Certification
    v. Learning Auditing
    vi. Maintenance

Research Focus Area: Societal ramifications of ethical decision making models

Research Identifier**:** **C-014**

POC: James Harrington james.l.harrington@nasa.gov 301-286-4063
Edward McLarney Edward.l.mclarney@nasa.gov
Yuri Gawdiak yuri.o.gawdiak@nasa.gov
Nikunj Oza nikunj.c.oza@nasa.gov

Societal ramifications of ethical decision making models

i. Inclusion of Multi-cultural/domain perspectives
ii. Prioritizations of lives and property
iii. Ranking of lives and property
iv. Tradeoffs of lives and property
v. Other collateral effects

Additional Information: All publications that result from an awarded EPSCOR study shall acknowledge NASA

Earth Science

NASA SMD Earth Science Division (ESD)

POC: Allison K. Leidner, allison.k.leidner@nasa.gov
Laura Lorenzoni, laura.lorenzoni@nasa.gov

Research Focus Area: Synthesis activities that combine multiple data sets to analyze the vulnerability and resilience of Arctic and boreal ecosystems in the Arctic Boreal Vulnerability Experiment (ABoVE) domain, across North America, and across the circumpolar region.

Research Identifier: **E-001**

Research Focus Area: Research that contributes to furthering our understanding of climate change impacts in high-latitude drainage basins, including coastal zones, and advance humanity's understanding of the potential feedback(s) of naturally- or anthropogenically-driven change in such zones
Research Identifier: **E-002**

Research Focus Area: Integration of research results and remote sensing data from ABoVE into a coherent modeling framework to diagnose and predict the impacts of environmental change on ecosystem dynamics and the consequent impacts on ecosystem services and society.
Research Identifier: **E-003**

Research Focus Area: Filling critical research gaps in our understanding of how environmental change impacts the dynamics of boreal and Arctic ecosystems within the ABoVE domain.
Research Identifier: **E-004**

Research Overview: NASA SMD Earth Science Division (ESD) Research Topics to better understanding climate change impacts on ecosystems and human in the Arctic-Boreal Zone (ABZ).
Climate change in the high northern latitudes of the Arctic-Boreal Zone (ABZ) is occurring faster than anywhere else on Earth, resulting in widespread transformation in landscape structure and ecosystem function. In addition to producing significant feedback to climate through changes in ecosystem processes, environmental change in this region is increasingly affecting ecosystem services, and these changes in services can impact society. For example, increased frequency and intensity of ecological disturbance can negatively influence forest resources and air quality, thawing permafrost can negatively change local water quality and human infrastructure, and alterations to wildlife populations can negatively reshape traditional food sources for local human populations.

To better understand changes is the ABZ and related impacts, the NASA Terrestrial Ecology Program (https://cce.nasa.gov/terrestrial_ecology/) developed the Arctic Boreal Vulnerability Experiment (ABoVE). ABoVE is a 10-year field campaign focused on developing improved abilities to observe, understand, and model the complex, multiscale, and nonlinear processes that drive the region's natural and social systems. ABoVE's overarching science questions are:
1. How vulnerable or resilient are ecosystems and society to environmental change in the Arctic and boreal region of western North America?
2. How can insights gained from previous ABoVE efforts be used to extrapolate to the continental and circumpolar boreal and/or Arctic zones?

More information on ABoVE can be found at: https://above.nasa.gov.

Proposals seeking to respond to this EPSCOR Research Topic must address research that contributes to furthering our understanding of how climate change impacts ecosystems and humans in the ABZ. NASA is specifically interested in proposals that make significant use of remote sensing data to improve understanding of the vulnerability and resilience of ecosystems and society to environmental change in the Arctic and boreal regions of western North America. Examples of potential topics suitable for the EPSCOR research on the ABZ include:

1. Synthesis activities that combine multiple data sets to analyze the vulnerability and resilience of Arctic and boreal ecosystems in the ABoVE domain, across North America, and across the circumpolar region.

2. Research that contributes to furthering our understanding of climate change impacts in high-latitude drainage basins, including coastal zones, and advance humanity's understanding of the potential feedback(s) of naturally- or anthropogenically-driven change in such zones.
3. Integration of research results and remote sensing data from ABoVE into a coherent modeling framework to diagnose and predict the impacts of environmental change on ecosystem dynamics and the consequent impacts on ecosystem services and society.
4. Filling critical research gaps in our understanding of how environmental change impacts the dynamics of boreal and Arctic ecosystems within the ABoVE domain.

Proposed investigations must utilize remotely sensed observations (e.g., MODIS, Landsat, etc.) for data analysis and as a primary research tool. Proposers are also encouraged to use data acquired via the NASA Commercial SmallSat Data Acquisition Program (CSDAP). A description of NASA's fleet of Earth observing satellites and sensors can be found at https://science.nasa.gov/missions-page/, with more details about related airborne missions at https://airbornescience.nasa.gov/. Information about data access and discovery can be found at https://earthdata.nasa.gov/.
This research opportunity will not fund the acquisition of new in situ data, but seeks to further leverage the large quantities of remotely sensed and/or in situ data that NASA has already collected over the years, in particular through the ABoVE program (https://above.nasa.gov).

Entry Systems Modeling Project

NASA SMD Earth Science Division (ESD)

Research Focus Area: Nitrogen/Methane Plasma Experiments Relevant to Titan Entry
Research Identifier: **E-005**

POC: Aaron Brandis aaron.m.brandis@nasa.gov

Research Overview: Provide experimental data to characterize TPS material response under simulated Titan entry conditions.

Research Focus: Data is needed to validate models for the material response of thermal protection system (TPS) materials under simulated Titan entry conditions, with the atmosphere being predominately nitrogen (N2) and a small amount of methane (CH4). The conditions should be traceable to conditions relevant to the upcoming Dragonfly mission. Furthermore, an understanding of how coatings, e.g. NuSil, are impacted (or not) by the presence of methane and in a non-oxidizing environment is of interest. Relevant facilities for such measurements could include ArcJets or Plasma Torches. Data of interest would include thermocouples imbedded in TPS materials (e.g. PICA, SLA) and non-intrusive surface temperature measurements. Characterization of the post-test materials is also of interest. Understanding the material response of NuSil/PICA in a Titan atmosphere is important to maximize the science return for the DrEAM instrumentation suite.

Research Focus Area: Thermal Conductivity Heat Transfer of Porous TPS Materials

Research Identifier: **E-006**

POC: Aaron Brandis aaron.m.brandis@nasa.gov

Research Overview: Provide data to allow for the development of models for predicting the effective thermal conductivity of TPS materials of interest to Entry Descent and Landing projects and missions at NASA.
Research Focus: This proposal seeks heat transfer measurements that can isolate the contributions of solid conduction, gas conduction, and radiation to the overall effective thermal conductivity of porous thermal protection system (TPS) materials for a range of temperatures. These measurements should allow for the radiative heat transfer to be isolated from the conductive heat transfer through a TPS material, allowing for the contribution of each of these heat transfer mechanisms to be characterized independently. The data would then be made available to the TPS materials modeling groups at NASA to improve thermal conductivity models.

Research Focus Area: Deposition of Ablation/Pyrolysis Products on Optical Windows
Research Identifier: **E-007**

POC: Aaron Brandis aaron.m.brandis@nasa.gov

Research Overview: Provide experimental data to characterize the deposition of ablation/pyrolysis products on radiometer/spectrometer windows that reduce transmissivity.
Research Focus: Mars 2020 carried a radiometer on the backshell of the entry vehicle as part of the MEDLI2 instrumentation suite. Pyrolysis and ablation products can be deposited on the radiometer window during entry, and reduce the transmissivity. This reduction in transmissivity is a function of spectral wavelength, and can reduce the signal level reaching the radiometer sensing element. Such a test could be conducted in an ArcJet or Plasma torch either with a scaled approximate model of Mars 2020, or a simplified geometry (e.g. a wedge, backward facing step). Relevant materials for testing include PICA, RTV and SLA 561V. After products have been deposited on the window during a test, these products need to be characterized and the transmissivity of the window measured. These post-test results could either be measured as part of the proposal, or the post-test models sent back to NASA for characterization.

Research Focus Area: Predictive Modeling of Plasma Physics Relevant to High Enthalpy Facilities
Research Identifier: **E-008**

POC: Aaron Brandis aaron.m.brandis@nasa.gov

Research Overview: Develop predictive models for arc and plasma processes used in the generation of high enthalpy flows in shock tube and arcjet facilities at NASA.
Research Focus: This proposal seeks predictive modeling of processes occurring in facilities that generate high-enthalpy flows at NASA, including Arcs and Plasma Torches. The objectives may differ depending on facilities being modeled. For instance, the Electric Arc Shock tube uses an Arc to produce a high velocity shock waves. Acoustic modes in the arc driver may determine velocity profiles in the tube while ionization processes produce radiating species that may heat driven freestream gases. In plasma torches, studies of recombination of Nitrogen and Air plasma flows have relevance for predicted backshell radiation modeling. Modeling in arc jets may improve estimates of enthalpy profile uniformity and mixing of arc gas with add air.

Human Research Program / Space Radiation

Space radiation exposure is one of numerous hazards astronauts encounter during spaceflight that impact human health. High priority health outcomes associated with space radiation exposure are carcinogenesis, cardiovascular disease (CVD), and central nervous sytem (CNS) changes that impact astronaut health and performance.

Research Focus Area: Tissue and Data sharing for space radiation risk and mitigation strategies
Research Identifier: **H-001**

POC: Robin Elgart shona.elgart@nasa.gov, (281)244-0596
Janice Zawaski janice.zawaski@nasa.gov

Research Overview: Research proposals are sought to accelerate risk characterization for high priority radiation health risks and inform mitigation strategies the NASA Human Research Program (HRP) Space Radiation Element (SRE) by sharing animal tissue samples and data. The proposed work should focus is on translational studies that support priority risk characterization (cancer, CVD, CNS), development of relative biological effectiveness (RBE) values, identification of actionable biomarkers, and evaluation of dose thresholds for relevant radiation-associated disease endpoints. Cross-species comparative analyses of rodent data/samples with higher order species (including human archival data and tissue banks) are highly encouraged.

- Data can include but is not limited to behavioral tasks, tumor data, physiological measurements, imaging, omics', etc. that has already been, or is in the process of being, collected.
- Tissue samples can include, but are not limited to, samples that have already been, or are in the process of, being collected and stored as well as tissues from other external archived banks (e.g., http://janus.northwestern.edu/janus2/index.php).
- Relevant tissue samples and data from other externally funded (e.g., non-NASA) programs and tissue repositories/archives for comparison with high linear energy transfer (LET), medical proton, neutron and other exposures can be proposed.
- A more detailed list of samples and tissues available from SRE can be found at our tissue sharing websites:
  - https://lsda.jsc.nasa.gov/Document/doc_detail/Doc13726
  - https://lsda.jsc.nasa.gov/Document/doc_detail/Doc13766
  - https://lsda.jsc.nasa.gov/Biospecimen by searching "NASA Space Radiation Laboratory (NSRL)" in the payloads field.
  - Instructions for accessing the tissue sharing information are posted at: https://spaceradiation.jsc.nasa.gov/tissue-sharing/.

Research Focus Area: Space radiation sex-differences
Research Identifier: **H-002**

POC: Robin Elgart shona.elgart@nasa.gov, (281)244-0596

Research Overview: Research proposals are sought to define the mechanisms underlying sexual dimorphism following exposure to space radiation. Research should focus on translational biomarkers relevant to changes in cognitive and/or behavioral performance, cardiovascular function, and the development of carcinogenesis **in non-sex-specific organs**. Due to limited time and budget, researchers are encouraged to utilize radiation sources located at home institutions at space relevant doses (0-5 Gy of photons or proton irradiation). A successful proposal will not necessitate the use of the NASA Space Radiation Laboratory (NSRL) at Brookhaven National Laboratory at this phase. Collaborations between investigators and institutions for the sharing of data and tissue samples are highly encouraged. Samples available for use by SRE, can be found at https://lsda.jsc.nasa.gov/Biospecimen by searching "NASA Space Radiation Laboratory (NSRL)" in the payloads field (SRE approval required). Instructions for accessing the tissue sharing information are posted at: https://spaceradiation.jsc.nasa.gov/tissue-sharing/.

Research Focus Area: Compound screening techniques to assess efficacy in modulating responses to radiation exposure
Research Identifier: **H-003**

POC: Robin Elgart shona.elgart@nasa.gov, (281)244-0596
Brock Sishc brock.j.sishc@nasa.gov

Research Overview: Research proposals are sought to establish screening techniques for compound-based countermeasures to assess their efficacy in modulating biological responses to radiation exposure relevant to the high priority health risks of cancer, CVD, and/or CNS. Techniques that can be translated into high-throughput screening protocols are highly desired, however high-content protocols will also be considered responsive.

Research Focus Area: Inflammasome role in radiation-associated health impacts
Research Identifier: **H-004**

POC: Robin Elgart shona.elgart@nasa.gov, (281)244-0596
Janapriya Saha janapriya.saha@nasa.gov

Research Overview: Research proposals are sought to evaluate the role of the inflammasome in the pathogenesis of radiation-associated cardiovascular disease (CVD), carcinogenesis, and/or central nervous system changes that impact behavioral and cognitive function. Although innate inflammatory immune responses are necessary for survival from infections and injury, dysregulated and persistent inflammation is thought to contribute to the pathogenesis of various acute and chronic conditions in humans, including CVD. A main contributor to the development of inflammatory diseases involves activation of inflammasomes. Recently, inflammasome activation has been increasingly linked to an increased risk and greater severity of CVD. Characterization of the role of inflammasome-mediated pathogenesis of disease after space-like chronic radiation exposure can provide evidence to better quantify space radiation risks as well as identify high value for countermeasure development.

Research Focus Area: Portable, non-ionizing radiation based, high resolution disease detection imaging
Research Identifier: **H-005**

POC: Robin Elgart shona.elgart@nasa.gov, (281)244-0596
Janice Zawaski janice.zawaski@nasa.gov

Research Overview: Research proposals are sought to develop portable, non-ionizing radiation based, high resolution imaging technologies for disease detection in rodent models with potential scalability to humans. Conventional imaging modalities including 2D planar x-rays, micro computed tomography (CT), positron emission tomography (PET), magnetic resonance (MR), ultrasound, and bioluminescence/fluorescence imaging require either large-scale equipment that is generally immobile, or require highly trained personnel to accurately identify disease. Furthermore, the resolution of these standard techniques limits detectability of small changes in small-animal models. To accelerate radiation risk characterization and mitigation the NASA Human Research Program Space Radiation Element is seeking development of portable, non-ionizing radiation-based, high resolution imaging modalities for the early detection and continuous monitoring of disease development and progression for use in rodent models with potential scalability to human systems and use in space flight.

Human Research Program / Precision Health Initiative

Research Focus Area: Pilot studies to adopt terrestrial precision health solutions for astronauts
Research Identifier: **H-006**

POC: Corey Theriot corey.theriot@nasa.gov , 281-244-7331
Carol Mullenax carol.a.mullenax@nasa.gov, 281-244-7068

The term "precision health" (also called personalized medicine, precision medicine, and individualized healthcare in clinical settings) refers to the strategy of collecting and analyzing individual medical data (clinical and molecular measures) along with environmental and lifestyle data to identify key factors that can improve the level of medical care for, and ultimately the health and performance of, the individual crewmember rather than the population. The term "technique" encompasses any clinical practice, strategy, test, or process that provides a clinically actionable medical outcome for an individual.

PHI seeks to maintain an individual astronaut's health and optimal mission performance, requiring in-depth understanding of individual molecular profiles and how they relate to health and performance. The practice of Precision Health encompasses the use of detailed phenotyping of an individual, using both clinical and molecular measures, along with the integrated analyses of those data to draw conclusions about an individual's response to the environment, diet, medications, exercise regimen, etc. **This topic seeks proposals for preliminary pilot studies that identify well-vetted and approved precision health techniques from terrestrial medicine that can be applied with little to no modification to crewmembers that will be exposed to the stressors of spaceflight: space radiation, altered gravity, isolation/confinement, distance from Earth, and hostile/closed environments.**

Research Focus: While most terrestrial precision medicine techniques focus on diagnosis and treatment of disease states, NASA is most interested in preventive measures that maintain crew health and performance during exposure to spaceflight stressors resulting in human health and performance risks as described in the Human Research Roadmap (https://humanresearchroadmap.nasa.gov). Proposed precision health techniques should have compelling evidence of efficacy for the overall crew population and be approved for terrestrial clinical practice by appropriate governing bodies, and proposals should address incorporation into the existing NASA operations, workflow, and infrastructure. Any proposed precision health techniques using genetic information must comply with the Genetic Information Nondiscrimination Act of 2008 (GINA) rules that preclude use of genetic information in employment decisions, which for NASA means that genetic data cannot be used to inform or influence crew selection or crew mission assignments.

Human Research Program / Systems Biology Translation

Research Focus Area: Pilot studies to demonstrate the utilization of full systems biology approaches in addressing human spaceflight risks
Research Identifier: **H-007**

POC: Corey Theriot corey.theriot@nasa.gov, 281-244-7331
Carol Mullenax carol.a.mullenax@nasa.gov, 281-244-7068

Research Overview: The environment astronauts are exposed to, particularly during future deep space missions, pose unique risks to human health and performance as well as research challenges that are fundamentally interdisciplinary. Systems biology frameworks offer inclusive approaches for the analysis and simulation of complex biological phenomena that in combination with the onset of new data sources and the availability of new tools for data analysis lead to a natural evolution towards the use of systems biology to understand complex biological responses. The anticipated outcome is a comprehensive understanding of the intricate interactions among biological system responses to spaceflight stressors by leveraging work across multiple disciplines. Additionally, improved identification of critical and influential system pathways corresponding to clinically and experimentally observed symptoms leads to the translation of results to human applications more quickly and economically. To develop these new capabilities and approaches, the NASA Human Research Program is interested in proof of concept development of systems biology research approaches: with particular interest in augmenting an existing HRP risk mitigation plan (such as Spaceflight Associated Neuro-ocular Syndrome) and developing a clean-sheet mitigation approach for a cross-cutting risk factor (such as inflammation). HRP human health and performance risks are described in the Human Research Roadmap (https://humanresearchroadmap.nasa.gov).
This topic seeks proposals for preliminary pilot studies that establish systems biology frameworks that utilize omics datasets, biochemical data, bioinformatics, and computational modeling to evaluate responses in biological systems due to exposure to spaceflight environments.

Research Focus: The research thopic focuses on proposals that establish the use of comprehensive systems biology approaches to understand biological responses to spaceflight. Particular focus should address (but not limited to) one of the following topics:

- Resolving aspects of the Spaceflight Associated Neuro-ocular Syndrome (SANS) risk to include multiple tissue (i.e., ocular and brain) responses.
- Assessment of the cross-risk factor of spaceflight-induced inflammation and inflammatory responses to include systemic as well as tissue specific responses in acute and chronic phases.

Human Research Program

Research Focus Area: Development and elaboration of Functional aids and testing paradigms to measure activity for use by parastronauts during spaceflight
Research Identifier: **H-008**

POC: Victor S. Schneider vschneider@nasa.gov
Kristin Fabre kristin.m.fabre@nasa.gov

Research Overview: 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.

Research Focus Area: Evaluation space capsule and spacesuit activity in stable and fit lower or upper extremity amputees and compare their responses to non-amputee fit individuals

Research Identifier: **H-009**

POC: Victor S. Schneider vschneider@nasa.gov
Kristin Fabre kristin.m.fabre@nasa.gov

Research Overview: 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.

Planetary Division

SMD requests that EPSCoR includes research opportunities in the area of Extreme Environments applicable to Venus, Io, Earth volcanoes. and deep-sea vents.

Venus has important scientific relevance to understanding Earth, the Solar System formation, and Exoplanets. For EPSCoR technology projects, Venus' highly acidic surface conditions are also a unique extreme environment with temperatures (~900F or 500C at the surface) and pressures (90 earth atmospheres or equivalent to pressures at a depth of 1 km in Earth's oceans). Furthermore, information on Venus' challenging environmental needs for its exploration can be found on the Venus Exploration Analysis Group (VEXAG) website: https://www.lpi.usra.edu/vexag/.

In particular, the technology requirements and challenges related to Venus exploration are discussed in the Venus Technology Roadmap at:

https://www.lpi.usra.edu/vexag/documents/reports/VEXAG_Venus_Techplan_2019.pdf

Research Focus Area: High-Temperature Subsystems and Components for Long-Duration (months) Surface Operations

Research Identifier: **P-001**

POC: Adriana Ocampo aco@nasa.gov W:202.358.2152/M:202.372.7058
Michael Lienhard michael.a.lienhard@nasa.gov 216.433.8932

Research Overview: Advances in high-temperature electronics and power generation would enable long-duration missions on the surface of Venus operating for periods as long as a year, where the sensors and all other components operate at Venus' surface ambient temperature. These advances are needed for both the long-duration lander and the lander network. Development of high-temperature electronics, memory, transmitters, sensors, thermal control, actuators, and power sources designed for operating in the Venus ambient would be enabling for future missions.

For example, Venus surface landers could investigate a variety of open questions that can be uniquely addressed through in-situ measurements. The Venus Exploration Roadmap describes a need to investigate the structure of Venus's interior and the nature of current activity, and potentially conduct the following measurements: a. Seismology over a large frequency range to constrain interior structure; b. Heat flow to discriminate between models of current heat loss; and c. Geodesy to determine core size and state. Landers with sample return capability would be of great interest.

Research Focus Area:	Aerial Platforms for Missions to Measure Atmospheric Chemical and Physical Properties
Research Identifier**:**	**P-002**

POC: Adriana Ocampo aco@nasa.gov W:202.358.2152/M:202.372.7058
Michael Lienhard michael.a.lienhard@nasa.gov 216.433.8932

Research Overview: More than three decades ago, two small (3.5 m) VEGA balloons launched by the Soviet Union completed two-day flights around Venus, measuring wind speeds, temperature, pressure, and cloud particle density. The time is ripe for modern NASA efforts to explore the Venus atmosphere with new technology.

Aerial platforms have a broad impact on science for Venus. Examples of science topics to be investigated include:

a. the identity of the unknown UV absorber and atmospheric chemistry (i.e. phosphine);

b. properties of the cloud particles in general;

c. abundances atmospheric gas species (including trace gases and noble gases);

d. the presence of lightning; and

e. properties of the surface mapped aerially.

Aerial vehicles that are able to operate at a variety of high and low altitudes in the middle atmosphere are needed to enable mid-term and far-term Venus missions addressing these issues. A platform able to operate close to the Venusian surface would be able to provide close surface monitoring but would require major development to operate in the hot dense lower atmosphere. Miniaturized guidance and control systems for aerial platform navigation for any altitudes are needed to track probe location and altitude.

Other topics of interest would include high pressure and acidic environments for technology development, which would be of interest to include in the $750K level EPSCoR call.

Research Focus Area: Extreme Environment Aerobot
Research Identifier: **P-003**

POC: Adriana Ocampo aco@nasa.gov W:202.358.2152/M:202.372.7058
Michael Lienhard michael.a.lienhard@nasa.gov 216.433.8932

Research Overview: Venus provides an important scientific link to Earth, Solar System formation, and to Exoplanets. This EPSCoR call is made for technology projects, which take intoconsideration Venus' middle atmosphere conditions and its unique extreme environment. The call concentrates on the challenge to develop an aerial platform that would survive the extreme conditions of the Venusian middle atmosphere. It is worth noting that in the middle atmosphere of Venus (79km to 45Km), the conditions are considerably more benign than its surface conditions. This EPSCoR call will focus on Variable Manurable (horizontally and vertically) altitude balloons or hybrid airship, or aerobots (buoyancy + lift). The top technical parameters to consider for the Extreme Environment Aerobot for Venus conditions are (* see references below):

- Altitude: Maintain 79km to 45km Altitude (avoids high temps)
- Structure: Airframe & Materials compatible with acids (PH -1.3 to 0.5). The cloud pH varies from about 0.5 at the top (65 km) to -1.3 at the base (48 km).
- Power source: Solar and/or Batteries
- Navigation: provide, Guidance & Control concepts
- Science Instruments: for atmosphere and ground remote sensing
- Lifetime: weeks to months
- Pressure and temperature range: 80mb-1.3bar, with pressure at 65 km (245Kelvin or -28C) from Pioneer Large probe measured 80 mb and at 48 km (385 Kelvin or 112C) is approximately 1.3 bar. At 60 deg. latitude the pressure at 65 km is about 70 mb and temperature is about 222 K (-51C).
- Winds: Vertical shear of horizontal wind, up to 5-10 m/s per km

References:

Further Information on Venus's challenging environment needs, for its exploration, can be found on the Venus Exploration Analysis Group (VEXAG) website:
https://www.lpi.usra.edu/vexag/.
"Aerial Platforms for the Scientific Exploration of Venus" report (JPL) Aug 2018.
In particular, the technology requirements and challenges related to Venus exploration are discussed in the Venus Technology Roadmap at:

https://www.lpi.usra.edu/vexag/documents/reports/VEXAG_Venus_Techplan_2019.pdf

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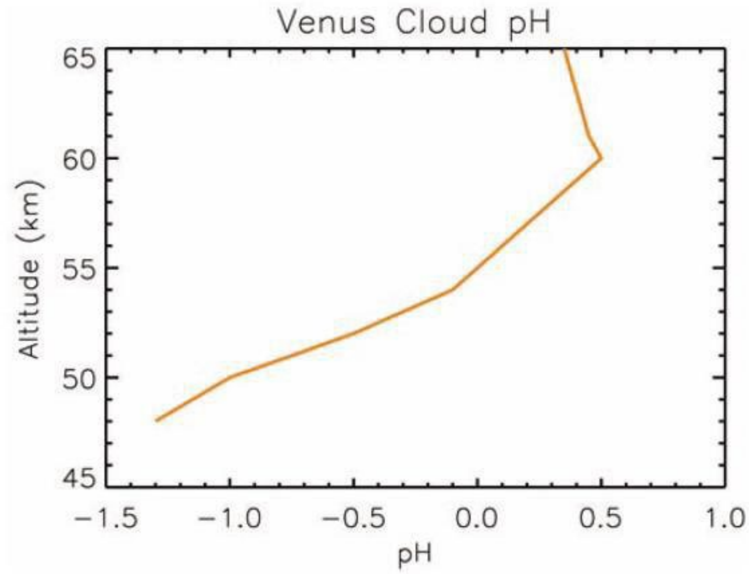

Plate 2. The pH of Venus' clouds as a function of altitude. The relatively water-rich aerosols in the upper cloud have a small range of positive pH, from 0.3 to 0.5. In the lower cloud, with its larger and more water-poor particles, pH can be as low as -1.3. Aerosol H_2SO_4 concentrations were calculated using the cloud model of Bullock and Grinspoon (2001), constrained by PV data. Correction for high activities is from Nordstrum et al. (2000).

Planetary Protection

Office of Safety & Mission Assurance

Research Focus Area:	Addressing Knowledge Gaps in Planetary Protection for Crewed Mars Mission Concepts - Microbial and Human Health Monitoring
Research Identifier**:**	**P-004**
POC:	J Nick Benardini James.N.Benardini@nasa.gov

Research Overview: Planetary Protection is the practice of protecting solar system bodies from contamination by Earth life and protecting Earth from possible life forms that may be returned from other solar system bodies. NASA's Office of Planetary Protection (OPP) promotes the responsible exploration of the solar system by implementing and developing efforts that protect the integrity of scientific discovery, the explored environments, and the Earth.

As NASA expands its exploration portfolio to include crewed missions beyond low Earth orbit, including planning for the first crewed Mars mission, a new paradigm for planetary protection is needed. Together with COSPAR, the Committee on Space Research, NASA has been working with the scientific and engineering communities to identify gaps in knowledge that need to be addressed before an end-to-end planetary protection implementation can be developed for a future crewed Mars mission2.

[2] Further information on the COSPAR meeting series on planetary protection knowledge gaps for crewed Mars missions can be found in the Conference Documents section of the OSMA Planetary Protection

For this EPSCoR Rapid Research Response Topic, NASA is interested in proposals that will address identified knowledge gaps in planetary protection for crewed Mars mission concepts, facilitating a knowledge-based transition from current robotic exploration-focused planetary protection practice to a new paradigm for crewed missions.
Research Focus: The capability to detect, monitor and then (if needed) mitigate the effects of adverse microbial-based events, whether terrestrial or Martian in origin, is critical in the ability to safely complete a crewed return mission to and from the red planet.
OPP is interested in proposals that would be the first steps on a path to develop -omics based approaches (including downstream bioinformatic analyses) for planetary protection decision making, with a particular emphasis on assessing perturbations in the spacecraft microbiome as indicators of key events such as exposure to the Mars environment, or changes in crew or spacecraft health.
Additionally, OPP is interested in technologies and approaches for mitigation of microbial growth in space exploration settings. This includes remediation of microbial contamination (removal, disinfection, sterilization) in spacecraft environments in partial or microgravity as well as on planetary surfaces.

Research Focus Area: Addressing Knowledge Gaps in Planetary Protection for Crewed Mars Mission Concepts - Natural Transport of Contamination on Mars

Research Identifier: **P-005**

POC: J Nick Benardini James.N.Benardini@nasa.gov

Research Overview: The threat of harmful biological contamination at Mars is a balance between the release and spread of terrestrial biota resulting from the spacecraft surface operations, and the lethality of the Martian environment to these organisms. To understand and manage the risk of such contamination, the OPP is interested in studies of the following:

- Modeling and experimentation to describe the surface/atmospheric transport of terrestrial microorganisms as they would be released from spacecraft hardware at the Martian surface.
- Modeling and experimentation to describe the subsurface transport of terrestrial microorganisms as they would be released from spacecraft hardware onto the Martian surface.
- Modeling and experimentation to describe the lethality of the Mars environment to terrestrial organisms as they would be released from spacecraft hardware at the Martian surface.

Proposed research could focus in individual (indicator) organisms or populations of organisms. Of particular interest is the resistance of terrestrial organisms to the Martian UV environment under conditions relevant to release from crewed spacecraft (in clumps, attached to dust particles, or as part of a biofilm matrix).

Additional Information: All publications that result from an awarded EPSCoR study shall acknowledge NASA OSMA. If the NASA GeneLab Data Systems (genelab.nasa.gov) is used, GeneLab shall be referenced in the resulting publication and included in the keyword list. All -omics data obtained from these studies shall be uploaded to the NASA GeneLab.

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web site, in particular the report of the 2018 meeting at: https://sma.nasa.gov/docs/default-source/sma-disciplines-and-programs/planetary-protection/cospar-2019-2nd-workshop-on-refining-planetary-protection-requirements-for-human-missions-and-work-meeting-on-developing-payload-requirements-for-addressing-planetary-protection-gaps-on-nat.pdf?sfvrsn=507ff8f8_8

Appendix H – Research Focus Area/Point of Contact (POC)

Research Focus Area/Point of Contact (POC)		
Aeronautic Research Mission Directorate / Advanced Air Vehicles Program / Revolutionary Vertical Lift Technology Project		
Research Focus Area	**Point of Contact**	**Id**
Safety of Electro-mechanical Powertrains for Electrified Vertical Takeoff and Landing (eVTOL) Vehicles	Timothy Krantz, timothy.l.krantz@nasa.gov	A-001
High power density power grids, power electronics, motors, and electro-mechanical powertrains	Timothy Krantz, timothy.l.krantz@nasa.gov	A-002
High reliability and robustness for safety-critical propulsion systems including but not limited to: a) arc fault protection; b) EMI/filtering; c) fault tolerant architectures; d) power management	Timothy Krantz, timothy.l.krantz@nasa.gov	A-003
Novel thermal management of the propulsion components and/or of the propulsion system	Timothy Krantz, timothy.l.krantz@nasa.gov	A-004
Application of advanced materials and manufacturing to achieve above 3 items.	Timothy Krantz, timothy.l.krantz@nasa.gov	A-005
Development of Characterization Techniques to Determine Key Composite Material Properties for the LS-DYNA MAT213 Model	Robert Goldberg robert.goldberg@nasa.gov Justin Littell justin.d.littell@nasa.gov Mike Pereira mike.pereira@nasa.gov	A-006
Astrophysics		
Research Focus Area	**Point of Contact**	**Id**
Astrophysics Technology Development	Hashima Hasan hhasan@nasa.gov Mario Perez mario.perez@nasa.gov	A-007
Biological and Physical Sciences		
Research Focus Area	**Point of Contact**	**Id**
Fundamental Physics - Quantum Science	Brad Carpenter bcarpenter@nasa.gov	B-001

Research Focus Area/Point of Contact (POC)		
Complex Fluids/Soft Matter - Soft Matter-Based Materials	Brad Carpenter bcarpenter@nasa.gov	B-002
Fluid Physics - Oscillating Heat Pipes (OHP)	John McQuillen john.b.mcquillen@nasa.gov	B-003
Combustion Science - High Pressure Transcritical Combustion (HPTC)	Daniel L. Dietrich Daniel.L.Dietrich@nasa.gov	B-004
Materials Science - Extraction and Utilization of Materials from Regolith	Michael SanSoucie michael.p.sansoucie@nasa.gov	B-005
Effects of Regolith Simulant on Growth, Survival, and Fitness of Animal Models	Sharmila Bhattacharya SpaceBiology@nasaprs.com	B-006
Effects of Space-Associated Stressors on Plant and Microbial Interactions	Sharmila Bhattacharya SpaceBiology@nasaprs.com	B-007
Center for Design and Space Architecture		
Research Focus Area	**Point of Contact**	**Id**
Repair, Manufacturing, And Fabrication (RMAF) Facility for the Common Habitat Architecture	Robert L. Howard, Jr. robert.l.howard@nasa.gov	C-001
Commercial Space Capabilities		
Research Focus Area	**Point of Contact**	**Id**
In-Space Welding	Warren Ruemmele warren.p.ruemmele@nasa.gov	C-002
Materials and Processes Improvements for Chemical Propulsion State of Art (SoA)	Warren Ruemmele warren.p.ruemmele@nasa.gov	C-003
Materials and Processes Improvements for Electric Propulsion State of Art (SoA)	Warren Ruemmele warren.p.ruemmele@nasa.gov	C-004
Improvements to Space Solar Power State of Art (SoA)	Warren Ruemmele warren.p.ruemmele@nasa.gov	C-005
Small Reentry Systems	Warren Ruemmele warren.p.ruemmele@nasa.gov	C-006
Other Commercial Space Topic	Warren Ruemmele warren.p.ruemmele@nasa.gov	C-007
Computational and Information Sciences and Technology Office (CISTO) Program		
Research Focus Area	**Point of Contact**	**Id**
Document the Current State-of-the-Art/Practice of Ethical Decision Making by Humans in Operational Systems.	James Harrington james.l.harrington@nasa.gov Edward McLarney Edward.l.mclarney@nasa.gov Yuri Gawdiak yuri.o.gawdiak@nasa.gov Nikunj Oza nikunj.c.oza@nasa.gov	C-008

Research Focus Area/Point of Contact (POC)		
Explore and document the parameters in play in the transition of ethical decision making from humans to autonomous systems.	James Harrington james.l.harrington@nasa.gov Edward McLarney Edward.l.mclarney@nasa.gov Yuri Gawdiak yuri.o.gawdiak@nasa.gov Nikunj Oza nikunj.c.oza@nasa.gov	C-009
Current & projected autonomous performance capabilities and limitations.	James Harrington james.l.harrington@nasa.gov Edward McLarney Edward.l.mclarney@nasa.gov Yuri Gawdiak yuri.o.gawdiak@nasa.gov Nikunj Oza nikunj.c.oza@nasa.gov	C-010
Current & projected autonomous performance capabilities and limitations.	James Harrington james.l.harrington@nasa.gov Edward McLarney Edward.l.mclarney@nasa.gov Yuri Gawdiak yuri.o.gawdiak@nasa.gov Nikunj Oza nikunj.c.oza@nasa.gov	C-011
Policy/Standards/Law Making Assessment.	James Harrington james.l.harrington@nasa.gov Edward McLarney Edward.l.mclarney@nasa.gov Yuri Gawdiak yuri.o.gawdiak@nasa.gov Nikunj Oza nikunj.c.oza@nasa.gov	C-012
Design, Development, & Implementation of Highly Automated / Autonomous Systems to abide by ethical decision-making policy, standards, guidelines, and laws.	James Harrington james.l.harrington@nasa.gov Edward McLarney Edward.l.mclarney@nasa.gov Yuri Gawdiak yuri.o.gawdiak@nasa.gov Nikunj Oza nikunj.c.oza@nasa.gov	C-013
Societal ramifications of ethical decision-making models.	James Harrington james.l.harrington@nasa.gov Edward McLarney Edward.l.mclarney@nasa.gov Yuri Gawdiak yuri.o.gawdiak@nasa.gov Nikunj Oza nikunj.c.oza@nasa.gov	C-014
Earth Science		

Research Focus Area/Point of Contact (POC)		
Research Focus Area	**Point of Contact**	**Id**
Synthesis activities that combine multiple data sets to analyze the vulnerability and resilience of Arctic and boreal ecosystems in the Arctic Boreal Vulnerability Experiment (ABoVE) domain, across North America, and across the circumpolar region.	Allison K. Leidner allison.k.leidner@nasa.gov Laura Lorenzoni laura.lorenzoni@nasa.gov	E-001
Research that contributes to furthering our understanding of climate change impacts in high-latitude drainage basins, including coastal zones, and advance humanity's understanding of the potential feedback(s) of naturally- or anthropogenically-driven change in such zones.	Allison K. Leidner allison.k.leidner@nasa.gov Laura Lorenzoni laura.lorenzoni@nasa.gov	E-002
Integration of research results and remote sensing data from ABoVE into a coherent modeling framework to diagnose and predict the impacts of environmental change on ecosystem dynamics and the consequent impacts on ecosystem services and society.	Allison K. Leidner allison.k.leidner@nasa.gov Laura Lorenzoni laura.lorenzoni@nasa.gov	E-003
Filling critical research gaps in our understanding of how environmental change impacts the dynamics of boreal and Arctic ecosystems within the ABoVE domain.	Allison K. Leidner allison.k.leidner@nasa.gov Laura Lorenzoni laura.lorenzoni@nasa.gov	E-004
Entry Systems Modeling Project		
Research Focus Area	**Point of Contact**	**Id**
Entry Systems Modeling - Nitrogen/Methane Plasma Experiments Relevant to Titan Entry	Aaron Brandis aaron.m.brandis@nasa.gov	E-005
Entry Systems Modeling - Thermal Conductivity Heat Transfer of Porous TPS Materials	Aaron Brandis aaron.m.brandis@nasa.gov	E-006
Entry Systems Modeling - Deposition of Ablation/Pyrolysis Products on Optical Windows	Aaron Brandis aaron.m.brandis@nasa.gov	E-007
Entry Systems Modeling - Predictive Modeling of Plasma Physics Relevant to High Enthalpy Facilities	Aaron Brandis aaron.m.brandis@nasa.gov	E-008
Human Research Program (Space Radiation, Precision Health Initiative)		
Research Focus Area	**Point of Contact**	**Id**
Tissue and Data sharing for space radiation risk and mitigation strategies	Robin Elgart shona.elgart@nasa.gov Janice Zawaski janice.zawaski@nasa.gov	H-001
Space radiation sex-differences	Robin Elgart shona.elgart@nasa.gov	H-002

Research Focus Area/Point of Contact (POC)		
Compound screening techniques to assess efficacy in modulating responses to radiation exposure	Robin Elgart shona.elgart@nasa.gov Brock Sishc brock.j.sishc@nasa.gov	H-003
Inflammasome role in radiation-associated health impacts	Robin Elgart shona.elgart@nasa.gov Janapriya Saha janapriya.saha@nasa.gov	H-004
Portable, non-ionizing radiation based, high resolution disease detection imaging	Robin Elgart shona.elgart@nasa.gov Janice Zawaski janice.zawaski@nasa.gov	H-005
Pilot studies to adopt terrestrial precision health solutions for astronauts	Corey Theriot corey.theriot@nasa.gov Carol Mullenax carol.a.mullenax@nasa.gov	H-006
Pilot studies to demonstrate the utilization of full systems biology approaches in addressing human spaceflight risks	Corey Theriot corey.theriot@nasa.gov Carol Mullenax carol.a.mullenax@nasa.gov	H-007
Development and elaboration of Functional aids and testing paradigms to measure activity for use by parastronauts during spaceflight	Victor S. Schneider vschneider@nasa.gov Kristin Fabre kristin.m.fabre@nasa.gov	H-008
Evaluation space capsule and spacesuit activity in stable and fit lower or upper extremity amputees and compare their responses to non-amputee fit individuals	Victor S. Schneider vschneider@nasa.gov Kristin Fabre kristin.m.fabre@nasa.gov	H-009
Planetary Science		
Research Focus Area	**Point of Contact**	**Id**
High-Temperature Subsystems and Components for Long-Duration (months) Surface Operations	Adriana Ocampo aco@nasa.gov	P-001
Aerial Platforms for Missions to Measure Atmospheric Chemical and Physical Properties	Adriana Ocampo aco@nasa.gov	P-002
Extreme Environment Aerobot	Adriana Ocampo aco@nasa.gov	P-003
Planetary Protection		
Research Focus Area	**Point of Contact**	**Id**
Addressing Knowledge Gaps in Planetary Protection for Crewed Mars Mission Concepts	J Nick Benardini James.N.Benardini@nasa.gov	P-004
Natural Transport of Contamination on Mars_	J Nick Benardini James.N.Benardini@nasa.gov	P-005