National Aeronautics and Space Administration

SMALL BUSINESS INNOVATION RESEARCH (SBIR) & SMALL BUSINESS TECHNOLOGY TRANSFER (STTR)

Fiscal Year 2018 General Solicitation

Opening Date: January 11, 2018
Closing Date: March 09, 2018

Fiscal Year 2018 SBIR/STTR Solicitation Noteworthy Changes

EHB Modernization

The SBIR/STTR Electronic Handbook (EHB) has been modernized with the goal of providing a seamless user experience by building an intuitive, user-friendly and integrated digital service. You will find clearer instructions as well as pop-up help throughout the process. The new interface should improve efficiency, eliminate duplication of effort and overall make your proposal submission process simpler.

Request for Information (RFI)

Right after last year's solicitation period, the SBIR/STTR Program released an RFI asking for feedback on our existing subtopics, ideas for potential new subtopics and general program feedback. We were overwhelmed with the response to our request. The inputs received were reviewed and considered by several teams involved in creating this solicitation – we hope that you see some of your inputs incorporated.

1.3 Three-Phase Program

The period of performance for the STTR Phase I contracts will be increased to **13** months.

1.4.5 Required Benchmark Transition Rate

The Small Business Administration (SBA) has updated the Benchmark Transition Rate language. Companies that failed to meet the transition rate benchmark on June 1, 2017 are not eligible to submit a Phase I proposal during the period June 1, 2017 through May 31, 2018.

3.3.2 (Phase I) and 3.4.2 (Phase II) Format Requirements

The page limits on the technical proposals have been made consistent across SBIR and STTR. For Phase I, both programs will now have a 19-page limit for the technical proposal. For Phase II, the page limit will be 46 pages. With the new EHB interface, all additional forms and requirements will be handled separately so the page limit for the technical proposal will be truly just for the technical proposal.

3.3.4 (Phase I) and 3.4.4 (Phase II) Technical Proposal

The Technical Proposal will have 10 parts this year instead of the 11 parts in previous years. The content that was previously captured in Part 7: Relationship with Phase II or Future R/R&D (Phase I) or Phase III Efforts, Commercialization and Business Planning (Phase II) and Part 10: Potential Post Applications have been consolidated to reduce potentially duplicate information being requested.

3.3.7 (Phase I) and 3.4.7 (Phase II) Briefing Chart

The Briefing Chart is used to assist in the ranking and advocacy of proposals prior to selection. To make the information received more informative, a requirement to indicate deliverables has been added. There is also additional guidance provided.

9. Research Topics for SBIR and STTR

The STTR subtopics will appear in an integrated list with the SBIR subtopics this year. They will be clearly marked as STTR subtopics so that offerors will know that the additional Research Institution (RI) partnership is required before submitting a proposal. This will assist Firms in seeing related subtopics across both programs.

This will be the second year that the subtopics are being organized by Focus Area within Chapter 9 of the solicitation. Focus Areas are a way of grouping NASA interests and related technologies. This is intended to make it easier for offerors to understand related needs across the agency and thus identify subtopics where their research and development capabilities may be a good match. If any offeror wishes to view subtopics sorted by mission directorate, this listing will still be accessible on the website, but will not be the default view.

1. Program Description

1.1 Introduction

This document includes two NASA program solicitations with separate subtopics under which small business concerns (SBCs) are invited to submit proposals: the Small Business Innovation Research (SBIR) Program and the Small Business Technology Transfer (STTR) Program. Each subtopic will indicate its program of origin. Program background information, eligibility requirements for participants, information on the three program phases, and information for submitting responsive proposals are contained herein. The fiscal year 2018 Solicitation period for Phase I proposals begins January 11, 2018 and ends March 09, 2018.

The NASA SBIR/STTR Programs do not accept proposals solely directed towards system studies, market research, routine engineering, development of existing product(s), proven concepts or modifications of existing products without substantive innovation.

It is anticipated that some SBIR and STTR Phase I proposals will be selected for negotiation of firm-fixed-price contracts approximately during the month of June 2018. Historically, the percentage of Phase I proposals to awards is approximately 13-15%, and approximately 35-40% of the selected Phase I contracts are competitively selected for Phase II follow-on efforts.

Under this Solicitation NASA will not accept more than 10 proposals to either program from any one firm (20 total) in order to ensure the broadest participation of the small business community. NASA does not plan to award more than 5 SBIR contracts and 2 STTR contracts to any offeror (7 total). See section 3.1.

Proposals including all relevant documentation must be submitted online via the Proposal Submissions Electronic Handbook at http://sbir.nasa.gov. Unsolicited proposals will not be accepted.

1.2 Program Management and Alignment

The Space Technology Mission Directorate (STMD) provides overall policy direction for implementation of the NASA SBIR/STTR Programs. The NASA SBIR/STTR Program Management Office, which operates the programs in conjunction with NASA mission directorates and centers, is hosted at the NASA Ames Research Center. NASA Shared Services Center (NSSC) provides the overall procurement management for the programs.

For the SBIR Program, NASA research and technology areas to be solicited are identified annually by the agency's mission directorates. The directorates identify high priority research problems and technology needs for their respective programs and projects. The range of problems and technologies is broad, and the list of topics and subtopics vary in content from year to year to maintain alignment with current interests.

The STTR Program is aligned with the priorities of NASA's Space Technology Roadmaps, as well as the associated core competencies of the NASA centers. Again, the range of technologies is broad, and the list of topics and subtopics vary in content from year to year to maintain alignment with current interests.

For information regarding the mission directorates and the NASA centers see section 7.1.

For details on the research topic descriptions by Focus Area please see section 9.

1.3 Three-Phase Program

Both the SBIR and STTR Programs are divided into three funding and development stages. These three phases are described in detail on the NASA SBIR/STTR website: http://sbir.nasa.gov/content/nasa-sbirsttr-basics.

Phase I and II

Maximum value and period of performance for Phase I and Phase II contracts:

Phase I Contracts	**SBIR**	**STTR**
Maximum Contract Value	$125,000	$125,000
Period of Performance	6 months	13 months
Phase II Contracts	**SBIR**	**STTR**
Maximum Contract Value	$750,000	$750,000
Maximum Period of Performance	24 months	24 months

Post-Phase II Opportunities for Continued Technology Development

The NASA SBIR/STTR Program has two initiatives for supporting its small business partners beyond the basic Phase II award. These are the Phase II Extended (Phase II-E) contract option and the Civilian Commercialization Readiness Pilot Program (CCRPP) contract.

Please refer to http://sbir.nasa.gov/content/post-phase-ii-initiatives for eligibility, application deadlines, matching requirements and further information.

Phase III

Phase III is the commercialization of innovative technologies, products and services resulting from either a Phase I or Phase II contract. This includes further development of technologies for transition into NASA programs, other government agencies or the private sector. Phase III contracts are funded from sources other than the SBIR and STTR programs and may be awarded without further competition.

Please refer to http://sbir.nasa.gov/content/post-phase-ii-initiatives for Phase III information.

1.4 Availability of Funds

All Phase I and Phase II and post-Phase II awards are subject to availability of funds. NASA has no obligation to make any specific number of awards based on this solicitation, and may elect to make several or no awards in any specific technical topic or subtopic.

1.5 Eligibility Requirements

1.5.1 Small Business Concern

Only firms qualifying as SBCs, as defined here: http://sbir.nasa.gov/content/nasa-sbirsttr-program-definitions, are eligible to participate in these programs. Socially and economically disadvantaged and women-owned SBCs are particularly encouraged to propose.

1.5.2 Place of Performance

Research/Research & Development (R/R&D) must be performed in the United States (See: http://sbir.nasa.gov/content/nasa-sbirsttr-program-definitions). However, based on a rare and unique circumstance (for example, if a supply or material or other item or project requirement is not available in the United States), NASA may allow a particular portion of the research or R&D work to be performed or obtained in a country outside of the United States. Proposals must clearly indicate if any work will be performed outside the United States, including subcontractor performance. Prior to award, approval by the Contracting Officer for such specific condition(s) must be in writing.

1.5.3 Principal Investigator (PI) Employment Requirement

The primary employment of the Principal Investigator (PI) shall be with the SBC under the SBIR Program, while under the STTR Program, either the SBC or Research Institution (RI) shall employ the PI. Primary employment means that more than 50% of the PI's total employed time (including all concurrent employers, consulting and self-employed time) is spent with the SBC or RI at time of award and during the entire period of performance. Primary employment with a small business concern precludes full-time employment at another organization. If the PI does not currently meet these primary employment requirements, then the offeror must explain how these requirements will be met if the proposal is selected for contract negotiations that may lead to an award. Co-Principal Investigators are not allowed.

Note: NASA considers a full-time workweek to be nominally 40 hours and we consider a 19.9-hour or more workweek elsewhere to be in conflict with this rule. In rare occasions, minor deviations from this requirement may be necessary; however, any minor deviation must be approved in writing by the Contracting Officer after consultation with the NASA SBIR/STTR Program Manager/Business Manager.

Requirements	SBIR	STTR
Primary Employment	PI shall be primarily employed with the SBC	PI shall be primarily employed with the RI or SBC
Employment Certification	The offeror must certify in the proposal that the primary employment of the PI will be with the SBC at the time of award and during the conduct of the project	The offeror must certify in the proposal that the primary employment of the PI will be with the SBC or the RI at the time of award and during the conduct of the project
Co-PIs	Not Allowed	Not Allowed
Misrepresentation of Qualifications	Shall result in rejection of the proposal or termination of the contract	Shall result in rejection of the proposal or termination of the contract
Substitution of PIs	Requires a prior approval from NASA	Requires a prior approval from NASA

1.5.4 Restrictions on Venture Capital-owned Businesses

As set forth in the SBIR Reauthorization Act of 2011, small businesses owned in majority part by multiple venture capital operating companies, hedge funds or private equity firms may be eligible for SBIR awards. SBA's regulations in 13 CFR part 121 set forth the eligibility criteria for SBIR applicants that are owned in majority part by multiple venture capital operating companies, hedge funds or private equity firms. SBIR agencies must submit a written determination (to the SBA; the Senate Committee on Small Business and Entrepreneurship; the House Committee on Small Business and the House Committee on Science, Space, and Technology) at least 30 calendar days before it begins making awards to SBCs that are owned in majority part by multiple venture capital operating companies, hedge funds or private equity firms.

Note: At the current time, such firms are not eligible to submit proposals to the NASA SBIR/STTR Solicitation.

1.5.5 Joint Ventures and Limited Partnerships

Both joint ventures and limited partnerships are permitted, provided the entity created qualifies as an SBC in accordance with the definition of an SBC here: http://sbir.nasa.gov/content/nasa-sbirsttr-program-definitions. A statement of how the workload will be distributed, managed and charged should be included in the proposal. A copy or comprehensive summary of the joint venture agreement or partnership agreement should be included on the Technical Proposal upload page.

1.5.6 Required Benchmark Transition Rate

To be eligible for a NASA Phase I SBIR or STTR award, the applicant must meet the Phase I to Phase II Transition Rate Benchmark as required by the SBIR/STTR Reauthorization Act of 2011. The Transition Rate requirement applies only to SBIR and STTR Phase I applicants that have received more than 20 Phase I awards over the past five fiscal years, excluding the most recently completed fiscal year. Companies with more than 20 Phase I awards during the past five years can view their Transition Rate if they log onto their Company Registry account at www.sbir.gov. For these companies, the benchmark establishes a minimum number of Phase II awards the company must have received for a given number of Phase I awards received during the five-year time period in order to be eligible to receive a new Phase I award. This requirement does not apply to companies that have received less than 20 Phase I awards over the five-year period.

On June 1 of each year, the SBA assesses SBIR/STTR awardees using SBIR and STTR award information across all federal agencies reported on www.sbir.gov to determine if they meet the benchmark requirements. Companies that failed to meet the transition rate benchmark on June 1, 2017 are not eligible to submit a Phase I proposal during the period June 1, 2017 through May 31, 2018. Companies were notified by the SBA if they failed to meet the benchmark.

More information on the Transition Rate requirements is available at https://www.sbir.gov/faqs/performance-benchmarks.

1.6 NASA Technology Available (TAV) for SBIR/STTR Use

Offerors have the option of using technology developed by NASA (Technology Available (TAV)) related to the subtopic to which they are proposing. While NASA scientists and engineers conduct breakthrough research that leads to innovations, the range of NASA's effort does not extend to commercial product development in any of its intramural research areas. Additional work is often necessary to exploit these NASA technologies (TAVs) for either infusion or commercial viability and likely requires innovation on behalf of the private sector. These can be found via the NASA Technology Transfer Portal, http://technology.nasa.gov, and may be a NASA owned patent and/or computer software. Use of a TAV requires a patent license or Software Usage Agreement from NASA. TAVs are available for use during both Phase I and Phase II award periods, including any extensions. NASA provides these technologies "as is" and makes no representation or guarantee that additional effort will result in infusion or commercial viability.

Whether or not a firm proposes the use of a NASA patent or computer software within their proposed effort will not in any way be a factor in the selection for award.

Use of NASA Software

If an offeror intends to use NASA software, a Software Usage Agreement (SUA), on a non-exclusive, royalty-free basis, is necessary, and the clause at 48 C.F.R. 1852.227-88, “Government-Furnished Computer Software and Related Technical Data,” will apply to the contract. A Software Usage Agreement (SUA) shall be requested from the appropriate NASA Center Software Release Authority (SRA), after contract award.

Use of NASA Patent
All offerors submitting proposals including the use of a NASA patent must submit an application for a non-exclusive, royalty-free research license. The NASA license application is available on the NASA SBIR/STTR website: http://sbir.gsfc.nasa.gov/sites/default/files/research_license_app.doc. The completed research license application must be uploaded on the Proposal Certifications page. Such grant of non-exclusive research license will be set forth in the successful offeror's SBIR/STTR contract. The evaluation license will automatically terminate at the end of the SBIR/STTR contract. License applications will be treated in accordance with federal patent licensing regulations as provided in 37 CFR Part 404.

In addition to a research license, if the proposed work includes the making, using or selling of products or services incorporating a NASA patent, successful awardees will be given the opportunity to negotiate a non-exclusive commercialization license or, if available, an exclusive commercialization license to the NASA patent. Commercialization licenses are also provided in accordance with 37 CFR Part 404.

An SBIR/STTR awardee that has been granted a non-exclusive, royalty-free research license to use a NASA patent under the SBIR/STTR award may, if available and on a non-interference basis, also have access to NASA personnel knowledgeable about the NASA patent. The NASA Intellectual Property Manager (IPM) located at the appropriate NASA center will be available to assist awardees requesting information about a patent that was identified in the SBIR/STTR contract and, if available and on a non-interference basis, provide access to the inventor or surrogate for the purpose of knowledge transfer.

Note: Access to the inventor for the purpose of knowledge transfer will require the requestor to enter into a Non-Disclosure Agreement (NDA). The awardee may be required to reimburse NASA for knowledge transfer activities. For Phase I proposals this is a time-consuming process and is not recommended.

1.7 I-Corps

The NASA SBIR/STTR Program is partnering with the National Science Foundation (NSF) to offer the NSF Innovation Corps Program (I-Corps). I-Corps focuses on educating teams on how to translate technologies from the laboratory into the marketplace. Participation in I-Corps will require selected contractors to conduct either 30 interviews (shortened version for the SBIR Program) or 100 interviews (full version for the STTR Program) to enable contractors to understand the commercial potential of their ideas. Selected contractors will be awarded training grants, separate from their Phase I contract, that must be completed prior to the conclusion of Phase I contracts. The program is described further at http://sbir.nasa.gov/content/I-Corps. The application process for I-Corps is described in Section 3.2.6. NASA will conduct an abbreviated competition for I-Corps after it selects offerors for Phase I SBIR and STTR contracts. NASA anticipates awarding a total of approximately 35 grants to SBIR and STTR Phase I contractors. The amount of funding is up to $25,000 for the full I-Corps Program for STTR firms, and up to $10,000 for the shortened version for SBIR firms.

1.8 Commercialization Technical Assistance

In accordance with the Small Business Act (15 U.S.C. 632), NASA will authorize the recipient of a Phase II SBIR/STTR award to purchase technical assistance services through an outside vendor, such as access to a network of non-NASA scientists and engineers engaged in a wide range of technologies, or access to technical and business literature available through online databases, for the purpose of assisting such concerns in:

1. Making better technical decisions concerning such projects.
2. Solving technical problems which arise during the conduct of such projects.

3. Minimizing technical risks associated with such projects.
4. Developing and commercializing new commercial products and processes resulting from such projects.

If you are interested in proposing the use of a vendor for technical assistance, you must complete the “Technical Assistance” section located under Other Direct Costs (ODCs) in the Proposal Budget form. You must provide the vendor name and contact information, the proposed amount not to exceed $5,000 and a detailed explanation of the services to be provided. You must also upload a price quote from the vendor including their DUNS number. Approval of technical assistance is not guaranteed and is subject to review by the Contracting Officer.

Note: Commercialization assistance does not count toward the maximum award size of your Phase II.

1.9 NASA Mentor-Protégé Program (MPP)

The purpose of the NASA Mentor-Protégé Program (MPP) is to provide incentives to NASA contractors, performing under at least one active approved subcontracting plan negotiated with NASA, to assist protégés in enhancing their capabilities to satisfy NASA and other contract and subcontract requirements. The NASA MPP, established under the authority of Title 42, U.S.C., 2473(c)(1) and managed by the Office of Small Business Programs (OSBP), includes an Award Fee Pilot Program. Under the Award Fee Pilot Program, a mentor is eligible to receive an award fee at the end of the agreement period based upon the mentor’s performance of providing developmental assistance to an active SBIR/STTR Phase II contractor in a NASA Mentor-Protégé agreement (MPA).

The evaluation criterion is based on the amount and quality of technology transfer and business development skills that will increase the protégé’s Technology Readiness Levels (TRLs). TRLs measure technology readiness on a scale of 1 to 9. A mentor should attempt to raise the TRL of the protégé and outline the goals and objectives in the MPA and the award fee plan. A separate award fee review panel set up by NASA OSBP will use the semiannual reports, annual reviews and the award fee plan in order to determine the amount of award fee given at the end of the performance period of the agreement.

For more information on the Mentor-Protégé Program please visit: http://www.osbp.nasa.gov/mpp/index.html.

1.10 NASA Procurement Ombudsman Program

The NASA Procurement Ombudsman Program is available under this solicitation as a procedure for addressing concerns and disagreements. The clause at NASA FAR Supplement (NFS) 1852.215-84 (“Ombudsman”) is incorporated into this solicitation.

The cognizant ombudsman is:

Monica Manning
Deputy Assistant Administrator for Procurement
Office of Procurement
NASA Headquarters
Washington, DC 20546-0001
Telephone: 202-358-4483
Fax: 202-358-3082
Email: agency-procurementombudsman@nasa.gov

1.11 General Information

1.11.1 Means of Contacting NASA SBIR/STTR Program

1. NASA SBIR/STTR Website: http://sbir.nasa.gov

2. Help Desk: The NASA SBIR/STTR Help Desk can answer any questions regarding clarification of proposal instructions and any administrative matters. The Help Desk may be contacted by:

    a. Email: sbir@reisystems.com
    b. Telephone: 301-937-0888 between 9:00 a.m.-5:00 p.m. (Mon.-Fri., Eastern Time)
    c. The requestor must provide the name and telephone number of the person to contact, the organization name and address, and the specific questions or requests.

3. NASA SBIR/STTR Program Manager: Specific information requests that could not be answered by the Help Desk should be emailed to:

    ARC-SBIR-PMO@mail.nasa.gov

1.11.2 Questions about this Solicitation

To ensure fairness, questions relating to the intent and/or content of research topics in this Solicitation cannot be addressed during the open solicitation period. Only questions requesting clarification of proposal instructions and administrative matters will be addressed.

The cut-off date and time for receipt of Phase I solicitation procurement related questions and answers is 5:00 p.m. Eastern, March 2, 2018.

The cut-off date and time for receipt of Phase II solicitation procurement related questions and answers is seven calendar days prior to the end of the Phase I contract.

1.12 Definitions

A comprehensive list of definitions related to the SBIR and STTR Programs is available at: http://sbir.nasa.gov/content/nasa-sbirsttr-program-definitions. These definitions include those from the SBIR and STTR policy directives, as well as terms specific to NASA. Offerors are strongly encouraged to review these prior to submitting a proposal.

2. Certifications and Other Proposal Information

2.1 SBA Firm Registry

SBA maintains and manages a Company Registry at http://www.sbir.gov to track ownership and affiliation requirements for all companies applying to the SBIR/STTR Program. The SBIR and STTR Policy Directives require each small business concern (SBC) applying for a Phase I or Phase II award to register in the Company Registry prior to submitting an application. A PDF document with the SBC registration information is available for download by the SBC upon successful registration. This PDF document must be saved by the SBC for inclusion in applications submitted to SBIR/STTR agencies. All SBCs must report and/or update ownership information to SBA prior to each SBIR/STTR application submission or if any information changes prior to award.

In the NASA SBIR/STTR Proposal Submissions Electronic Handbook (EHB), the SBC must provide their unique SBC Control ID that gets assigned by SBA upon completion of the Company Registry registration, as well as upload the PDF document validating their registration. This information is submitted to NASA via the Firm Certifications form and is applicable across all proposals submitted by the SBC for that specific solicitation.

2.2 System for Award Management (SAM) Registration

Offerors should be aware of the requirement to register in SAM prior to contract award.

Note: To avoid a potential delay in contract award, offerors are required to register prior to submitting a proposal. To be eligible for SBIR/STTR awards firms must be registered under the applicable NAICS code. Most SBIR/STTR awards use 541713, 541714, or 541715.

SAM is the primary repository for contractor information required for the conduct of business with NASA. It is maintained by the Department of Defense. To be registered in SAM, all mandatory information, which includes the Data Universal Numbering System (DUNS) or DUNS+4 number, and a Commercial and Government Entity (CAGE) code, must be validated in SAM. The DUNS number or Data Universal Number System is a 9-digit number assigned by Dun and Bradstreet Information Services (http://www.dnb.com) to identify unique business entities. The DUNS+4 is similar, but includes a 4-digit suffix that may be assigned by a parent (controlling) business concern. The CAGE code or Commercial and Government Entity Code is assigned by the Defense Logistics Information Service (DLIS) to identify a commercial or government entity. If an SBC does not have a CAGE code, one will be assigned during the SAM registration process.

The DoD has established a goal of registering an applicant in SAM within 48 hours after receipt of a complete and accurate application via the SAM.gov website. Offerors that are not registered should consider applying for registration immediately upon receipt of this solicitation. Offerors and contractors may obtain information on SAM registration and annual confirmation requirements at https://www.sam.gov or by calling (866) 606-8220.

The following links are provided for contractors that have never registered in SAM.gov or acquired a DUNS number:

- Overall guidelines:
  - https://www.fws.gov/international/pdf/sam-duns-registration-instructions.pdf
- New DUNS Number Request:
  - http://fedgov.dnb.com/webform
- New SAM Registration Information:
  - https://www.sam.gov/sam/transcript/Quick_Guide_for_Grants_Registrations.pdf

- For additional assistance, please visit SAM HELP link at the top of the home page or by visiting www.fsd.gov or calling 866-606-8220.

It is recommended to list Purpose of Registration as "All Awards" on your SAM Registration. Information about updating SAM Registration can be found here:

- https://www.sam.gov/sam/transcript/Quick_Guide_for_Updating_or_Renewing_CCR-SAM_Registrations.pdf

2.3 Firm Certifications

Offerors must complete the Firm Certifications section of the Proposal Submissions Electronic Handbook, answering Yes or No to certifications as applicable.

Firms should carefully read each of the certification statements. The federal government relies on the information to determine whether the business is eligible for a SBIR or STTR Program award. A similar certification will be used to ensure continued compliance with specific program requirements during the life of the funding agreement. The definitions for the terms used in this certification are set forth in the Small Business Act, SBA regulations (13 C.F.R. Part 121), the SBIR and STTR Policy Directives and any statutory and regulatory provisions referenced in those authorities.

If the Contracting Officer believes that the business may not meet certain eligibility requirements at the time of award, they are required to file a size protest with the U.S. Small Business Administration (SBA), who will determine eligibility. At that time, SBA will request further clarification and supporting documentation in order to assist in the eligibility determination. Additionally, the Contracting Officer may request further clarification and supporting documentation regarding eligibility to determine whether a referral to SBA is required.

2.4 FAR Certifications

SAM contains required certifications offerors may access at https://www.acquisition.gov/browsefar as part of required registration (see FAR 4.1102). Offerors must complete these certifications to be eligible for award.

Offerors should be aware that SAM requires all offerors provide representations and certifications electronically via the website, and to update the representations and certifications as necessary, but at least annually, to keep them current, accurate and complete. NASA will not enter into any contract wherein the Contractor is not compliant with the requirements stipulated herein.

2.4.1 52.222-37 Employment Reports on Special Disabled Veterans, Veterans of the Vietnam-Era and Other Eligible Veterans

In accordance with Title 38, United States Code, Section 4212(d), the U.S. Department of Labor (DOL) Veterans' Employment and Training Service (VETS) collects and compiles data on the Federal Contractor Program Veterans' Employment Report (VETS-4212 Report) from federal contractors and subcontractors who receive federal contracts that meet the threshold amount of $100,000. The VETS-4212 reporting cycle begins annually on August 1 and ends September 30. Any federal contractor or prospective contractor that has been awarded or will be awarded a federal contract with a value of $100,000 or greater must have a current VETS-4212 report on file. Please visit the DOL VETS-4212 website at http://www.dol.gov/vets/programs/fcp/main.htm. NASA will not enter into any contract wherein the firm is not compliant with the requirements stipulated herein.

2.5 NASA Clauses

The following NASA clauses are necessary to implement restrictions in NASA appropriations. Offerors must comply with these clauses to be eligible for award.

1852.203-71 Requirement to Inform Employees of Whistleblower Rights (Aug 14)

(a) The Contractor shall inform its employees in writing, in the predominant native language of the workforce, of contractor employee whistleblower rights and protections under 10 U.S.C. 2409, as described in subpart 1803.9 of the NASA FAR Supplement.
(b) The Contractor shall include the substance of this clause, including this paragraph (b), in all subcontracts.

1852.225-72 Restriction on funding Activity with China – Representation

(a) Definition - "China" or "Chinese-owned" means the People's Republic of China, any firm owned by the People's Republic of China or any firm incorporated under the laws of the People's Republic of China.
(b) Public Laws 112-10, Section 1340(a) 112-55, Section 536 and Section 535, PL 113-6 restrict NASA from contracting to participate, collaborate or coordinate bilaterally in any way with China or a Chinese-owned firm with funds appropriated on or after April 25, 2011. NASA anticipates this restriction will be in future appropriation acts. Contracts for commercial and non-developmental items are excepted from the prohibition as they constitute purchase of goods or services that would not involve participation, collaboration, or coordination between the parties.
(c) Representation. By submission of its offer, the offeror represents that the offeror is not China or a Chinese-owned firm.

2.6 False Statements

Note: Knowingly and willfully making any false, fictitious or fraudulent statements or representations may be a felony under the Federal Criminal False Statement Act (18 U.S.C. Sec 1001), punishable by a fine and imprisonment of up to five years in prison. The Office of the Inspector General (OIG) has full access to all proposals submitted to NASA.

Pursuant to NASA policy, any company representative who observes crime, fraud, waste, abuse, or mismanagement or receives an allegation of crime, fraud, waste, abuse or mismanagement from a federal employee, contractor, grantee, contractor or grantee employee, or any other source will report such observation or allegation to the OIG. NASA contractor employees and other individuals are also encouraged to report crime, fraud, waste and mismanagement in NASA's programs to the OIG. The OIG offers several ways to report a complaint:

NASA OIG Hotline
1-800-424-9183
TDD: 1-800-535-8134

NASA OIG Cyber Hotline
http://oig.nasa.gov/cyberhotline.html

NASA OIG Headquarters
Office of Investigations fax number: 202-358-3914

Or by mail:
NASA Office of Inspector General
P.O. Box 23089
L'Enfant Plaza Station
Washington, DC 20026

2.7 Software Development Standards

Offerors proposing projects involving the development of software may be required to comply with the requirements of NASA Procedural Requirements (NPR) 7150.2A, "NASA Software Engineering Requirements" which are available online at http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7150&s=2.

2.8 Human and/or Animal Subject

Offerors should be aware of the requirement that an approved protocol by a NASA Review Board is required if the proposed work includes human or animal subject. An approved protocol shall be provided to the Contracting Officer prior to the initiation of any human and/or animal subject research. Offerors shall identify the use of human or animal subject in the Proposal Certifications form. For additional information, contact the NASA SBIR/STTR Program Management Office at ARC-SBIR-PMO@mail.nasa.gov. Reference 14 CFR 1230 and 1232.

Note: Due to the complexity of the approval process, use of human and/or animal subjects is not allowed for Phase I contracts.

2.9 HSPD-12

Firms that require access to federally controlled facilities or access to a federal information system (federally controlled facilities and federal information system are defined in FAR 2.101(b)(2)) **for six consecutive months or more** must adhere to Homeland Security Presidential Directive 12 (HSPD-12), "Policy for a Common Identification Standard for Federal Employees and Contractors", and Federal Information Processing Standards Publication (FIPS PUB) Number 201, "Personal Identity Verification (PIV) of Federal Employees and Contractors," which require agencies to establish and implement procedures to create and use a government-wide secure and reliable form of identification no later than October 27, 2005. See: http://csrc.nist.gov/publications/fips/fips201-1/FIPS-201-1-chng1.pdf. In accordance with the FAR clause 52.204-9, "Personal Identity Verification of Contractor Personnel," which states in part that the contractor shall comply with the requirements of this clause and shall ensure that individuals needing such access shall provide the personal background and biographical information requested by NASA.

If applicable, detailed procedures for the issuance of a PIV credential can be found at the following URL:
http://csrc.nist.gov/groups/SNS/piv.

3. Proposal Preparation Instructions and Requirements

3.1 Fundamental Considerations

Multiple Proposal Submissions
Each proposal submitted must be based on a unique innovation, must be limited in scope to just one subtopic and shall be submitted only under that one subtopic within each program. An offeror shall not submit more than 10 proposals to each of the SBIR or STTR Programs (20 total). An offeror may submit more than one unique proposal to the same subtopic; however, an offeror shall not submit the same (or substantially equivalent) proposal to more than one subtopic. Submitting substantially equivalent proposals to several subtopics may result in the rejection of all such proposals. In order to enhance SBC participation, NASA does not plan to select more than 5 SBIR proposals and 2 STTR proposals from any one offeror under this solicitation (7 total).

3.2 Proprietary Information in the Proposal Submission

If proprietary information is provided by an applicant in a proposal, which constitutes a trade secret, proprietary commercial or financial information, confidential personal information or data affecting the national security, it will be treated in confidence to the extent permitted by law. This information must be clearly marked by the applicant as confidential proprietary information. NASA will treat in confidence pages listed as proprietary during the review step of proposal submission.

Information contained in unsuccessful proposals will remain the property of the applicant. The government will, however, retain copies of all proposals.

3.2.1 Release of Certain Proposal Information

In submitting a proposal, the offeror agrees to permit the government to disclose publicly the information contained in the Contact Information form, Proposal Summary form and Briefing Chart. Other proposal data is considered to be the property of the offeror, and NASA will protect it from public disclosure to the extent permitted by law including requests submitted under the Freedom of Information Act (FOIA).

3.3 Phase I Proposal Requirements

3.3.1 General Requirements

A competitive proposal will clearly and concisely: (1) describe the proposed innovation relative to the state of the art; (2) address the scientific, technical, and commercial merit and feasibility of the proposed innovation, and its relevance and significance to NASA interests as described in section 9 of this solicitation; and (3) provide a preliminary strategy that addresses key technical, market and business factors pertinent to the successful development, demonstration of the proposed innovation, and its transition into products and services for NASA mission programs, the commercial aerospace industry, and other potential markets and customers.

3.3.2 Format Requirements

Note: The government administratively screens all proposals and reserves the right to reject any proposal that does not conform to the following formatting requirements.

Page Limitations and Margins

Note: Technical proposal uploads with any page(s) going over the required page limit will not be accepted.

A Phase I technical proposal shall not exceed a total of 19 standard 8 1/2 x 11 inch (21.6 x 27.9 cm) pages. Proposals uploaded with more than 19 pages will prompt a warning which will prevent the completed proposal from being submitted. Each page shall be numbered consecutively at the bottom. Margins shall be 1.0 inch (2.5 cm). The space allocated to each part of the technical content will depend on the project chosen and the offeror's approach. The additional forms required for proposal submission will not count against the 19-page limit.

Each complete proposal package submitted shall contain the following items:

1. Proposal Contact Information
2. Proposal Certifications, electronically endorsed.
3. Proposal Summary (must not contain proprietary data).
4. Proposal Budget (including letters of availability for facilities and subcontractors/consultants, if applicable)
5. Technical Proposal - 10 parts in the order specified in section 3.3.4, and not to exceed 19 pages **(both SBIR and STTR)**, including all graphics, with a table of contents.
6. Research Agreement between the SBC and RI **(STTR only)**.
7. Briefing Chart (must not contain proprietary data).
8. NASA Research License Application, only if TAV is being proposed.
9. I-Corps Opt-In Form

Note: Letters expressing general technical interest or letters of funding support commitments (for Phase I) are not required or desired and will not be considered during the review process. However, if submitted, such letter(s) will count against the page limit.

In addition to the above items, each offeror must submit the following firm level forms, which must be filled out once during each submission period and are applicable to all firm proposal submissions:

1. Firm Certifications
2. Audit Information
3. Prior Awards Addendum
4. Commercial Metrics Survey

Previews of all forms and certifications are available via the NASA SBIR/STTR Firm Library, located at: http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html.

Note: Website references, relevant technical papers, product samples, videotapes, slides or other ancillary items will not be considered during the review process.

Type Size

No type size smaller than 10 point shall be used for text or tables, except as legends on reduced drawings. Proposals prepared with smaller font sizes may be rejected without consideration.

Header/Footer Requirements

Header must include firm name, proposal number and project title. Footer must include the page number and proprietary markings if applicable. Margins can be used for header/footer information.

Classified Information
NASA does not accept proposals that contain classified information.

Project Title
The proposal project title shall be concise and descriptive of the proposed effort. The title should not use acronyms or words like "Development of" or "Study of." The NASA research topic title must not be used as the proposal title.

3.3.3 Forms

All form submissions shall be completed electronically, and do not count towards the 19-page limit for the technical proposal.

3.3.3.1 Proposal Contact Information

A sample Contact Information form is provided in the NASA SBIR/STTR Firm Library http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html. The offeror shall provide complete information for each contact person and submit the form as required in section 6.

Note: Contact Information is public information and may be disclosed.

3.3.3.2 Proposal Certifications

A sample Proposal Certifications form is provided in the NASA SBIR/STTR Firm Library http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html. The offeror shall provide complete information for each item and submit the form as required in section 6.

3.3.3.3 Proposal Summary

A sample Proposal Summary form is provided in the NASA SBIR/STTR Firm Library http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html. The offeror shall provide complete information for each item and submit the form as required in section 6.

Note: Proposal Summary, including the Technical Abstract, is public information and may be disclosed. Do not include proprietary information in this form.

3.3.3.4 Proposal Budget

A sample of the Proposal Budget form is provided in the NASA SBIR/STTR Firm Library http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html. The offeror shall complete the Proposal Budget following the instructions provided with the sample form. The total requested funding for the Phase I effort shall not exceed $125,000. Contextual help is provided on the electronic budget form for additional explanation. Information shall be submitted to explain the offeror's plans for use of the requested funds to enable NASA to determine whether the proposed price is fair and reasonable.

Note: The government is not responsible for any monies expended by the firm before award of any contract.

In addition, the following additional uploads, must be submitted in the Proposal Budget form, as applicable:

Proposal Requirements for Use of Federal Services, Facilities or Equipment:
In cases where an offeror seeks to use NASA or another federal department or agency services, equipment or facilities, the offeror shall provide the following:

1. Statement, signed by the appropriate government official at the effected federal department or agency, verifying that the resources should be available during the proposed period of performance.
2. Signed letter on company letterhead from the contractor's Small Business Official explaining why the SBIR/STTR research project requires the use of federal services, equipment or facilities, including data that verifies the absence of non-federal facilities or personnel capable of supporting the research effort, a statement confirming that the facility proposed is not a federal laboratory, if applicable, and the associated cost estimate.

See Part 8 of the Technical Proposal for additional information on use of federal facilities.

Use of Subcontractors and Consultants:
Subject to the restrictions set forth below, the SBC may establish business arrangements with other entities or individuals to participate in performance of the proposed R/R&D effort.

Note:

1. ***Offerors should list consultants by name and specify, for each, the number of hours and hourly costs.***
2. ***Breakdown of subcontractor budget should mirror the SBC's own breakdown in the Proposal Budget form and include breakdowns of direct labor, other direct costs, profit, as well as indirect rate agreements.***
3. ***A signed letter of commitment is required for each subcontractor and/or consultant. For educational institutions, the letter must be from the institution's Office of Sponsored Programs.***

Subcontractors' and consultants' work has the same place of performance restrictions as stated in section 1.5.2.

The following restrictions apply to the use of subcontracts/consultants and the formula below must be used in preparing budgets with subcontractors/consultants:

SBIR Phase I Subcontracts/Consultants	STTR Phase I Subcontracts/Consultants
The proposed subcontracted business arrangements, including consultants, must not exceed 33 percent of the research and/or analytical work [as determined by the total cost of the proposed subcontracting effort (to include the appropriate OH and G&A) in comparison to the total effort (total contract price including cost sharing, if any, less profit if any)].	A minimum of 40 percent of the research or analytical work must be performed by the proposing SBC and minimum of 30 percent must be performed by the RI. Any subcontracted business effort other than that performed by the RI, shall not exceed 30 percent of the research and/or analytical work [as determined by the total cost of the subcontracting effort (to include the appropriate OH and G&A) in comparison to the total effort (total contract price including cost sharing, if any, less profit if any)].

Example:		
	Total price to include profit	- $99, 500
	Profit	- $3,000
	Total price less profit	- $99,500 - $3,000 = $96,500
	Subcontractor cost	- $29,500
	G&A	- 5%
	G&A on subcontractor cost	- $29,500 x 5% = $1,475
	Subcontractor cost plus G&A	- $29,500 + $1,475 = $30,975
	Percentage of subcontracting effort – subcontractor cost plus G&A / total price less profit	**- $30,975 / $96,500 = 32.1%**

For an SBIR Phase I this is acceptable since it is below the limitation of 33%.
For an STTR Phase I, where there is a subcontract with a company other than the RI, this is unacceptable since it is above the 30% limitation.

See Part 9 of the Technical Proposal for additional information on the use of Subcontractors and Consultants.

3.3.4 Technical Proposal

This part of the submission should not contain any budget data and must consist of all ten (10) parts listed below in the given order. All ten parts of the technical proposal must be numbered and titled. Parts that are not applicable must be included and marked "Not Applicable." A proposal omitting any part will be considered non-responsive to this solicitation and may be rejected during administrative screening. The required table of contents is provided below:

Phase I Table of Contents

Part 1: Table of Contents……………………………………………………………………….………Page 1
Part 2: Identification and Significance of the Innovation
Part 3: Technical Objectives
Part 4: Work Plan
Part 5: Related R/R&D
Part 6: Key Personnel and Bibliography of Directly Related Work
Part 7: Potential Future Applications and Relationship with Future R/R&D
Part 8: Facilities/Equipment
Part 9: Subcontracts and Consultants
Part 10: Related, Essentially Equivalent and Duplicate Proposals and Awards

Part 1: Table of Contents

The technical proposal shall begin with a brief table of contents indicating the page numbers of each of the parts of the proposal.

Part 2: Identification and Significance of the Proposed Innovation

Succinctly describe:

- The proposed innovation.
- The relevance and significance of the proposed innovation to an interest, need or needs, within a subtopic described in section 9.
- The proposed innovation relative to the state of the art.

Part 3: Technical Objectives
State the specific objectives of the Phase I R/R&D effort including the technical questions posed in the subtopic description that must be answered to determine the feasibility of the proposed innovation.

Note: All offerors submitting proposals who are planning to use NASA Intellectual Property (IP) must describe their planned developments with the IP. The NASA Research License Application should be added as an attachment in the Proposal Certifications form (see paragraph 1.5).

Part 4: Work Plan

Include a detailed description of the Phase I R/R&D plan to meet the technical objectives. The plan should indicate what will be done, where it will be done and how the R/R&D will be carried out. Discuss in detail the methods planned to achieve each task or objective. Task descriptions, schedules, resource allocations, estimated task hours for each key personnel and planned accomplishments including project milestones shall be included. Offerors should ensure that the estimated task hours provided in the work plan for key personnel are consistent with the hours reported in the Proposal Budget form. If the offeror is a joint venture or limited partnership, a statement of how the workload will be distributed, managed and charged should be included here.

STTR: In addition, the work plan will specifically address the percentage and type of work to be performed by the SBC and the RI. The plan will provide evidence that the SBC will exercise management direction and control of the performance of the STTR effort, including situations in which the PI may be an employee of the RI.

Part 5: Related R/R&D
Describe significant current and/or previous R/R&D that is directly related to the proposal including any conducted by the PI or by the offeror. Describe how it relates to the proposed effort and any planned coordination with outside sources. The offeror must persuade reviewers of his or her awareness of key recent R/R&D conducted by others in the specific subject area.

Part 6: Key Personnel and Bibliography of Directly Related Work
Identify all key personnel involved in Phase I activities whose expertise and functions are essential to the success of the project. Provide bibliographic information including directly related education and experience.

The PI is considered key to the success of the effort and must make a substantial commitment to the project. The following requirements are applicable:

> **Functions:** The functions of the PI are: planning and directing the project, leading it technically and making substantial personal contributions during its implementation, serving as the primary contact with NASA on the project and ensuring that the work proceeds according to contract agreements. Competent management of PI functions is essential to project success. The Phase I proposal shall describe the nature of the PI's activities and the amount of time that the PI will personally apply to the project. The amount of time the PI proposes to spend on the project must be acceptable to the Contracting Officer.
>
> **Qualifications:** The qualifications and capabilities of the proposed PI and the basis for PI selection are to be clearly presented in the proposal. NASA has the sole right to accept or reject a PI based on factors such as education, experience, demonstrated ability and competence, and any other evidence related to the specific assignment.

Eligibility: This part shall also establish and confirm the eligibility of the PI, and indicate the extent to which other proposals recently submitted or planned for submission in Fiscal Year 2018 and existing projects commit the time of the PI concurrently with this proposed activity. Any attempt to circumvent the restriction on PIs working more than half time for an academic or a nonprofit organization by substituting an ineligible PI will result in rejection of the proposal. However, for an STTR the PI can be primarily employed by either the SBC or the RI. Please see section 1.5.3 for further explanation.

Part 7: Potential Future Applications and Relationship with Future R/R&D

Discuss the anticipated results of the proposed investigation if this project is successful (through Phase I & II). Discuss the significance of the Phase I effort in relation to its foundation for Phase II and potential follow-on development, applications and commercialization.

Commercialization is defined as the transition of technology into products and services for NASA mission programs, other government agencies and non-government markets. Discuss (1) potential and targeted applications of the technology and paths to infusion in future NASA missions and/or programs (2) possible applications in other government agencies and (3) potential non-government markets. Provide a preliminary commercialization strategy that addresses key technical, market and business factors pertinent to the successful development of the proposed innovation, and its transition into products and services for NASA mission programs, other government agencies and non-government markets. If feasible, discuss potential barriers to entry, potential competitors, risks, and existing and projected commitments for Phase III funding, investment, sales, licensing, and other indicators of commercial potential and feasibility.

Please also discuss your experience and record in technology commercialization, as applicable.

Note: Companies with no SBIR/STTR awards or fairly recent awards will not be penalized under past performance for the lack of past SBIR/STTR commercialization.

Part 8: Facilities/Equipment

Offerors must describe the necessary instrumentation and facilities to be used to perform the proposed work. Offerors must ensure the resources are adequate and address any reliance on external sources, such as government furnished equipment or facilities. In cases where an offeror seeks to use NASA or another federal department or agency services, equipment or facilities, the offeror shall describe in this part why the use of government furnished equipment or facilities is necessary. See section 3.3.3.4 and 5.13 for additional requirements when proposing use of federal facilities. The narrative description of facilities and equipment should support the proposed approach and documentation in the Proposal Budget form.

Note: Use of federal laboratories/facilities for Phase I contracts is highly discouraged. Approval for use of federal facilities and labs, for a Phase I proposal, requires Program Executive approval during negotiations if selected for award.

Part 9: Subcontracts and Consultants

The offeror must describe all subcontracting or other business arrangements and identify the relevant organizations and/or individuals with whom arrangements are planned. The expertise to be provided by the entities must be described in detail, as well as the functions, services and number of hours. Offerors are responsible for ensuring that all organizations and individuals proposed to be utilized are actually available for the time periods proposed. Subcontract costs shall be documented in the Subcontractors/Consultants section of the Proposal Budget form and supporting documentation should be uploaded for each (appropriate documentation is specified in the form). The narrative description of subcontracts and consultants should support the proposed approach and documentation in the Proposal Budget form.

Part 10: Related, Essentially Equivalent, and Duplicate Proposals and Awards
WARNING – While it is permissible with proper notification to submit identical proposals or proposals containing a significant amount of essentially equivalent work for consideration under numerous federal program solicitations, it is unlawful to enter into funding agreements requiring essentially equivalent work.

If an applicant elects to submit identical proposals or proposals containing a significant amount of essentially equivalent work under other federal program solicitations, a statement must be included in each such proposal indicating:

1. The name and address of the agencies to which proposals were submitted or from which awards were received.
2. Date of proposal submission or date of award.
3. Title, number and date of solicitations under which proposals were submitted or awards received.
4. The specific applicable research topics for each proposal submitted or award received.
5. Titles of research projects.
6. Name and title of principal investigator or project manager for each proposal submitted or award received.

Offerors are at risk for submitting essentially equivalent proposals and therefore are strongly encouraged to disclose these issues to the soliciting agency to resolve the matter prior to award.

A summary of essentially equivalent work information, as well as related research and development on proposals and awards is also required on the Proposal Certifications form (if applicable).

3.3.5 Research Agreement (Applicable for STTR proposals only)

STTR: The Research Agreement (different from the Allocation of Rights Agreement, see: http://sbir.nasa.gov/content/nasa-sbirsttr-program-definitions) is a single-page document electronically submitted and endorsed by the SBC and RI. A model agreement is provided, or firms can create their own custom agreement. The Research Agreement should be submitted as required in section 6.

All STTR Phase I proposals must provide sufficient information to convince NASA that the proposed SBC/RI cooperative effort represents a sound approach for converting technical information resident at the RI into a product or service that meets a need described in a Solicitation research topic.

3.3.6 Applications to I-Corps

Firms proposing to this solicitation will be allowed to also propose participation in the SBIR/STTR I-Corps Program using the following submittal process. I-Corps awards will be made separately from the Phase I contract as a training grant.

3.3.6.1 Step 1: Opt-In Form

Phase I SBIR/STTR offerors must complete a short I-Corps Opt-In Form as part of their Phase I proposal submission. Representations in the form will determine an offeror's eligibility to participate in I-Corp. The form also asks that offerors provide a brief summary explaining the value of I-Corps to their companies. In the event a large number of offerors express interest, the government reserves the right to limit the number of offerors invited to submit I-Corps proposals based upon the government's assessment of the initial summary statements.

3.3.6.2 I-Corps Proposal

To be qualified to submit an I-Corps proposal: 1) offerors must have opted in to I-Corps as part of their Phase I proposals; 2) offerors must be qualified to participate in I-Corps and 3) offerors must be selected for a Phase I award. Participating offerors must form a team composed of three main members: The Principal Investigator, the Entrepreneurial Lead and the Mentor, as described in http://sbir.nasa.gov/content/I-Corps. The I-Corps proposal shall follow the same format requirements as the SBIR/STTR Phase I proposal, shall be limited to six pages and shall include the following sections in order to be considered complete:

- I-Corps Team and Commercialization Plan (limited to five pages).
    - I-Corps Team: Biographical sketches of I-Corps team members and their commitment to participate in I-Corps (limited to one page per team member).
    - Commercialization Plan (limited to one page). This shall include:
        - Composition and roles (Principal Investigator, Entrepreneurial Lead and Mentor) of the team members proposing to undertake the commercialization feasibility research.
        - Building off the commercialization information provided in the Phase I proposal, include an additional, brief description of the potential non-NASA commercial impacts of the project, what types of customer discovery the firm hopes to accomplish through I-Corps and what steps the company will take to move the project closer to commercialization.
- I-Corps Proposal Budget (limited to one page).
    - Capped at $10,000 for each SBIR team and $25,000 for each STTR team.
    - Only recovery of certain direct costs associated with participation in I-Corps is allowed, no recovery of indirect costs is allowed.
    - The budget should include the following five components:
        - Maximum of $5,500 for Entrepreneurial Lead stipend (no stipend for the Principal Investigator or I-Corps Mentor)
        - An estimate for the travel costs associated with team member participation in required kick-off and close out/lessons learned meetings (i.e., airfare, per diem costs). Suggested limit is $5,500 per team.
        - Costs for workshop registration fees that will be paid to the instruction service (logistics) providers. This is expected to be $4,500 per team.
        - Estimated costs for travel associated with the three team members traveling as a group to conduct customer interviews (30 interviews for SBIR participants and 100 interviews for STTR participants). Suggested limits are $2,550 for SBIR teams and $10,000 for STTR teams.

The I-Corps proposal will be due one week after formal notification that the firm has been selected for negotiation of a Phase I SBIR or STTR contract. The firm shall submit their I-Corps proposal into the Proposal Submissions EHB, which shall be re-opened for those firms which have met the three qualifications identified above.

Note: Proposals for I-Corps have separate page limitations outside the page limitations for the technical proposal.

3.3.7 Briefing Chart

The one-page briefing chart is required to assist in the ranking and advocacy of proposals prior to selection and contains the following sections with summary information:

- Identification and Significance of Innovation
- Technical Objectives, Work Plan and Proposed Deliverables
- NASA Applications
- Non-NASA Applications
- Graphic

It shall not contain any proprietary data or ITAR restricted data. An electronic form will be provided during the submissions process.

Note: The briefing chart is public information and may be disclosed. Do not include proprietary information in this form.

3.3.8 Firm Certifications

Firm certifications that are applicable across all proposal submissions submitted to this solicitation must be completed via the Firm Certifications section of the Proposal Submissions Electronic Handbook. The offeror shall answer Yes or No as applicable. An example of the certifications can be found in the NASA SBIR/STTR Firm Library http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html. An electronic form will be provided during the submissions process.

Note: The designated Firm Admin, typically the first person to register your firm, is the only individual authorized to update the certifications.

3.3.9 Audit Information

Although firms are not required to have an approved accounting system, knowledge that a firm has an approved accounting system facilitates NASA's determination that rates are fair and reasonable. To assist NASA, the SBC shall complete the questions in the Audit Information form regarding the firm's rates and upload the federal agency audit report or related information that is available from the last audit. There is a separate "Audit Information" section in the Proposal Budget form that shall also be completed. If your firm has never been audited by a federal agency, then answer "No" to the first question and you do not need to complete the remainder of the form. An electronic form will be provided during the submissions process.

The Contracting Officer will use this Audit Information to assist with negotiations if the proposal is selected for award. The Contracting Officer will advise offerors what is required to determine reasonable cost and/or rates in the event the Audit Information is not adequate to support the necessary determination on rates.

Note: The designated firm admin, typically the first person to register your firm, is the only individual authorized to update the audit information.

3.3.10 Prior Awards Addendum

If the SBC has received more than 15 Phase II awards in the prior 5 fiscal years, submit name of awarding agency, solicitation year, phase, date of award, funding agreement/contract number, and topic or subtopic title for each Phase II. If your firm has received any SBIR or STTR Phase II awards, even if it has received fewer than 15 in the last 5 years, it is still recommended that you complete this form for those Phase II awards your firm did receive. This information will be useful when completing the Commercialization Metrics Survey, and in tracking the overall success of the SBIR and STTR Programs. Any NASA Phase II awards your firm has received will be automatically populated in the electronic form, as well as any Phase II awards previously entered by the SBC during prior submissions (you may update the information for these awards). An electronic form will be provided during the submissions process.

Note: The designated firm admin, typically the first person to register your firm, is the only individual authorized to update the addendum information.

3.3.11 Commercial Metrics Survey

NASA has instituted a comprehensive commercialization survey/data gathering process for firms with prior NASA SBIR/STTR awards. If the SBC has received any Phase III awards resulting from work on any NASA SBIR or STTR awards, provide the related Phase I or Phase II contract number, name of Phase III awarding agency, date of award, funding agreement number, amount, project title and period of performance. The survey will also ask for firm financial, sales and ownership information, as well as any commercialization success the firm has had as a result of Phase II SBIR or STTR awards. This information must be updated annually. This information will allow firms to demonstrate their ability to carry SBIR/STTR research through to achieve commercial success, and allow agencies to track the overall commercialization success of their SBIR and STTR Programs. The survey should be limited to information requested above. An electronic form will be provided during the submissions process.

Note: Information received from SBIR/STTR awardees completing the survey is kept confidential, and will not be made public except in broad aggregate, with no firm-specific attribution.

The Commercialization Metrics Survey is a required part of the proposal submissions process and must be completed via the Proposal Submissions Electronic Handbook. Also, Companies with no SBIR/STTR awards or only fairly recent awards will not be penalized under past performance for the lack of past SBIR/STTR commercialization.

3.3.12 Allocation of Rights Agreement (STTR awards only)

No more than 10 business days after the notification of selection for negotiation, the offeror should provide to the Contracting Officer, a completed **Allocation of Rights Agreement (ARA)**, which has been signed by authorized representatives of the SBC, RI, and subcontractors and consultants, as applicable. The ARA shall state the allocation of intellectual property rights with respect to the proposed STTR activity and planned follow-on research, development and/or commercialization. A sample ARA is available in the NASA SBIR/STTR Firm Library http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html of this Solicitation.

If the ARA form is completed and available at the time of submission, offers should upload it in in the Proposal Budget form, which will help to expedite contract negotiations.

3.4 Phase II Proposal Requirements

3.4.1 General Requirements

The Phase I contract will serve as a request for proposal (RFP) for the Phase II follow-on project. Phase II proposals are more comprehensive than those required for Phase I. Submission of a Phase II proposal is in accordance with Phase I contract requirements and is voluntary. NASA assumes no responsibility for any proposal preparation expenses.

A competitive Phase II proposal will clearly and concisely (1) describe the proposed innovation relative to the state of the art and the market, (2) address Phase I results relative to the scientific, technical merit and feasibility of the proposed innovation and its relevance and significance to the NASA interests and (3) provide the planning for a focused project that builds upon Phase I results and encompasses technical, market, financial and business factors relating to the development and demonstration of the proposed innovation, and its transition into products and services for NASA mission programs, other government agencies and non-government markets.

3.4.2 Format Requirements

Note: The government administratively screens all proposals and reserves the right to reject any proposal that does not conform to the following formatting requirements.

Page Limitations and Margins

Note: Technical proposal uploads with any page(s) going over the required page limit will not be accepted.

A Phase II technical proposal shall not exceed a total of 46 standard 8 1/2 x 11 inch (21.6 x 27.9 cm) pages. Proposals uploaded with more than 46 pages will prompt a warning which will prevent the completed proposal from being submitted. Each page shall be numbered consecutively at the bottom. Margins shall be 1.0 inch (2.5 cm). The space allocated to each part of the technical content will depend on the project chosen and the offeror's approach. The additional forms required for proposal submission will not count against the 46-page limit.

Each complete proposal package submitted shall contain the following items:

1. Proposal Contact Information (must not contain proprietary data).
2. Proposal Certifications, electronically endorsed.
3. Proposal Summary (must not contain proprietary data).
4. Proposal Budget.
5. Technical Content - 10 Parts in the order specified in section 3.4.4, not to exceed 46 pages **(for SBIR AND STTR)**, including all graphics, and starting with a table of contents.
6. Research Agreement between the SBC and RI **(STTR only)**.
7. Briefing Chart (must not contain proprietary data).
8. NASA Research License Application, only if TAV is being proposed.
9. Capital Commitments Addendum Supporting Phase II and Phase III (optional).

Note: Letters expressing general technical interest are not required or desired and will not be considered during the review process. However, if submitted, such letter(s) will count against the page limit. Letters of funding support commitments are allowable for Phase II proposals but will be considered only under Factor 4 - Commercial Potential and Feasibility. Letters of funding support commitments should be submitted as part of the Capital Commitments Addendum.

In addition to the above items, each offeror must submit the following firm level forms, which must be filled out once during each submission period and are applicable to all firm proposal submissions:

1. Firm Certifications
2. Audit Information
3. Prior Awards Addendum
4. Commercial Metrics Survey

Previews of all forms and certifications are available via the NASA SBIR/STTR Firm Library, located at: http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html.

Note: Website references, relevant technical papers, product samples, videotapes, slides or other ancillary items will not be considered during the review process.

Type Size
No type size smaller than 10 point shall be used for text or tables, except as legends on reduced drawings. Proposals prepared with smaller font sizes may be rejected without consideration.

Header/Footer Requirements
Header must include firm name, proposal number and project title. Footer must include the page number and proprietary markings if applicable. Margins can be used for header/footer information.

Classified Information
NASA does not accept proposals that contain classified information.

Project Title
The proposal project title shall be concise and descriptive of the proposed effort. The title should not use acronyms or words like "Development of" or "Study of." The NASA research topic title must not be used as the proposal title.

3.4.3 Forms

All form submissions shall be done electronically, and do not count towards the 46-page limit.

3.4.3.1 Contact Information

A sample Contact Information form is provided in the NASA SBIR/STTR Firm Library http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html. The offeror shall provide complete information for each contact person and submit the form as required in section 6.

Note: Contact Information, is public information and may be disclosed.

3.4.3.2 Proposal Certifications

A sample Proposal Certifications form is provided in the NASA SBIR/STTR Firm Library http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html. The offeror shall provide complete information for each item and submit the form as required in section 6.

3.4.3.3 Proposal Summary

A sample Proposal Summary form is provided in the NASA SBIR/STTR Firm Library http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html. The offeror shall provide complete information for each item and submit the form as required in section 6.

Note: Proposal Summary, including the Technical Abstract, is public information and may be disclosed. Do not include proprietary information in this form.

3.4.3.4 Proposal Budget

A sample of the Proposal Budget form is provided in the NASA SBIR/STTR Firm Library http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html. The offeror shall complete the Budget Summary following the instructions provided with the sample form. The total requested funding for the Phase II effort shall not exceed $750,000. Contextual help is provided on the electronic budget form for additional explanation. Information shall be submitted to explain the offeror's plans for use of the requested funds to enable NASA to determine whether the proposed price is fair and reasonable.

Note: The government is not responsible for any monies expended by the firm before award of any contract.

In addition, the following additional uploads, must be submitted in the Proposal Budget form, as applicable:

Proposal Requirements for Use of Federal Services, Facilities or Equipment:
In cases where an offeror seeks to use NASA or another federal department or agency services, equipment or facilities, the offeror shall provide the following:

1. Statement, signed by the appropriate government official at the effected federal department or agency, verifying that the resources should be available during the proposed period of performance. Offerors must upload this letter in the Proposal Budget form.
2. Signed letter on company letterhead from the contractor's Small Business Official explaining why the SBIR/STTR research project requires the use of federal services, equipment or facilities, including data that verifies the absence of non-federal facilities or personnel capable of supporting the research effort, a statement confirming that the facility proposed is not a federal laboratory, if applicable, and the associated cost estimate. Offerors must upload this letter in the Proposal Budget form.

See Part 8 of the Technical Proposal for additional information on use of federal Facilities.

Use of Subcontractors and Consultants:

Subject to the restrictions set forth below, the SBC may establish business arrangements with other entities or individuals to participate in performance of the proposed R/R&D effort.

Note:
1. ***Offerors should list consultants by name and specify, for each, the number of hours and hourly costs.***
2. ***Breakdown of subcontractor budget should mirror the SBC's own breakdown in the Proposal Budget form and include breakdowns of direct labor, other direct costs, profit, as well as indirect rate agreements.***
3. ***A signed letter of commitment is required for each subcontractor and/or consultant. For educational institutions, the letter must be from the institution's office of sponsored programs.***

Subcontractors' and consultants' work has the same place of performance restrictions as stated in section 1.5.2.

The following restrictions apply to the use of subcontracts/consultants and the formula below must be used in preparing budgets with subcontractors/consultants:

SBIR Phase II Subcontracts/Consultants	STTR Phase II Subcontracts/Consultants
The proposed subcontracted business arrangements including consultants, must not exceed 50 percent of the research and/or analytical work [as determined by the total cost of the proposed subcontracting effort (to include the appropriate OH and G&A) in comparison to the total effort (total contract price including cost sharing, if any, less profit if any)].	A minimum of 40 percent of the research or analytical work must be performed by the proposing SBC and minimum of 30 percent must be performed by the RI. Any subcontracted business effort other than that performed by the RI, shall not exceed 30 percent of the research and/or analytical work [(as determined by the total cost of the subcontracting effort (to include the appropriate OH and G&A) in comparison to the total effort (total contract price including cost sharing, if any, less profit if any)].

Example:	Total price to include profit	- $725,000
	Profit	- $21,750
	Total price less profit	- $725,000 - $21,750 = $703,250
	Subcontractor cost	- $250,000
	G&A	- 5%
	G&A on subcontractor cost	- $250,000 x 5% = $12,500
	Subcontractor cost plus G&A	- $250,000 + $12,500 = $262,500
	Percentage of subcontracting effort – subcontractor cost plus G&A / total price less profit	**- $262,500 / $703,250 = 37.3%**

For an SBIR Phase II this is acceptable since it is below the limitation of 50%.

For an STTR Phase II, where there is a subcontract with a company other than the RI, this is unacceptable since it is above 30% limitation.

See Part 9 of the Technical Proposal for additional information on the use of Subcontractors and Consultants.

Milestone Plan

For Phase II, offerors shall submit a proposed quarterly milestone plan with the Proposal Budget form. The milestone plan shall be in accordance with the proposed work plan outlining the work to be accomplished each quarter and the cost proposed associated with each of the quarterly milestones. The cost breakdown shall be similar to the Proposal Budget form for each of the proposed quarterly milestones (i.e., each milestone should include the labor, supplies, travel and profit associated with those tasks to be accomplished that quarter). The proposed cost associated with each quarterly milestone must be realistic for the work to be accomplished but is not required to be equally distributed across each quarter.

3.4.4 Technical Proposal

This part of the submission shall not contain any budget data and must consist of all ten (10) parts listed below in the given order. All ten parts of the technical proposal must be numbered and titled. Parts that are not applicable must be included and marked "Not Applicable." A proposal omitting any part will be considered non-responsive to this Solicitation and may be rejected during administrative screening. The required table of contents is provided below:

Phase II Table of Contents

Part 1: Table of Contents

The technical proposal shall begin with a brief table of contents indicating the page numbers of each of the parts of the proposal.

Part 2: Identification and Significance of the Innovation and Results of the Phase I Proposal

Please provide a summary of your Phase I results and succinctly describe:

- The proposed innovation.
- The relevance and significance of the proposed innovation to an interest, need or needs within the subtopic.
- The proposed innovation relative to the state of the market, the state of the art and its feasibility.

Please be advised that the evaluators may review the Phase I final technical report to verify accuracy of this summary.

Part 3: Technical Objectives

Define the specific objectives of the Phase II research and technical approach, including the technical questions posed in the subtopic description that must be answered to determine the feasibility of the proposed innovation.

Note: All offerors submitting proposals who are planning to use NASA IP must describe their planned developments with the IP. The NASA Research License Application should be added as an attachment under Proposal Certifications (see section 1.6).

Part 4: Work Plan

Include a detailed description of the Phase II R/R&D plan to meet the technical objectives. The plan should indicate what will be done, where it will be done and how the R/R&D will be carried out. Discuss in detail the methods planned to achieve each task or objective. Task descriptions, schedules, resource allocations, estimated task hours for each key personnel and planned accomplishments including project milestones shall be included. Offerors should ensure that the estimated task hours provided in the work plan for key personnel are consistent with the hours reported in the Proposal Budget form. If the offeror is a joint venture or limited partnership, a statement of how the workload will be distributed, managed and charged should be included in the proposal.

STTR: In addition, the work plan will specifically address the percentage and type of work to be performed by the SBC and the RI. The plan will provide evidence that the SBC will exercise management direction and control of the performance of the STTR effort, including situations in which the PI may be an employee of the RI.

Part 5: Related R/R&D
Describe significant current and/or previous R/R&D that is directly related to the proposal including any conducted by the PI or by the offeror. Describe how it relates to the proposed effort and any planned coordination with outside sources. The offeror must persuade reviewers of his or her awareness of key recent R/R&D conducted by others in the specific subject area.

Part 6: Key Personnel and Bibliography of Directly Related Work
Identify all key personnel involved in Phase II activities whose expertise and functions are essential to the success of the project. Provide bibliographic information including directly related education and experience.

The PI is considered key to the success of the effort and must make a substantial commitment to the project. The following requirements are applicable:

> **Functions:** The functions of the PI are: planning and directing the project, leading it technically and making substantial personal contributions during its implementation, serving as the primary contact with NASA on the project and ensuring that the work proceeds according to contract agreements. Competent management of PI functions is essential to project success. The Phase II proposal shall describe the nature of the PI's activities and the amount of time that the PI will personally apply to the project. The amount of time the PI proposes to spend on the project must be acceptable to the Contracting Officer.
>
> **Qualifications:** The qualifications and capabilities of the proposed PI and the basis for PI selection are to be clearly presented in the proposal. NASA has the sole right to accept or reject a PI based on factors such as education, experience, demonstrated ability and competence, and any other evidence related to the specific assignment.
>
> **Eligibility:** This part shall also establish and confirm the eligibility of the PI, and indicate the extent to which other proposals recently submitted or planned for submission in the year and existing projects commit the time of the PI concurrently with this proposed activity. Any attempt to circumvent the restriction on PIs working more than half time for an academic or a nonprofit organization by substituting an ineligible PI will result in rejection of the proposal. However, for an STTR the PI can be primarily employed by either the SBC or the RI. Please see section 1.5.3 for further explanation.

Note: If the Phase II PI is different than that proposed under the Phase I, please provide rationale for the change.

Part 7: Phase III Efforts, Commercialization and Business Planning
Present a plan for commercialization of the proposed innovation. Commercialization encompasses the transition of technology into products and services for NASA mission programs, other government agencies and non-government markets.

This part should complement, through narrative, the data provided by the applicant in the Commercialization Metrics Survey (CMS), including financial information. The CMS data is intended to support the company's claims about their ability to achieve the proposed innovation's commercialization for firms that have previously received SBIR/STTR awards, and provide a level of confidence regarding the SBC's future viability.

Note: Letters of funding support commitments should be submitted as part of the Capital Commitments Addendum and will be considered only under Factor 4 - Commercial Potential and Feasibility (section 4).

The commercialization plan should address the following areas:

Commercial Potential – Market

Describe (1) market segmentation and analysis, by providing the scope in dollars, and describe the commercial Total Addressable Market (TAM) that is appropriate to the proposed innovation, the segment in dollars of the TAM addressable by the proposed innovation and the projected percentage of the offeror's market share in 2-3 years after entry into the identified market; (2) the proposed innovation in terms of target customers (e.g., NASA, other federal agency, commercial enterprise); and (3) the competitive landscape, by identifying potential competitors by company name within the identified market, discussing the barriers to entry and how many years it would take a competitor to enter this segment in terms of capitalization, technology, and people, and describing how the proposed innovation is different from the potential competition.

Commercial Intent – Plan

Describe (1) the commercial development plan by providing a development timeline to bring technology to market, discuss consultants, incubators and research institutions to achieve the plan; (2) the applicable business model (spin-out, license, OEM) the offeror would use to bring the innovation to market, the channels of distribution (direct sales, distributors, etc.) that would be used in bringing the innovation into the identified market, the pro-forma 2-3 year revenue dollar projections based on the proposed innovation's penetration of the identified market and any follow-on development (long term > 5 years) plans to expand your proposed innovation's market presence; (3) the risks to the commercial development plan and what mitigations, if any, can be taken over a reasonable period of time to lessen the risks and (4) Intellectual Property protection methods, plans or processes within your company.

Commercial Capability – Execution

Describe (1) the current and future company capitalization by discussing the technical, operations/manufacturing and business staff conducting the project; the physical plant, including facilities and the capital equipment, tooling and test equipment used to conduct the investigation; how the innovation will enter into production (i.e., in house or through a licensee) and what changes (if any) will be made to company capitalization for commercialization; (2) existing and future business relationships in terms of any formal Partnerships, Joint Ventures, Licensing Agreements with other companies/organizations and; (3) as applicable, the approach, path to market and revenues from past commercialization(s) resulting from SBIR/STTR awards disclosed in the CMS.

Part 8: Facilities/Equipment

Offerors must describe the necessary instrumentation and facilities to be used to perform the proposed work. Offerors must ensure the resources are adequate and address any reliance on external sources, such as government furnished equipment or facilities. In cases where an offeror seeks to use NASA or another federal department or agency services, equipment or facilities, the offeror shall describe in this part why the use of government furnished equipment or facilities is necessary. See section 3.4.3.4 and 5.13 for additional requirements when proposing use of federal facilities.

Part 9: Subcontracts and Consultants

The offeror must describe all subcontracting or other business arrangements, and identify the relevant organizations and/or individuals with whom arrangements are planned. The expertise to be provided by the entities must be described in detail, as well as the functions, services, number of hours and labor rates. Offerors are responsible for ensuring that all organizations and individuals proposed to be utilized are actually available for the time periods proposed. Subcontract costs shall be documented in the Subcontractors/Consultants section of the Proposal Budget form and supporting documentation should be uploaded for each (appropriate documentation is specified in the form). The narrative description of subcontracts and consultants should support the proposed approach and documentation in the Proposal Budget form.

Part 10: Related, Essentially Equivalent, and Duplicate Proposals and Awards
WARNING – While it is permissible with proposal notification to submit identical proposals or proposals containing a significant amount of essentially equivalent work for consideration under numerous federal program solicitations, it is unlawful to enter into funding agreements requiring essentially equivalent work.

If an applicant elects to submit identical proposals or proposals containing a significant amount of essentially equivalent work under other federal program solicitations, a statement must be included in each such proposal indicating:

1. The name and address of the agencies to which proposals were submitted or from which awards were received.
2. Date of proposal submission or date of award.
3. Title, number and date of solicitations under which proposals were submitted or awards received.
4. The specific applicable research topics for each proposal submitted for award received.
5. Titles of research projects.
6. Name and title of principal investigator or project manager for each proposal submitted or award received.

Offerors are at risk for submitting essentially equivalent proposals and therefore, are strongly encouraged to disclose these issues to the soliciting agency to resolve the matter prior to award.

A summary of essentially equivalent work information, as well as related research and development on proposals and awards is also required on the Proposal Certifications form (if applicable).

3.4.5 Research Agreement (Applicable for STTR proposals only)

STTR: The Research Agreement (different from the Allocation of Rights Agreement, see: http://sbir.nasa.gov/content/nasa-sbirsttr-program-definitions) is a single-page document electronically submitted and endorsed by the SBC and RI. A model agreement is provided, or firms can create their own custom agreement. The Research Agreement should be submitted as required in section 6.

All STTR Phase I proposals must provide sufficient information to convince NASA that the proposed SBC/RI cooperative effort represents a sound approach for converting technical information resident at the RI into a product or service that meets a need described in a Solicitation research topic.

3.4.6 Capital Commitments Addendum Supporting Phase II and Phase III

Offerors for Phase II contracts are strongly urged to obtain non-SBIR/STTR funding support commitments for follow-on Phase III activities along with additional support of their Phase II effort from viable sources outside of the SBC. In order to be considered valid, the funding support commitments must show that a specific and substantial amount ($\geq$ \$50,000) will be made available to the SBC to provide capital for the Phase III activities and (if applicable) support of their Phase II effort. They must indicate the source, date, and conditions and contingencies under which the funds will be made available. If Phase III activities will be funded internally by the SBC, the offeror should ensure that the financials provided in the Commercial Metric Survey (CMS) are current and accurate.

Evidence of funding support commitments from outside parties must be provided in writing and shall accompany the Phase II proposal. Letters of commitment will specify the level of funding commitments, other sources to be provided and any funding contingencies/conditions, in addition to timing of the funding being made available to the SBC. Expressions of technical interest in the Phase II research or of potential future financial support are not sufficient and will not be considered as capital commitments to the Phase II proposal and Phase III activities. Letters of commitment must be signed by a duly authorized representative of the outside funding source and SBC with the authority to obligate funding.

3.4.7 Briefing Chart

A one-page briefing chart is required to assist in the ranking and advocacy of proposals prior to selection and contains the following sections:

- Identification and Significance of Innovation
- Technical Objectives, Work Plan and Deliverables
- NASA Applications
- Non-NASA Applications
- Graphic

The briefing chart shall not contain any proprietary data or ITAR restricted data. An electronic form will be provided during the submissions process.

Note: The briefing chart is public information and may be disclosed. Do not include proprietary information in this form.

3.4.8 Firm Certifications

Firm certifications that are applicable across all proposal submissions submitted to this solicitation must be completed via the Firm Certifications section of the Proposal Submissions Electronic Handbook. The offeror shall answer Yes or No as applicable. An example of the certification can be found in the NASA SBIR/STTR Firm Library http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html.

Note: The designated firm admin, typically the first person to register your firm, is the only individual authorized to update the certifications.

3.4.9 Audit Information

Although firms are not required to have an approved accounting system, knowledge that a firm has an approved accounting system facilitates NASA's determination that rates are fair and reasonable. To assist NASA, the SBC shall complete the questions in the Audit Information form regarding the firm's rates and upload the federal agency audit report or related information that is available from the last audit. There is a separate "Audit Information" section in the Proposal Budget form that shall also be completed. If your firm has never been audited by a federal agency, then answer "No" to the first question and you do not need to complete the remainder of the form. An electronic form will be provided during the submissions process.

The Contracting Officer will use this Audit Information to assist with negotiations if the proposal is selected for award. The Contracting Officer will advise offerors what is required to determine reasonable cost and/or rates in the event the Audit Information is not adequate to support the necessary determination on rates.

Note: The designated firm admin, typically the first person to register your firm, is the only individual authorized to update the audit information.

3.4.10 Prior Awards Addendum

If the SBC has received more than 15 Phase II awards in the prior 5 fiscal years, submit name of awarding agency, solicitation year, phase, date of award, funding agreement/contract number, and topic or subtopic title for each Phase II. If your firm has received any SBIR or STTR Phase II awards, even if it has received fewer than 15 in the last 5 years, it is still recommended that you complete this form for those Phase II awards your firm did receive. This information will be useful when completing the Commercialization Metrics Survey, and in tracking the overall success of the SBIR and STTR Programs. Any NASA Phase II awards your firm has received will be automatically populated in the electronic form, as are any Phase II awards previously entered by the SBC during prior submissions (you may update the information for these awards). An electronic form will be provided during the submissions process.

Note: The designated firm admin, typically the first person to register your firm, is the only individual authorized to update the addendum information.

3.4.11 Commercial Metrics Survey

NASA has instituted a comprehensive commercialization survey/data gathering process for firms with prior NASA SBIR/STTR awards. If the SBC has received any Phase III awards resulting from work on any NASA SBIR or STTR awards, provide the related Phase I or Phase II contract number, name of Phase III awarding agency, date of award, funding agreement number, amount, project title and period of performance. The survey will also ask for firm financial, sales and ownership information, as well as any commercialization success the firm has had as a result of Phase II SBIR or STTR awards. This information must be updated annually. This information will allow firms to demonstrate their ability to carry SBIR/STTR research through to achieve commercial success, and allow agencies to track the overall commercialization success of their SBIR and STTR Programs. The survey should be limited to information requested above. An electronic form will be provided during the submissions process.

Note: Information received from SBIR/STTR awardees completing the survey is kept confidential, and will not be made public except in broad aggregate, with no firm-specific attribution.

The Commercialization Metrics Survey is a required part of the proposal submissions process and must be completed via the Proposal Submissions Electronic Handbook. Also, Companies with no SBIR/STTR awards or only fairly recent SBIR/STTR awards will not be penalized under past performance for the lack of past SBIR/STTR commercialization.

3.4.12 Contractor Responsibility Information

No later than 10 business days after the notification of selection for negotiations, the offeror shall provide a signed statement from your financial institution(s), on its letterhead, stating whether or not your firm is in good standing and how long you have been with the institution.

3.4.13 Allocation of Rights Agreement (STTR awards only)

No more than 10 business days after the notification of selection for negotiation, the offeror should provide to the Contracting Officer, a completed **Allocation of Rights Agreement (ARA)**, which has been signed by authorized representatives of the SBC, RI, and subcontractors and consultants, as applicable. The ARA shall state the allocation of intellectual property rights with respect to the proposed STTR activity and planned follow-on research, development and/or commercialization. A sample ARA is available in the NASA SBIR/STTR Firm Library http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html of this Solicitation.

If the ARA form is completed and available at the time of submission, offers should upload it in the Proposal Budget form, which will help to expedite contract negotiations.

4. Method of Selection and Evaluation Criteria

4.1. Access to Proprietary Data by Non-NASA Personnel

4.1.1 Non-NASA Reviewers

In addition to government personnel, NASA, at its discretion and in accordance with 1815.207-71 of the NASA FAR Supplement, may utilize individuals from outside the government with highly specialized expertise not found in the government in the proposal review process. Any decision to obtain an outside evaluation shall take into consideration requirements for the avoidance of organizational or personal conflicts of interest and the competitive relationship, if any, between the prospective contractor or subcontractor(s) and the prospective outside evaluator. Any such evaluation will be under agreement with the evaluator that the information (data) contained in the proposal will be used only for evaluation purposes and will not be further disclosed. Such requests for non-NASA Reviewers must be approved by the NASA SBIR/STTR Program Manager.

4.1.2 Non-NASA Access to Confidential Business Information

In the conduct of proposal processing and potential contract administration, the agency may find it necessary to provide proposal access to other NASA contractor and subcontractor personnel. NASA will provide access to such data only under contracts that contain an appropriate NFS 1852.237-72 Access to Sensitive Information clause that requires the contractors to fully protect the information from unauthorized use or disclosure.

4.2 Phase I Proposals

All proposals will be evaluated and ranked on a competitive basis. Proposals will be initially screened to determine responsiveness. Proposals determined to be responsive to the administrative requirements of this Solicitation and having a reasonable potential of addressing a NASA interest, as evidenced by the technical abstract included in the Proposal Summary form, will be technically evaluated by NASA personnel to determine the most promising technical and scientific approaches. Each proposal will be reviewed on its own merit. NASA is under no obligation to fund any proposal or any specific number of proposals in a given topic. It also may elect to fund several or none of the proposed approaches to the same topic or subtopic.

4.2.1 Evaluation Process

Proposals shall provide all information needed for complete evaluation. Evaluators will not seek additional information. NASA scientists and engineers will perform evaluations. Also, qualified experts outside of NASA (including industry, academia and other government agencies) may assist in performing evaluations as required to determine or verify the merit of a proposal. Offerors should not assume that evaluators are acquainted with the firm, key individuals, or with any experiments or other information. Any pertinent references or publications should be noted in Part 5 of the technical proposal.

4.2.2 Phase I Evaluation Criteria

NASA intends to select for award those proposals that offer the most advantageous research and development, deliver technological innovation that contribute to NASA's missions, provide societal benefit and grow the US economy. NASA will give primary consideration to the scientific and technical merit and feasibility of the proposal and its benefit to NASA interests. Each proposal will be evaluated and scored on its own merits using the factors described below:

Factor 1: Scientific/Technical Merit and Feasibility

The proposed R/R&D effort will be evaluated on whether it offers a clearly innovative and feasible technical approach to the described NASA problem area. Proposals must clearly demonstrate relevance to the subtopic as well as one or more NASA mission and/or programmatic needs. Specific objectives, approaches and plans for developing and verifying the innovation must demonstrate a clear understanding of the problem and the current state of the art. The degree of understanding and significance of the risks involved in the proposed innovation must be presented.

Factor 2: Experience, Qualifications and Facilities

The technical capabilities and experience of the PI, project manager, key personnel, staff, consultants and subcontractors, if any, are evaluated for consistency with the research effort and their degree of commitment and availability. The necessary instrumentation or facilities required must be shown to be adequate and any reliance on external sources, such as government furnished equipment or facilities, addressed (section 3.3.4, part 8).

Factor 3: Effectiveness of the Proposed Work Plan

The work plan will be reviewed for its comprehensiveness, effective use of available resources, labor distribution and the proposed schedule for meeting the Phase I objectives. The methods planned to achieve each objective or task should be discussed in detail. Please see Factor 5 for price evaluation criteria.

STTR: The clear delineation of responsibilities of the SBC and RI for the success of the proposed cooperative R/R&D effort will be evaluated. The offeror must demonstrate the ability to organize for effective conversion of intellectual property into products and services of value to NASA and the commercial marketplace.

Factor 4: Commercial Potential and Feasibility

The proposal will be evaluated for the commercial potential and feasibility of the proposed innovation and associated products and services for NASA mission programs, other government agencies and non-government markets. The offeror's experience and record in technology commercialization, co-funding commitments from private or non-SBIR/non-STTR funding sources, existing and projected commitments for Phase III funding, investment, sales, licensing, and other indicators of commercial potential and feasibility will be considered along with the initial commercialization strategy for the innovation.

Factor 5: Price Reasonableness

The offeror's cost proposal will be evaluated for price reasonableness based on the information provided in the Proposal Budget form. NASA will comply with the FAR and NASA FAR Supplement (NFS) to evaluate the proposed price/cost to be fair and reasonable.

The Contracting Officer shall submit a recommendation for award to the Source Selection Official after completion of evaluation for price reasonableness and determination of responsibility.

Scoring of Factors and Weighting

Factors 1, 2 and 3 will be scored numerically with Factor 1 worth 50 percent and Factors 2 and 3 each worth 25 percent. The sum of the scores for Factors 1, 2 and 3 will comprise the Technical Merit score. The evaluation for Factor 4, Commercial Potential and Feasibility, will be in the form of an adjectival rating (Excellent, Very Good, Average, Below Average, Poor). For Phase I proposals, Technical Merit is more important than Commercial Merit. Factors 1 - 4 will be evaluated and used in the selection of proposals for negotiation. Factor 5 will be evaluated and used in the award decision, i.e., NASA will only make award when the price is fair and reasonable.

4.2.3 Prioritization

In prioritizing proposals recommended for negotiations NASA will also consider other factors including recommendations from the centers and mission directorates regarding such things as overall NASA priorities, program balance and available funding.

4.2.4 Selection

Proposals recommended for negotiations will be forwarded to the Program Management Office for analysis and presented to the Source Selection Official and Mission Directorate Representatives. The Source Selection Official has the final authority for choosing the specific proposals for contract negotiation. Each proposal selected for negotiation will be evaluated for cost/price reasonableness, the terms and conditions of the contract will be negotiated and a responsibility determination made. The Contracting Officer will advise the Source Selection Official on matters pertaining to cost reasonableness, responsibility and known past performance issues.

The list of proposals selected for negotiation will be posted on the NASA SBIR/STTR website (http://sbir.nasa.gov). All firms will receive a formal notification letter. A Contracting Officer will negotiate an appropriate contract to be signed by both parties before work begins.

4.3 I-Corps

For awardees invited to submit an I-Corps proposal pursuant to section 3.3.6.2, NASA will provide a programmatic assessment of firms and their technologies to include:

- Number of previous SBIR/STTR awards received by the firm and the firm's commercialization success rate.
- Potential for commercialization of the selected Phase I research/solution to non-NASA markets (distinct from integration/transition into NASA programs).
- Technical relevance to NASA.

Based on these assessments, certain offerors will be selected to participate in phone interviews conducted by the NASA SBIR/STTR PMO and the NSF-provided I-Corps instructors. NASA will use these interviews to determine the dynamics of the teams and gauge their level of commitment to meeting requirements for I-Corps to make the final selection. NASA will make the final selections for I-Corps based upon its initial assessments of the I-Corps proposals and the assessments of the phone interviews.

NASA anticipates a total of approximately 35 SBIR/STTR firms will be selected for participation in I-Corps for Phase I.

4.4 Phase II Proposals

All Phase II proposals will be evaluated and ranked on a competitive basis. Proposals will be initially screened to determine responsiveness. Proposals determined to be responsive to the administrative requirements of this solicitation and having a reasonable potential of meeting a NASA need, as evidenced by the technical abstract included in the Proposal Summary form, will be technically evaluated by NASA personnel to determine the most promising technical and scientific approaches. Each proposal will be reviewed on its own merit. NASA is under no obligation to fund any proposal or any specific number of proposals in a given topic. It also may elect to fund several or none of the proposed approaches to the same topic or subtopic.

4.4.1 Evaluation Process

The Phase II evaluation process is similar to the Phase I process. Each proposal will be reviewed by NASA scientists and engineers and by qualified experts outside of NASA as needed. In addition, the proposals will be reviewed for commercial merit. NASA may use a peer review panel to evaluate commercial merit. Panel membership may include non-NASA personnel with expertise in business development and technology commercialization.

4.4.2 Phase II Evaluation Criteria

NASA intends to select for award those proposals that offer the most advantageous research and development, deliver technological innovation that contributes to NASA's missions, provides societal benefit and grows the US economy. NASA will give primary consideration to the scientific and technical merit and feasibility of the proposal and its benefit to NASA interests. Each proposal will be evaluated and scored on its own merits using the factors described below:

Note: Past performance will not be a separate evaluation factor but will be evaluated under Factors 1 (with respect to performance in Phase I) and 4 (with respect to commercialization past performance, as applicable) below.

Factor 1: Scientific/Technical Merit and Feasibility
The proposed R/R&D effort will be evaluated on its originality, the feasibility of the innovation and potential technical value. In addition, past performance of Phase I will be evaluated to determine the degree to which Phase I objectives were met, and whether the Phase I results indicate a Phase II project is appropriate. The evaluators may review the Phase I final technical report to verify the Phase I results.

Factor 2: Experience, Qualifications and Facilities
The technical capabilities and experience of the PI or project manager, key personnel, staff, consultants and subcontractors, if any, are evaluated for consistency with the research effort and their degree of commitment and availability. The necessary instrumentation or facilities required must show to be adequate and any reliance on external sources, such as government furnished equipment or facilities, addressed (section 3.4.4, Part 8).

Factor 3: Effectiveness of the Proposed Work Plan
The work plan will be reviewed for its comprehensiveness, effective use of available resources, labor distribution and the proposed schedule for meeting the Phase II objectives. The methods planned to achieve each objective or task should be discussed in detail. The proposed path beyond Phase II for further development and infusion into a NASA mission or program will also be reviewed. Please see Factor 5 for price evaluation criteria.

STTR: The clear delineation of responsibilities of the SBC and RI for the success of the proposed cooperative R/R&D effort will be evaluated. The offeror must demonstrate the ability to organize for effective conversion of intellectual property into products and services of value to NASA and the commercial marketplace.

Factor 4: Commercial Potential and Feasibility
The proposal and Commercial Metrics Survey will be evaluated for the commercial potential and feasibility of the proposed innovation and associated products and services. The offeror's experience and record in technology commercialization; current funding commitments from private or non-SBIR funding sources; existing and projected commitments for Phase III funding, investment, sales, licensing, and other indicators of commercial potential and feasibility will be considered along with the commercialization plan for the innovation. Evaluation of the commercialization plan and the overall proposal will include consideration of the following areas:

1. **Commercial Potential and Feasibility of the Innovation:** This includes assessment of (a) the transition of the innovation into a well-defined product or service; (b) a realistic target market niche; (c) a product or service that has strong potential for meeting a well-defined need within the target market and (d) a commitment of necessary financial, physical and/or personnel resources.
2. **Intent and Commitment of the Offeror:** This includes assessing the commercialization of the innovation for (a) importance to the offeror's current business and strategic planning; (b) reliance on (or lack thereof) government markets and (c) adequacy of funding sources necessary to bring technology to identified market.
3. **Capability of the Offeror to Realize Commercialization:** This includes assessment of (a) the offeror's past performance, experience and success in technology commercialization; (b) the likelihood that the offeror will be able to obtain the remaining necessary financial, technical and personnel-related resources; and (c) the current strength and continued financial viability of the offeror.

Factor 5: Price Reasonableness
The offeror's cost proposal will be evaluated for price reasonableness based on the information provided in the Proposal Budget form. NASA will comply with the FAR and NASA FAR Supplement (NFS) to evaluate the proposed price/cost to be fair and reasonable.

The Contracting Officer shall submit a recommendation for award to the Source Selection Official after completion of evaluation for price reasonableness and determination of responsibility.

Scoring of Factors and Weighting

Factors 1, 2, 3 and 4 will be scored numerically with Factor 1 worth 45 percent, Factors 2 and 3 each worth 25 percent and Factor 4 worth five percent. The sum of the scores for Factors 1, 2, 3 and 4 will comprise the Technical Merit score. Factors 1 - 4 will be evaluated and used in the selection of proposals for negotiation. Factor 5 will be evaluated as part of the award decision, i.e., NASA will only make award when the price is fair and reasonable.

4.4.3 Prioritization

In prioritizing proposals recommended for negotiations NASA will also consider other factors including recommendations from the centers and mission directorates regarding such things as overall NASA priorities, program balance and available funding.

4.4.4 Selection

Proposals recommended for negotiations will be forwarded to the Program Management Office for analysis and presented to the Source Selection Official and Mission Directorate Representatives. The Source Selection Official has the final authority for choosing the specific proposals for contract negotiation. Each proposal selected for negotiation will be evaluated for cost/price reasonableness. After completion of evaluation for cost/price reasonableness and a determination of responsibility the Contracting Officer will submit a recommendation for award to the Source Selection Official.

The list of proposals selected for negotiation will be posted on the NASA SBIR/STTR website (http://sbir.nasa.gov). All firms will receive a formal notification letter. A Contracting Officer will negotiate an appropriate contract to be signed by both parties before work begins.

4.5 Debriefing of Unsuccessful Offerors

After Phase I and Phase II selections for negotiation have been announced, debriefings for unsuccessful proposals will be available to the offeror's corporate official or designee via email. Written debriefings will be sent only to the Business Official designated in the proposal. Telephone requests for debriefings will not be accepted. Debriefings are not opportunities to reopen selection decisions. Debriefings will not disclose the identity of the proposal evaluators, proposal scores, the content of, or comparisons with other proposals. The debriefing process for Phase I and Phase II proposals are described below.

4.5.1 Phase I Debriefings

Debriefings will be automatically emailed to the designated Business Official within 60 days of the announcement of selection for negotiation. If you have not received your debriefing by this time, contact the SBIR/STTR Program Support Office at ARC-SBIR-PMO@mail.nasa.gov.

4.5.2 Phase II Debriefings

For Phase II, offerors must send a debriefing request via email to the SBIR/STTR Program Office at ARC-SBIR-PMO@mail.nasa.gov within 60 days after the selection announcement. Late requests will not be honored.

5. Considerations

5.1 Awards

5.1.1 Model Contracts

An example of the Phase I and II contracts can be found in the NASA SBIR/STTR Firm Library: http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html.

Note: Model contracts are subject to change.

5.2 Reporting and Required Deliverables

All contracts shall require the delivery of reports that present: (1) the work and results accomplished; (2) the scientific, technical and commercial merit and feasibility of the proposed innovation, and project results; (3) its relevance and significance to one or more NASA interests (section 9); and (4) the strategy for development, transition of the proposed innovation, and project results into products and services for NASA mission programs and other potential customers. Deliverables may also include the demonstration of the proposed innovation and/or the delivery of a prototype or test unit, product or service for NASA testing and utilization. An IT Security Plan is required at the beginning of the contract. A final New Technology Summary Report (NTSR) is due at the end of the contract, and New Technology Report(s) (NTR) are required if technology(s) are developed under the award, prior to submission of the final invoice.

The technical reports and other deliverables are required as described in the contract and are to be provided to NASA. These reports shall document progress made on the project and activities required for completion. Periodic certification for payment will be required as stated in the contract. A final report must be submitted to NASA upon completion of the Phase I or Phase II R/R&D effort in accordance with applicable contract provisions.

Report deliverables shall be submitted electronically via the EHB and NASA requests the submission of report deliverables in PDF or MS Word format.

Note: To access contract management in the EHB you will be required to have an identity in the NASA Account Management System (NAMS). This is the agency's centralized system for requesting and maintaining accounts for NASA IT systems and applications. The system contains user account information, access requests and account maintenance processes for NASA employees, contractors, and remote users such as educators and foreign users. A basic background check is required for this account.

5.3 Payment Schedule

All NASA SBIR and STTR contracts are firm-fixed-price contracts. The exact payment terms will be included in the contract.

All invoices are required to be submitted electronically in the EHB via the SBIR/STTR website.

5.4 Profit or Fee

Contracts may include a reasonable profit. The reasonableness of proposed profit is determined by the Contracting Officer during contract negotiations. Reference FAR 15.404-4.

5.5 Rights in Data Developed Under SBIR Funding Agreements

The clause at FAR 52.227-20, Rights in Data—SBIR/STTR Program, governs rights to data used in, or first produced under, any Phase I, Phase II or federally funded SBIR Phase III contract.

Rights in technical data, including software developed under the terms of any funding agreement resulting from applications submitted in response to this solicitation, shall remain with the contractor, except that the government shall have the limited right to use such data for government purposes and shall not release such SBIR/STTR data outside the government without permission of the recipient for a period of not less than 4 years from delivery of the last deliverable under that agreement (either Phase I, Phase II or federally funded SBIR Phase III). Agencies are released from obligation to protect SBIR data upon expiration of the protection period except that any such data that is also protected and referenced under a subsequent SBIR award must remain protected through the protection period of that subsequent SBIR award. However, effective at the conclusion of the 4-year period, the government shall have unlimited rights in any data delivered under the award.

5.6 Copyrights

The contractor may copyright and publish (consistent with appropriate national security considerations, if any) material developed with NASA support. NASA receives a royalty-free license for the federal government and requires that each publication contain an appropriate acknowledgment and disclaimer statement.

5.7 Patents, Invention Reporting, Election of Title and Patent Application Filing

Small business concerns normally may retain the principal worldwide patent rights to any invention developed with government support. In such circumstances, the government receives a royalty-free license for federal government use, reserves the right to require the patent holder to license others in certain circumstances and may require that anyone exclusively licensed to sell the invention in the United States must normally manufacture it domestically. To the extent authorized by 35 U.S.C. 205, the government will not make public any information disclosing a government-supported invention for a minimum 4-year period (that may be extended by subsequent SBIR funding agreements) to allow the contractor a reasonable time to pursue a patent.

NASA SBIR and STTR contracts will include FAR 52.227-11 Patent Rights – Ownership by the Contractor, which requires SBIR/STTR contractors to disclose all subject inventions to NASA within two (2) months of the inventor's report to the contractor. A subject invention is any invention or discovery which is or may be patentable, and is conceived or first actually reduced to practice in the performance of the contract. Once the contractor discloses a subject invention, the contractor has up to 2 years to notify the government whether it elects to retain title to the subject invention. If the contractor elects to retain title, a patent application covering the subject invention must be filed within 1 year. If the contractor fails to do any of these within time specified periods, the government has the right to obtain title.

The awardee may use whatever format is convenient to report inventions, although NASA prefers that the awardee use the electronic version of NASA Form 1679, Disclosure of Invention and New Technology (Including Software), to report inventions. A NTSR listing all inventions developed under the contract or certifying that no inventions were developed must be also be submitted. Both NASA Form 1679 and the NTSR shall be submitted via the SBIR/STTR EHB at http://sbir.nasa.gov under the Handbooks section.

5.8 1852.225-70 Export Licenses

The contractor shall comply with all U.S. export control laws including Export Administration Regulations (EAR) and International Traffic in Arms Regulations (ITAR). Offerors are responsible for ensuring that all employees who will work on this contract are eligible under export control laws, EAR and ITAR. Any employee who is not a U.S. citizen or a permanent resident may be restricted from working on this contract if the technology is restricted under export control laws, ITAR, or EAR unless the prior approval of the Department of State or the Department of Commerce is obtained via a technical assistance agreement or an export license. Violations of these regulations can result in criminal or civil penalties.

For further information on ITAR visit http://www.pmddtc.state.gov/regulations_laws/itar.html. For further information on EAR visit https://www.bis.doc.gov/index.php/regulations/export-administration-regulations-ear. For additional assistance, refer to http://sbir.gsfc.nasa.gov/content/training-resources or contact the NASA SBIR helpdesk at sbir@reisystems.com.

5.9 Government Furnished and Contractor Acquired Property

Title to property furnished by the government or acquired with government funds will be vested with NASA, unless it is determined that transfer of title to the contractor would be more cost effective than recovery of the equipment by NASA.

5.10 Essentially Equivalent Awards and Prior Work

If an award is made pursuant to a proposal submitted under either SBIR or STTR Solicitations, the firm will be required to certify with every invoice that it has not previously been paid nor is currently being paid for essentially equivalent work by any agency of the federal government. **Failure to report essentially equivalent or duplicate efforts can lead to the termination of contracts or civil or criminal penalties.**

5.11 Additional Information

5.11.1 Precedence of Contract over Solicitation

This Program Solicitation reflects current planning. If there is any inconsistency between the information contained herein and the terms of any resulting SBIR/STTR contract, the terms of the contract take precedence over the solicitation.

5.11.2 Evidence of Contractor Responsibility

In addition to the information required to be submitted in section 3.4.12, before award of an SBIR or STTR contract, the government may request the offeror to submit certain organizational, management, personnel and financial information to establish responsibility of the offeror. Contractor responsibility includes all resources required for contractor performance, i.e., financial capability, work force and facilities.

5.12 Requirement for Contracting

To simplify making contract awards and to reduce processing time, all contractors selected for Phase I and Phase II contracts shall ensure that:

1. All information in your proposal is current, e.g., your address has not changed, the proposed PI is the same, etc. If changes have occurred since submittal of your proposal, notify the Contracting Officer immediately.
2. Your firm is registered with System for Award Management (SAM) (section 2.2).
3. Your firm is in compliance with the VETS-4212 requirement (section 2.4.1). Confirmation of that the report has been submitted to the Department of Labor is current shall be provided to the Contracting Officer within 10 business days of the notification of selection for negotiation.
4. Your firm HAS NOT proposed a Co-Principal Investigator.
5. STTR selectees should provide a copy of their executed Allocation of Rights Agreement to the Contracting Officer within 10 business days of receiving notification of selection for negotiation.
6. Your firm is required to provide timely responses to all communications from the NSSC Contracting Officer.
7. All proposed cost is supported with documentation such as a quote, previous purchase order, published price lists, etc. All letters of commitment are dated and signed by the appropriate person. If a University is proposed as a subcontractor or a RI, the signed letter shall be on the University letterhead from the Office of Sponsored Programs. If an independent consultant is proposed, the signed letter should not be on a University letterhead. If the use of government facility or equipment is proposed, your firm shall submit a signed letter from the government facility stating the availability, cost if any, and authorizing the use of it, and a signed letter from your firm justifying the need to use the facility.

From the time of proposal notification of selection for negotiation, until the award of a contract, all communications shall be submitted electronically to NSSC-SBIR-STTR@nasa.gov.

Note: Costs incurred prior to and in anticipation of award of a contract are entirely the risk of the contractor in the event that a contract is not subsequently awarded. A notification of selection for negotiation is not to be misconstrued as an award notification to commence work.

5.13 Use of Federal Services, Facilities or Equipment

Federal Departments and Agencies

Use of SBIR funding for unique federal/non-NASA services, equipment or facilities from a federal department or agency which does not meet the definition of a federal laboratory as defined in the SBA Policy Directive on the SBIR/STIR Program, requires a waiver from the SBA. Proposals requiring waivers must include an explanation of why the waiver is appropriate. NASA will provide the offeror's request, along with an explanation to SBA during the negotiation process. NASA cannot guarantee that a waiver can be obtained from SBA. Specific proposal instructions to request use of Federal Services, Facilities or Equipment are in section 3.3 of the solicitation.

Note: NASA Facilities qualify as Federal Laboratories.

Agreement to Use Any Federal Facility

All offerors selected for award that require the use of any federal facility shall, within twenty (20) business days of notification of selection for negotiations, provide to the NASA Shared Services Center Contracting Officer an agreement by and between the Contractor and the appropriate federal facility, executed by the government official authorized to approve such use. The Agreement must delineate the terms of use, associated costs, facility responsibilities and liabilities. Having a signed agreement for use of federal facilities is a requirement for award.

An executed SBIR/STTR Use Agreement, available in the Firm Library (http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html), is required before a contractor can use NASA services, facilities, or equipment. Offerors should not include an executed SBIR/STTR Use Agreement in the proposals. NASA expects selected offerors to execute the SBIR/STTR Use Agreement during their negotiations with NSSC. The information required in the proposals should facilitate executing the SBIR/STTR Use Agreement.

Contractor Responsibilities for Costs
In accordance with the Federal Acquisition Regulations (FAR) Part 45, it is NASA's policy not to provide services, equipment or facilities (resources) [capital equipment, tooling, test and computer facilities, etc.] for the performance of work under SBIR/STTR contracts. Generally, any contractor will furnish its own resources to perform the proposed work on the contract.

In all cases, the Contractor shall be responsible for any costs associated with services, equipment or facilities provided by NASA or another federal department or agency, and such costs shall result in no increase in the price of this contract.

6. Submission of Proposals

6.1 Submission Requirements

NASA uses electronically supported business processes for the SBIR/STTR Programs. An offeror must have Internet access and an email address. Paper submissions are not accepted.

The EHB for submitting proposals is located at http://sbir.nasa.gov under the Handbooks section. The EHB has been updated for the 2018 cycle to look more modern and be easier to use. The Proposal Submissions EHB guides the firms through the steps for submitting an SBIR/STTR proposal. All EHB submissions are through a secure connection. Communication between NASA's SBIR/STTR Programs and the firm is primarily through a combination of EHBs and email.

6.2 Submission Process

New SBCs must register in the EHB to begin the submission process. Returning firms can use the same account that they have used for previous submissions. Firms are encouraged to start the proposal process early, to allow for sufficient time to complete the submissions process. It is recommended that the Business Official, or an authorized representative designated by the Business Official, be the first person to register for the SBC. The SBC's Employer Identification Number (EIN)/Taxpayer Identification Number is required during registration.

Note: The designated firm admin, typically the first person to register your firm, is the only individual authorized to update and change the firm level forms.

For successful proposal submission, SBCs shall complete all forms online, upload their technical proposal in an acceptable format, and have the Business Official and Principal Investigator electronically endorse the proposal. Electronic endorsement of the proposal is handled online with no additional software requirements. The term "technical proposal" refers to the part of the submission as described in section 3.3.4.

STTR: The Research Institution is required to electronically endorse the Research Agreement prior to the SBC endorsement of the completed proposal submission.

6.2.1 What Needs to Be Submitted

The entire proposal package must be submitted via the Submissions EHB located on the NASA SBIR/STTR website.

Note: Other forms of submissions such as postal, paper, fax, diskette, or email attachments are not acceptable.

The proposal package includes:

1. Contact Information
2. Proposal Certifications
3. Proposal Budget
4. Research Agreement (STTR only)
5. Proposal Summary
6. Technical Proposal (upload)
7. Briefing Chart
8. I-Corps Opt-In (Phase I only)

9. Firm Level Forms (completed once for all proposals submitted to a single Solicitation)

6.2.2 Technical Proposal Submissions

NASA converts all technical proposal files to PDF format for evaluation. Therefore, NASA requests that technical proposals be submitted in PDF format.

Note: Embedded animation or video, as well as reference technical papers for "further reading" will not be considered for evaluation.

Virus Check
The offeror is responsible for performing a virus check on each submitted technical proposal. As a standard part of entering the proposal into the processing system, NASA will scan each submitted electronic technical proposal for viruses.

Note: The detection, by NASA, of a virus on any electronically submitted technical proposal, may cause rejection of the proposal.

6.2.3 Technical Proposal Uploads

Firms will upload their proposals using the Submissions EHB. Directions will be provided to assist users. All transactions via the EHB are encrypted for security. Firms cannot submit security/password protected technical proposal and/or supporting documentation, as reviewers may not be able to open and read the files.

You may upload the technical proposal multiple times, with each new upload replacing the previous version, but only the final uploaded and electronically endorsed version will be considered for review. Before you can submit the proposal package, you must download the entire proposal package and certify that you have reviewed it to ensure that you have uploaded the correct materials.

6.3 Deadline for Phase I Proposal Receipt

All Phase I proposal submissions shall be received no later than *5:00 p.m. EST on Friday, March 09, 2018* via the NASA SBIR/STTR website (http://sbir.nasa.gov), under the Handbooks section.

The EHB will not allow internet submissions after this deadline, but firms will have read-only access to the materials they have already submitted.

Note: Offerors are strongly encouraged to start the submission process early in order to allow sufficient time for completing their proposal.

6.4 Deadline for Phase II Proposal Receipt

All Phase II proposal submissions shall be received no later than 5:00 p.m. EST the last day of the Phase I contract original period of performance, via the NASA SBIR/STTR website (http://sbir.nasa.gov) under the Handbooks section.

The EHB will be available for Internet submissions approximately 6 weeks prior to completion date of Phase I contracts. Receipt of Phase II proposals are due on the last day of performance under SBIR/STTR Phase I contracts.

The EHB will not be available for internet submissions after this deadline, but firms will have read-only access to the materials they have already submitted.

6.5 Acknowledgment of Proposal Receipt

The final proposal submission includes successful completion of all firm level forms, Contact Information, Proposal Certifications, Proposal Budget, Proposal Summary, the Technical Proposal upload, the Briefing Chart, the I-Corps Opt-In (if applicable in Phase I), and electronic endorsement by the SBC Official and Principal Investigator. For STTR submissions, it also includes the Research Agreement and endorsement of this agreement by the Research Institution official. NASA will acknowledge receipt of electronically submitted proposals upon endorsement by the SBC Official to the SBC Official's email address as provided on the proposal cover sheet, as well as to the user who created the proposal, if different. If a proposal acknowledgment is not received, the offeror should contact the NASA SBIR/STTR Program Support Office at 301-937-0888 or sbir@reisystems.com.

6.6 Withdrawal of Proposals

Prior to the close of submissions, proposals may be withdrawn via the Proposal Submissions Electronic Handbook hosted on the NASA SBIR/STTR website (http://sbir.nasa.gov) under the Handbooks section. In order to withdraw a proposal after the deadline, the designated SBC Official must send written notification via email to sbir@reisystems.com.

6.7 Service of Protests

Copies of any protests, as defined in section 33.101 of the FAR, shall be served on the Contracting Officer by obtaining written and dated acknowledgement of receipt from the NASA SBIR/STTR Program contact listed below:

Benjamin Benvenutti
NASA Shared Services Center
Building 1111, C Road
Stennis Space Center, MS 39529
benjamin.s.benvenutti@nasa.gov

The copy of any protest shall be received within one calendar day of filing a protest with the GAO.

7. Proposal, Scientific and Technical Information Sources

7.1 NASA Websites

General sources relating to organizational and programmatic information at NASA is available via the following websites:

NASA Budget Documents, Strategic Plans and Performance Reports:
http://www.nasa.gov/about/budget/index.html
NASA Organizational Structure: http://www.nasa.gov/centers/hq/organization/index.html
NASA SBIR/STTR Programs: http://sbir.nasa.gov

Information regarding the mission directorates and the NASA centers can be obtained at the following websites:

Space Technology	
Space Technology Roadmaps	http://www.nasa.gov/offices/oct/home/roadmaps/index.html

NASA Mission Directorates	
Aeronautics Research	http://www.aeronautics.nasa.gov/
Human Exploration and Operations	http://www.nasa.gov/directorates/heo/home/
Science	http://nasascience.nasa.gov
Space Technology	http://www.nasa.gov/directorates/spacetech/home/index.html

NASA Centers	
Armstrong Flight Research Center (AFRC)	http://www.nasa.gov/centers/armstrong/home/index.html
Ames Research Center (ARC)	http://www.nasa.gov/centers/ames/home/index.html
Glenn Research Center (GRC)	http://www.nasa.gov/centers/glenn/home/index.html
Goddard Space Flight Center (GSFC)	http://www.nasa.gov/centers/goddard/home/index.html
Jet Propulsion Laboratory (JPL)	http://www.nasa.gov/centers/jpl/home/index.html
Johnson Space Center (JSC)	http://www.nasa.gov/centers/johnson/home/index.html
Kennedy Space Center (KSC)	http://www.nasa.gov/centers/kennedy/home/index.html
Langley Research Center (LaRC)	http://www.nasa.gov/centers/langley/home/index.html
Marshall Space Flight Center (MSFC)	http://www.nasa.gov/centers/marshall/home/index.html
Stennis Space Center (SSC)	http://www.nasa.gov/centers/stennis/home/index.html
NASA Shared Services Center (NSSC)	https://www.nssc.nasa.gov/

7.2 United States Small Business Administration (SBA)

The Policy Directives for the SBIR/STTR Programs may be obtained from the following source. SBA information can also be obtained at: http://www.sbir.gov.

U.S. Small Business Administration
Office of Technology – Mail Code 6470
409 Third Street, S.W.
Washington, DC 20416
Phone: 202-205-6450

7.3 National Technical Information Service

The National Technical Information Service is an agency of the Department of Commerce and is the federal government's largest central resource for government-funded scientific, technical, engineering and business-related information. For information regarding their various services and fees, call or write:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Phone: 703-605-6000
URL: http://www.ntis.gov

7.4 Other Sources of Assistance

The U.S. Government invests in a wide variety of resources designed to aid and assist small business owners and their employees. A variety of websites containing these resources and links to additional resources can be found at: http://sbir.nasa.gov/content/additional-sources-assistance.

8. Submission Forms

Note: Previews of all forms and certifications are available via the NASA SBIR/STTR Firm Library, located at: http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html.

SBIR Phase I Check List

For assistance in completing your Phase I proposal, use the following checklist to ensure your submission is complete.

1. The proposal and innovation is submitted for one subtopic only (section 3.1).

2. The entire proposal package is submitted consistently with the requirements outlined in section 3.3.
    a. Contact Information
    b. Proposal Certifications
    c. Proposal Budget
    d. Proposal Summary
    e. Technical Proposal
    f. Briefing Chart
    g. I-Corps Opt-In
    h. Firm Level Forms (completed once for all proposals submitted to a single Solicitation)
        i. Firm Certifications
        ii. Audit Information
        iii. Prior Awards Addendum
        iv. Commercialization Metrics Survey

3. **The technical proposal shall not exceed a total of 19 8.5 x 11 inch pages and follow the format requirements (section 3.3.2).**

4. The technical proposal contains all ten parts in order (section 3.3.4).

5. Any additional required letters/documentation.
    a. A letter of commitment from the facility manager, if the research or R&D effort requires use of federal facilities (section 3.3.3.4).
    b. Letters of commitment from Subcontractors/Consultants.
    c. If the firm is an eligible joint ventures and limited partnership, a copy or comprehensive summary of the joint venture agreement or partnership agreement is included.
    d. NASA Research License Application if proposing the use of NASA Technology (TAV).

6. Proposed funding does not exceed $125,000 (section 1.3).

7. Proposed project duration does not exceed 6 months (section 1.3).

8. Proposal package electronically endorsed by the SBC Official and the PI.

9. **Proposals must be received no later than 5:00 p.m. EST on March 09, 2018 (section 6.3).**

STTR Phase I Check List

For assistance in completing your Phase I proposal, use the following checklist to ensure your submission is complete.

1. The proposal and innovation is submitted for one subtopic only (section 3.1).

2. The entire proposal package is submitted consistently with the requirements outlined in section 3.3.
    a. Contact Information
    b. Proposal Certifications
    c. Proposal Budget
    d. Research Agreement (STTR only)
    e. Proposal Summary
    f. Technical Proposal
    g. Briefing Chart
    h. I-Corps Opt-In
    i. Firm Level Forms (completed once for all proposals submitted to a single Solicitation)
        i. Firm Certifications
        ii. Audit Information
        iii. Prior Awards Addendum
        iv. Commercialization Metrics Survey

3. **The technical proposal shall not exceed a total of 19 8.5 x 11 inch pages and follow the format requirements (section 3.3.2).**

4. The technical proposal contains all ten parts in order (section 3.3.4).

5. Any additional required letters/documentation.
    a. A letter of commitment from the facility manager, if the research or R&D effort requires use of federal facilities (section 3.3.3.4).
    b. Letters of commitment from Subcontractors/Consultants.
    c. If the firm is an eligible joint ventures and limited partnership, a copy or comprehensive summary of the joint venture agreement or partnership agreement is included.
    d. NASA Research License Application if proposing the use of NASA Technology (TAV).

6. Proposed funding does not exceed $125,000 (section 1.3).

7. Proposed project duration does not exceed 13 months (section 1.3).

8. Research Agreement has been electronically endorsed by both the SBC Official and the RI (section 3.3.5, 6.2).

9. Proposal package electronically endorsed by the SBC Official and the PI.

10. **Proposals must be received no later than 5:00 p.m. EST on March 09, 2018 (section 6.3).**

11. Signed Allocation of Rights Agreement available for Contracting Officer within 10 days of selection.

SBIR Phase II Check List

For assistance in completing your Phase II proposal, use the following checklist to ensure your submission is complete.

1. The proposal and innovation is submitted for one subtopic only (section 3.1).

2. The entire proposal package is submitted consistently with the requirements outlined in section 3.4.
    a. Contact Information
    b. Proposal Certifications
    c. Proposal Budget
    d. Proposal Summary
    e. Technical Proposal
    f. Briefing Chart
    g. Capital Commitments Addendum (if applicable)
    h. Firm Level Forms (completed once for all proposals submitted to a single Solicitation)
        i. Firm Certifications
        ii. Audit Information
        iii. Prior Awards Addendum
        iv. Commercialization Metrics Survey

3. **The technical proposal shall not exceed a total of 46 8.5 x 11 inch pages and follow the format requirements (section 3.4.2).**

4. The technical proposal contains all ten parts in order (section 3.4.4).

5. Any additional required letters/documentation
    a. A letter of commitment from the facility manager, if the research or R&D effort requires use of federal facilities (section 3.4.4).
    b. Letters of commitment from Subcontractors/Consultants.
    c. Letters in support of Capital Commitments Addendum.
    d. If the firm is an eligible joint ventures and limited partnership, a copy or comprehensive summary of the joint venture agreement or partnership agreement is included.
    e. NASA Research License Application if proposing the use of NASA Technology (TAV).

6. Proposed funding does not exceed $750,000, excluding the $5,000 Commercialization Technical Assistance, if requested (section 1.3).

7. Proposed project duration does not exceed 24 months (section 1.3).

8. Proposal package electronically endorsed by the SBC Official and the PI.

9. **Phase II proposal submissions will be due the last day of the Phase I contract (section 6.4).**

STTR Phase II Check List

For assistance in completing your Phase II proposal, use the following checklist to ensure your submission is complete.

1. The proposal and innovation is submitted for one subtopic only (section 3.1).

2. The entire proposal package is submitted consistently with the requirements outlined in section 3.4.
    a. Contact Information
    b. Proposal Certifications
    c. Proposal Budget
    d. Research Agreement
    e. Proposal Summary
    f. Technical Proposal
    g. Briefing Chart
    h. Capital Commitments Addendum (if applicable)
    i. Firm Level Forms (completed once for all proposals submitted to a single Solicitation)
        i. Firm Certifications
        ii. Audit Information
        iii. Prior Awards Addendum
        iv. Commercialization Metrics Survey

3. **The technical proposal shall not exceed a total of 46 8.5 x 11 inch pages and follow the format requirements (section 3.4.2).**

4. The technical proposal contains all ten parts in order (section 3.4.4).

5. Any additional required letters/documentation
    a. A letter of commitment from the facility manager, if the research or R&D effort requires use of federal facilities (section 3.4.4).
    b. Letters of commitment from Subcontractors/Consultants.
    c. Letter in support of Capital Commitments Addendum.
    d. If the firm is an eligible joint ventures and limited partnership, a copy or comprehensive summary of the joint venture agreement or partnership agreement is included.
    e. NASA Research License Application if proposing the use of NASA Technology (TAV).

6. Proposed funding does not exceed $750,000 excluding the $5,000 Commercialization Technical Assistance, if requested (section 1.3).

7. Proposed project duration does not exceed 24 months (section 1.3).

8. Research Agreement has been electronically endorsed by both the SBC Official and the RI (section 3.4.5, 6.2).

9. Proposal package electronically endorsed by the SBC Official and the PI.

10. **Phase II proposal submissions will be due the last day of the Phase I contract (section 6.4).**

11. Signed Allocation of Rights Agreement, available for the Contracting Officer within 10 days of the selection.

9. Research Topics for SBIR and STTR

Introduction

The SBIR and STTR subtopics are organized into groupings called "Focus Areas". Focus Areas are a way of grouping NASA interests and related technologies with the intent of making it easier for proposers to understand related needs across the agency and thus identify subtopics where their research and development capabilities may be a good match.

Note: This year, the SBIR and STTR Subtopics will appear in one combined listing. The STTR subtopics will begin with a "T" and will be clearly marked so that offerors will know that the additional Research Institution (RI) partnership is required before submitting a proposal.

Subtopic numbering conventions from previous year's solicitations have been maintained for traceability of like-subtopics from previous solicitations. The mapping is as follows:

A – Aeronautics Research Mission Directorate (ARMD)
H – Human Exploration and Operations Mission Directorate (HEOMD)
S – Science Mission Directorate (SMD)
Z – Space Technology Mission Directorate (STMD)
T – Small Business Technology Transfer (STTR)

Proposers should think of the Subtopic Lead Mission Directorates and Lead/Participating Centers as potential customers for their proposals. Multiple Mission Directorates and Centers may have interests across the subtopics within a Focus Area.

Related subtopic pointers are identified when applicable in the subtopic headers to assist proposers with identifying related subtopics that also potentially seek related technologies for different customers or applications. As stated in section 3.1, an offeror shall not submit the same (or substantially equivalent) proposal to more than one subtopic. It is the offeror's responsibility to select which subtopic to propose to.

Focus Area 1: In-Space Propulsion Technologies
Lead MD: STMD
Participating MD(s): SMD

NASA is interested in technologies for advanced in-space propulsion systems to reduce travel time, increase payload mass, reduce acquisition costs, reduce operational costs, and enable new science capabilities for exploration and science spacecraft. The future will require demanding propulsive performance and flexibility for more ambitious missions requiring high duty cycles, more challenging environmental conditions, and extended operation. This focus area seeks innovations for NASA propulsion systems in chemical, electric, nuclear thermal and advanced propulsion systems related to human exploration and science missions. Propulsion technologies will focus on a number of mission applications including ascent, descent, orbit transfer, rendezvous, station keeping, and proximity operations.

Z10.01 Cryogenic Fluid Management (SBIR)
Lead Center: GRC
Participating Center(s): JSC, MSFC

This subtopic solicits technologies related to cryogenic propellants (such as hydrogen, oxygen, and methane) storage, and transfer to support NASA's exploration goals. This includes a wide range of applications, scales, and environments consistent with future NASA missions. Such missions include but are not limited to a Methane Upper Stage, Nuclear Thermal Propulsion, Lander Propulsion, and In-Situ Resource Utilization in support of the Evolvable Mars Campaign.

Specifically, listed in order of importance:

- Develop reliable cryogenic screen channel acquisition devices (NASA is mainly interested in screens with pore sizes < 100 µm) using innovative manufacturing techniques to minimize stresses of cryogenic screen channels to improve screen-to-window manufacturing reliability. Reliability should be based on changes in bubble point pressure before and after thermal cycling the elements (> 10 times) at or below 77 K.
- New and improved technologies that provide for the densification (or sub-cooling) of cryogenic propellants. Propellant conditioning systems that allow for the production and maintenance of densified propellants that support operations including transfer and low-loss storage are of prime interest for future space vehicle and ground launch processing facilities.
- Advanced numerical design tools are sought for cryogenic propellant management systems accounting for large EUS-scale operations in relevant low-gravity (low-acceleration) environments. Ideally, such a tool should consider thermal gradients, acceleration gradients, perturbations due to docking, and orbital maneuvers in order to help system designers evaluate the impacts of these various environments to the propellant management system. Advanced numerical design tools are sought for fuels/cryogenic management systems accounting for large EUS-scale operations in relevant low-gravity (low-acceleration) environments considering the impacts of thermal gradients, gravity gradients, perturbations due to docking, orbital maneuvers, self-gravitation, and others.
- Develop an insulation to reduce the heat leak in the annulus space of approximately ¾”, which is located over a liquid hydrogen tank but under a broad area cooled (BAC) shield at 90 K for space applications. The insulation concept has the dual function of structurally supporting the 5 mil thick broad area cooled shield and roughly 35-40 outer layers of traditional multi-layer insulation (MLI) (or less with high performing MLI) and reducing the heat leak from the 90K surface to the LH_2 tank. Analysis shall focus on the thermal design’s reduction of conductive and radiative heat transfer in the vacuum of space to minimize heat load (> 70% reduction in insulation heat load compared to equivalent MLI system without BAC shield) to the tank while being lightweight for flight.

- System/stage cryogenic valves sized for 3 in. (7.62 cm) tube size for low pressure (<50 psia; 3.4 bar), scalable to 10 in. (25.4 cm) size, with Cv > 200, low internal (~ 1 sccm, goal of < 0.1 sccm) and external (~ 3 sccm, goal of < 0.1 sccm) leakage, > 500 cycles with a goal of 5,000 cycles, low heat leak (<3 W/valve), low actuation power. The valve should have a clear path to combine with an actuator and its requirements.
- Electric Pump technologies with low power (<40-50 kW) at flowrates suitable for feeding iRCS accumulator(s) supplying a bank of four (4) 1000-lb RCS engines operating at total oxygen or methane mass flowrates of ~8-10 lb/s (3.6-4.5 kg/s), or Low power (<4-6 kW) supplying a bank of four (4) 100-lb RCS engines, operating at a total flowrate of ~1 lb/s (0.45 kg/s). The pumps will operate between low pressure (<50 psia; <3.4 bar) propellant tanks, up to supercritical pressures >667 psia (>46 bar) under varying duty cycle demand regimes. Note actual duty cycle requirements will be mission specific – proposers should describe scalability to handle changes in demand, and changes in the scale of thrusters per thruster bank (e.g., 3x100-lb & 1x1000-lb, etc.).

Phase I proposals should at a minimum deliver proof of the concept including some sort of testing or physical demonstration (not just a paper study). Phase II proposals will be expected to provide component validation in a laboratory environment preferably with a hardware deliverable to NASA.

Z10.02 Propulsion Systems for Robotic Science Missions (SBIR)
Lead Center: GRC
Participating Center(s): JPL, MSFC
Related Subtopic Pointer(s): S4.03, Z8.01, T9.01

The Science Mission Directorate (SMD) needs spacecraft with more demanding propulsive performance and flexibility for more ambitious missions requiring high duty cycles, more challenging environmental conditions, and extended operation. Planetary spacecraft need the ability to rendezvous with, orbit, and conduct in-situ exploration of planets, moons, and other small bodies in the solar system. Mission priorities are outlined in the decadal surveys for each of the SMD Divisions. (https://science.nasa.gov/about-us/science-strategy/decadal-surveys) Future spacecraft and constellations of spacecraft will have high-precision propulsion requirements, usually in volume-, mass-, and power-limited envelopes.

This subtopic seeks innovations to meet SMD propulsion in chemical and electric propulsion systems related to sample return missions to Mars, small bodies (like asteroids, comets, and Near-Earth Objects), outer planet moons, and Venus. Additional electric propulsion technology innovations are also sought to enable low-cost systems for Discovery class missions, and low-power, nuclear electric propulsion (NEP) missions. The roadmap for in space propulsion technologies can be found at the following Office of Chief Technologist website (https://www.nasa.gov/sites/default/files/atoms/files/2015_nasa_technology_roadmaps_ta_2_in-space_propulsion_final.pdf).

Proposals should show an understanding of the state-of-the-art (SOA), how their technology is superior, and of one or more relevant science needs. The proposals should provide a feasible plan to fully develop a technology and infuse it into a NASA program. In addressing technology requirements, proposers should identify potential mission applications and quantify the expected advancement over SOA alternatives.

Advanced Electric Propulsion Components
Towards that end, this subtopic seeks proposals that explore uses of technologies that will provide superior performance, reduce complexity, increase reliability, and/or lower cost for high specific impulse/low mass electric propulsion systems. These technologies include:

- Long-life heaters for hollow cathodes made with lanthanum hexaboride (LaB_6) or other materials. In order to achieve reliable cathode ignition, the LaB_6 heaters typically must operate at 1500 – 1700° C. Reproducible fabrication processes that minimize unit-to-unit variations in performance and lifetime will be critical for the practical adaptation of a new heater technology.
- High-temperature electromagnets for Hall thrusters, capable of operating reliably at >500° C.
- 3D printing of magnetic materials for Hall thruster magnetic circuits.
- Low-cost gas distributors capable of achieving a high degree of flow uniformity in Hall thruster anode gas feeds.
- Advanced ceramics for Hall thruster discharge chambers.
- Feed systems for ultra-high-Isp gridded ion thrusters running on lithium propellant.

This subtopic also seeks to mature and demonstrate iodine electric propulsion technologies. Iodine propellant has two key advantages over the SOA xenon propellant: (i) increased storage density and (ii) reduced storage pressure. These key advantages permit iodine propulsion systems with conformal storage tanks, reduced structural mass, and reduced volume compared with the SOA xenon, while retaining similar thrust, specific impulse, and thruster efficiency. Technologies of interest include, but are not limited to:

- Robust and electrically efficient iodine storage and delivery technology (scalable 1 kg to 100 kg iodine) for sub-kilowatt Hall Effect and Ion thrusters:
    - Computational models are desired to evaluate novel iodine feed system concepts and CONOPS. Modeling capabilities of interest include, but are not limited to:
        - Optimizing power consumption and iodine mass transport.
        - Predicting sublimation rate and system pressures.
        - Understanding expected anomalies such as iodine deposition, clog formation, clog recovery, and material interactions.
    - Proposals are desired that systematically validate new modeling predictive capabilities with appropriate experimental demonstrations and perform investigations where existing literature is insufficient.
    - High-reliability, long-life iodine storage and delivery systems are desired that package efficiently in volume-limited spacecraft, minimize spacecraft energy consumption, minimize thermal loading on spacecraft structures and neighboring components, and can remain quiescent for long periods with minimal or no maintenance or degenerative material interactions. Proposals are desired that offer supporting analysis or experimental evidence that a concept has merit. Proposals should provide a plan to theoretically refine the design concept, construct a prototype with a minimum 1 kg iodine capacity, perform experimental analysis in a relevant environment, refine the concept as necessary, and demonstrate. Demonstrations need not be performed with an operational thruster, but should be integrated in a test apparatus that reasonably replicates the fluid-dynamic and thermodynamic loads expected when integrated in a complete system. Given the current lack of demonstrated high life iodine compatible cathodes, hybrid feed systems are preferentially desired, which accommodate an iodine thruster matched with a xenon cathode (High life iodine compatible cathodes are also sought in this subtopic).
- High-reliability, long-life, compact, low-power iodine feed subsystem technologies are desired, including:
    - Iodine compatible high-accuracy pressure sensors, novel propellant flow control and metering technologies, filtration, propellant management devices, etc.
    - New iodine-compatible materials, coating, or otherwise innovative construction techniques leading to long-life, reliable, and corrosion resistant components.
- Iodine compatible cathodes with lifetimes of at least 2,000 hours, goal of greater than 10,000 hours.

Solar/Electric Sail Propulsion

This subtopic seeks sail propulsion innovations in three areas for future robotic science and exploration missions:

- Large solar sail propulsion systems with at least 1000 square meters of deployed surface area for small (<150 kg) spacecraft to enable multiple Heliophysics missions of interest.
- Electric sail propulsion systems capable of achieving at least 1 mm/sec2 characteristic acceleration to support Heliophysics missions of interest and rapid outer solar system exploration.
- Electrodynamic tether/sail propulsion systems capable of generating from the Lorentz Force delta-V sufficient to de-orbit from altitudes up to 2,000 km and to maintain a small (< 500 kg) spacecraft in LEO at altitudes up to 400 km for 5 years enabling Earth ionospheric and plasmasphere investigations.

Design solutions must demonstrate high deployment reliability and predictability with minimum mass and launch volume and maximum strength, stiffness, stability, and durability. In the case of tethers, advancements are needed for tether deployment and control, and for dynamic modeling/simulation and ground test methods, due to the high rate of space mission failures and anomalies for tether systems. For electric sail concepts and related future flight demonstrations, wire/tether deployment and control is considered one of the highest risk areas for successful flight.

Innovations are sought in the following areas:

- Novel design, packaging, and deployment/control concepts.
- Lightweight, compact components including booms, substrates, and mechanisms.
- Validated modeling, analysis, and simulation techniques.
- Ground and in-space test methods.
- High-fidelity, functioning laboratory models.

Note: Cubesat propulsion technologies for spacecraft smaller than 27U should be submitted to STMD subtopic: Z8.01 - Cubesat Propulsion Systems.

Z10.03 Nuclear Thermal Propulsion (NTP) (SBIR)
Lead Center: MSFC
Participating Center(s): GRC, SSC

Solid core NTP has been identified as an advanced propulsion concept which could provide the fastest trip times with fewer SLS launches than other propulsion concepts for human missions to Mars over a variety of mission years. NTP had major technical work done between 1955-1973 as part of the Rover and Nuclear Engine for Rocket Vehicle Application (NERVA) programs. A few other NTP programs followed including the Space Nuclear Thermal Propulsion (SNTP) program in the early 1990's. The NTP concept is similar to a liquid chemical propulsion system, except instead of combustion in the thrust chamber, a monopropellant is heated with a fission reactor (heat exchanger) in the thrust chamber and exposes the engine components and surrounding structures to a radiation environment.

Engine System Design

Focus is on a range of modern technologies associated with NTP using solid core nuclear fission reactors and technologies needed to ground test the engine system and components. The engines are pump fed ~25,000 lbf with a specific impulse goal of 900 seconds (using hydrogen), and are used individually or in clusters for the spacecraft's primary propulsion system. The NTP can have multiple start-ups (>4) with cumulative run time >100 minutes in a single mission, which can last a few years. The Rover/NERVA program ground tested a variety of engine sizes, for a variety of burn durations and start-ups with the engine exhaust released to the open air. Current regulations require exhaust filtering of any radioactive noble gases and particulates. The NTP primary test requirements can have multiple start-ups (>8) with the longest single burn time ~50 minutes.

Technologies being sought include:

- Low Enriched Uranium reactor fuel element designs with high temperature (> 2600 K), high power density (>5 MW/L) to optimize hydrogen propellant heating.
- New advanced manufacturing processes to quickly manufacture the fuel with uniform channel coatings and/or claddings that reduce fission product gas release and reactor particulates into the engines exhaust stream. Fuels are focused on Ceramic-metallic (cermet) designs:
    - New fuel element geometries which are easy to manufacture and coat, and better performing than the traditional prismatic fuel geometries with small through holes with coatings.
    - Best joining and manufacturing processes for tungsten, molybdenum, and molybdenum/tungsten alloys.
- Insulator design (one application is for tie tubes and the other is for interface with the pressure vessel) which has very low thermal conductivity and neutron absorption, withstands high temperatures, compatible with hot hydrogen and radiation environment, and light weight.

Operations and Safety
Engine operation involves start-up, full thrust operation, shutdown, coast, and restart. Technologies being sought include advanced instrumentation and special reactor safety design features which prevent uncontrolled reactor criticality accidents. Specific areas of interest include:

- Concepts to cool down the reactor decay heat after shutdown to minimize the amount of open cycle propellant used in each engine shutdown (Depending on the engine run time for a single burn, cool down time can take many hours).
- Low risk reactor design features which allow more criticality control flexibility during burns beyond the reactor circumferential rotating control drums, and/or provide nuclear safety for ground processing, launch, and possible launch aborts:
    - Control of criticality with water submersion and compaction accidents.

Ground Test Technologies
Included in this area of technology development needs are identification and application of robust materials, advanced instruments and monitoring systems capable of operating in extreme temperature, pressure and radiation environments. Specific areas of interest include:

- Efficient generation of high temperature, high flow rate hydrogen (<30 lb/sec).
- Devices for measurement of radiation, pressure, temperature and strain in a high temperature and radiation environment:
    - Non-intrusive diagnostic technology to monitor engine exhaust for fuel element erosion/failure and release of radioactive particulates.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path towards Phase II hardware/software demonstration with delivery of a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables - Feasibility study, including simulations and measurements, proving the proposed approach to develop a given product (TRL 2-3). Verification matrix of measurements to be performed at the end of Phase II, along with specific quantitative pass-fail ranges for each quantity listed.

Phase II Deliverables - Working engineering model of proposed product, along with full report of component and/or breadboard validation measurements, including populated verification matrix from Phase I (TRL 4-5). Opportunities and plans should also be identified and summarized for potential commercialization.

Focus Area 2: Power Energy and Storage

Lead MD: STMD
Participating MD(s): SMD, STTR

Power is a ubiquitous technology need across many NASA missions. Within the SBIR Program, power is represented across a broad range of topics in human exploration, space science, space technology and aeronautics. New technologies are needed to generate electrical power and/or store energy for future human and robotic space missions and to enable hybrid electric aircraft that could revolutionize air travel. A key goal is to develop technologies that are multi-use and cross-cutting for a broad range of NASA mission applications. In aeronautics, power technologies are needed to supply large-scale electric power and efficiently distribute the power to aircraft propulsors (see Focus Area 18 – Air Vehicle Technologies). In the space power domain, mission applications include planetary surface power, large-scale spacecraft prime power, small-scale robotic probe power, and smallsat/cubesat power. Applicable technology options include photovoltaic arrays, radioisotope power systems, nuclear fission, thermal energy conversion, motor/generators, fuel cells, batteries or other energy storage devices, power management, transmission, distribution and intelligent control. An overarching objective is to mature technologies from analytical or experimental proof-of-concept (TRL 3) to breadboard demonstration in a relevant environment (TRL 5). Successful efforts will transition into NASA Projects where the SBIR/STTR deliverables will be incorporated into ground testbeds or flight demonstrations.

S3.01 Power Generation and Conversion (SBIR)
Lead Center: GRC
Participating Center(s): ARC, JPL, JSC

Photovoltaic Energy Conversion: advances in, but not limited to, the following:

- Photovoltaic cell and blanket technologies capable of low intensity, low-temperature operation applicable to outer planetary (low solar intensity) missions.
- Photovoltaic cell, blanket and array technologies capable of enhancing solar array operation in a low-intensity, high-temperature environment (such as the Venus surface).
- Solar arrays to support Extreme Environments Solar Power type missions, including long-lived, radiation tolerant, cell and blanket technologies applicable to Jupiter missions.
- Lightweight solar array technologies applicable to science missions using solar electric propulsion.

Current missions being studied require solar arrays that provide 1 to 20 kilowatts of power at 1 AU, greater than 300 watts/kilogram specific power, operation in the range of 0.7 to 3 AU, low stowed volume, and the ability to provide operational array voltages up to 300 volts to enable direct drive electric propulsion systems for science missions.

Dynamic Power Conversion: advances in, but not limited to, the following:

- Novel Stirling, Brayton or Rankine convertors that can be integrated with one or more 250 watt-thermal General Purpose Heat Source modules to provide high thermal-to-electric efficiency (>25%), low mass, long life (>10 years), and high reliability for planetary spacecraft, landers, and rovers.
- Micro-miniature dynamic power convertors that can be integrated with one or more 1 watt-thermal Radioisotope Heater Units to provide long duration electric power for planetary smallsats and distributed instruments.
- Advanced dynamic conversion components including hot-end heat exchangers, cold-end heat exchangers, regenerators/recuperators, alternators, engine controllers, heat pipes and radiators that improve system performance, reliability and fault tolerance.

Direct Energy Conversion; advances in, but not limited to, the following: Recent advancements in alpha/beta-voltaic energy conversion devices have the potential to increase the power level, improve reliability, and increase the lifetime of this power technology. The development of continuous, low-power generation technology for autonomous remote sensors and other specialized applications would support NASA Science Mission goals and enhance/enable new mission capabilities. The area of Direct Energy Conversion seeks technology advancements that address, but are not limited to experimental demonstration of long life (years) alpha-voltaic, beta-voltaic, and other non-solar conversion concepts with device-level conversion efficiencies in excess of 10% and the ability to scale up to 1-10 W of electrical power output with system-level specific power of 5 W/kg or higher.

S3.03 Power Electronics and Management, and Energy Storage (SBIR)
Lead Center: GRC
Participating Center(s): ARC, GSFC, JPL

Power Electronics and Management
NASA's Planetary Science Division is working to implement a balanced portfolio within the available budget and based on a decadal survey that will continue to make exciting scientific discoveries about our solar system. This balanced suite of missions shows the need for low mass/volume power electronics and management systems and components that can operate in extreme environment for future NASA Science Missions.

Advances in electrical power technologies are required for the electrical components and systems of these future spacecrafts/platforms to address program size, mass, efficiency, capacity, durability, and reliability requirements. Radioisotope power systems (RPS), Advanced Modular Power Systems (AMPS) and In-Space Electric Propulsion (ISP) are several programs of interest which would directly benefit from advancements in this technology area. These types of programs, including Mars Sample Return using Hall thrusters and power processing units, require advancements in components and control systems beyond the state-of-the-art. Of importance are expected improvements in system robustness, energy density, speed, efficiency, or wide-temperature operation (-125° C to over 450° C) with a number of thermal cycles. Novel approaches to minimizing the weight of advanced PPUs are also of interest. Advancements are sought for power electronic devices, components, packaging and cabling for programs with power ranges of a few watts for minimum missions to up to 20 kilowatts for large missions. In addition to electrical component development, the Science Mission Directorate has a need for intelligent, fault-tolerant Power Management and Distribution (PMAD) technologies to efficiently manage the system power for deep space missions.

Overall technologies of interest include:

- High power density/high efficiency power electronics and associated drivers for switching elements.
- Non-traditional approaches to switching devices, such as addition of graphene and carbon nanotubes to material.
- Lightweight, highly conductive power cables and/or cables integrated with vehicle structures.
- Intelligent power management and fault-tolerant electrical components and PMAD systems.
- Advanced electronic packaging for thermal control and electromagnetic shielding.
- Integrated packaging technology for modularity.

Energy Storage
Future science missions will require advanced primary and secondary battery systems capable of operating at temperature extremes from -100° C for Titan missions to 400 to 500° C for Venus missions, and a span of -230° C to +120° C for Lunar Quest. The Outer Planet Assessment Group and the 2011 PSD Relevant Technologies Document have specifically called out high energy density storage systems as a need for the Titan/Enceladus Flagship and planetary exploration missions. In addition, high energy-density rechargeable electrochemical battery systems that offer greater than 50,000 charge/discharge cycles (10-year operating life) for low-earth-orbiting spacecraft, 20-year life for geosynchronous (GEO) spacecraft, are desired. Advancements to battery energy storage capabilities that address one or more of the above requirements for the stated missions combined with very high specific energy and energy density (>200 Wh/kg for secondary battery systems), along with radiation tolerance are of interest.

In addition to batteries, other advanced energy storage/load leveling technologies designed to the above mission requirements, such as mechanical or magnetic energy storage devices, are of interest. These technologies have the potential to minimize the size and mass of future power systems.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II, and when possible, deliver a demonstration unit for NASA testing at the completion of the Phase II contract. Phase II emphasis should be placed on developing and demonstrating the technology under relevant test conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into science-worthy systems.

Z1.01 High Power Arrays for Solar Electric Propulsion (SBIR)
Lead Center: GRC
Participating Center(s): JPL, LaRC
Related Subtopic Pointer(s): H5.01

NASA is seeking developments in advanced solar array power technology for very high power (500kW) systems to support future NASA missions involving Solar Electric Propulsion (SEP) and other in-space applications. The objective is to develop solar-powered systems and components that are lightweight, reliable, compactly stowed, survivable within the space environment (i.e., minimal degradation due to space particulate radiation, UV, micrometeoroid impacts, thermal cycling, spacecraft contaminants, and space environmental effects), and provide sufficient stiffness to minimize adverse spacecraft dynamics issues. Of particular interest are technologies that:

- Reduce the overall solar array cost through modularity, minimization of part counts, automated fabrication and testing, and reduced material costs.
- Enable high voltage operation of the solar array with minimal space environmental interactions that could lead to degraded array performance.
- Survive long-term exposure within a solar electric propulsion thruster environment.

Technology advancements may include developments in solar cells, blanket technology, array designs, array deployment techniques (including in-space robotic assembly), improved manufacturing processes, and the ability to adequately ground-test and space-qualify these large array designs.

Z1.03 Fission Surface Power Generation (SBIR)
Lead Center: GRC
Participating Center(s): JPL, JSC

NASA is considering the use of kilowatt class Fission Power Systems for surface missions to the moon and Mars. Current work in fission power systems is focused on the Kilopower project which uses a highly-enriched Uranium-Molybdenum reactor core with a Beryllium oxide reflector. Depleted uranium, tungsten, and lithium hydride provide shielding of gamma rays and neutrons to the power conversion system, control electronics, payload, and habitat. Heat is removed from the core at approximately 800° C using sodium heat pipes and delivered to dynamic power conversion systems with conversion efficiencies over 25%. Waste heat is removed from the power conversion system at approximately 100° C using water heat pipes coupled to aluminum or composite radiator panels. The Kilopower project targets the 1-10 kW power range with most previous work focused on a demonstration of the 1 kWe design. The current solicitation is focused on innovations that enable the scaling of the 1 kWe design to 10 kWe, with a specific focus on surface power applications. Areas of interest include:

- Isolation of core, heat pipes, and convertor hot end from Martian environment with minimal impact to neutronics.
- Thermal interface methods including bonding of heat pipes to the core and direct coupling of heat pipes to power conversion (both hot and cold side).
- Reduction in shield mass through:
    - Increased radiation tolerance of electronics including power electronics, control electronics, and instrumentation.
    - Increased distance from core with mass effective PMAD and transmission or lightweight possibly retractable booms.
- Robust and reliable power conversion and controller technology. Power conversion can consist of multiple lower power units which could be combined to create 10 kW of electric power. Power conversion must be reliable and robust while maintaining at least 25% efficiency from heat in to usable electric output from PMAD.
- Compact/stowable heat rejection. Options could include flexible / deployable heat pipe radiators or alternatives that make use of the Martian atmosphere for cooling.

T3.02 Intelligent/Autonomous Electrical Power Systems (STTR)
Lead Center: GRC
Participating Center(s): JPL

Missions to Mars and beyond experience communication delays with Earth of between 3 to 45 minutes. Due to this, it is impractical to rely on ground-based support and troubleshooting in the event of a power system fault or component failure. Intelligent/autonomous systems are required that can manage the power system in both normal mode and failure mode.

In normal mode, the system would predict energy availability, perform load scheduling, maintain system security and status on-board and ground based personnel. One aspect of overall system autonomy would be solar array characterization, for spacecraft utilizing this technology. One drawback of current satellite systems is the lack of adequate means of determining solar panel or cell status. Being able to automatically characterize solar panel status can enhance energy availability prediction. Similar technology to access that status of battery systems would further enhance these predictions.

In failure mode, the system must identify a fault or failure and perform contingency planning to react or reconfigure the system appropriately to move it back into normal mode of operation, without human involvement. The technologies to detect and identify specific failures in both the generation, distribution and storage systems are needed along with strategies to utilize the failure data to identify recovery strategies for the power system.

With the potential of future manned missions to Mars, this technology will become increasingly important for electrical power management and distribution. Specific areas of interest include:

- Autonomous/intelligent PMAD.
- Failure detection strategies.
- Recovery strategies.
- Generation and storage characterization.

T3.03 Bio-inspired Concepts for the Development of Power, Energy and Storage Technologies for Air and Space (STTR)
Lead Center: GRC
Participating Center(s): ARC, LaRC

Biomimicry is the imitation of life and life's principles characterized by reduced use of energy, water and raw materials. Energy and material use is substituted by information and structure. The goal of this topic is to focus efforts on system driven technology development that draws from nature to solve technical challenges in aeronautics and space exploration. This subtopic is also looking for proposals that include data collection that would add to the Periodic Table of Life database. For example, if looking at building a solar concentrator based on plants, it would be valuable to collect and share information on a wide variety of applicable plants and related biological models. The data may be from literature, museums, or through measurements conducted as part of the STTR.

Proposals must demonstrate that the proposed technology complies with natural principles, patterns and mechanisms. Refer to the following sources to understand biomimetic principles.

Some resources are provided here:

- V.I.N.E. (Virtual Interchange for Nature-inspired Exploration) - https://www.grc.nasa.gov/vine.
- PeTaL - https://www.grc.nasa.gov/vine/about/what-is-petal/.
- Taxonomy tool - https://asknature.org/.
- Systems tool - http://toolbox.biomimicry.org/.

Technology is sought in the following areas:

Bio-inspired resource utilization, power generation, energy storage, power management and distribution
The NRC has identified a NASA Top Technical Challenge as the need to "Increase Available Power". Additionally, a NASA Grand Challenge is "Affordable and Abundant Power" for NASA mission activities. It is essential to be able to harness, store and distribute energy while maintaining minimal system mass and complexity. Biological models such as the oriental hornet or electric eel may be obvious candidates. Methods to improve solar cell efficiency or to create structural solar cells are of interest.

Power generation and management systems are also of interest to the growing Hybrid Gas Electric Propulsion Project under ARMD. There is specific interest in motor thermal management and low loss power distribution and storage. New concepts for electric motors and hybrid systems are desirable.

Topics include, but are not limited to:

- Solar electric propulsion concepts (packing strategies based on nature, cell orientation/stabilization)
- Thermal management for solar electric propulsion.
- In Situ Resource Utilization using nature-inspired principles (passive, feedback controls, using local resources and energy sources, water-based chemistry and processes).
- Life support systems and personal protective equipment including anti-microbial films, first aid, radiation protection. Examples of natural models include tardigrades, structural color in butterflies/peacocks, shark skin.
- Swarm topologies, communication strategies and system dynamics applied to CubeSats or rovers.

Cross cutting technology making use of bio-inspired processes
Specific areas of interest include:

- Tools to aid in discovery of bio-inspired materials or technology.
- Demonstrations of advantages in mass savings made possible through bioinspired topologies enabled by additive manufacturing methods.
- Controlled synthesis of lightweight engineering materials due to bioinspired synthesis methods.

Focus Area 3: Autonomous Systems for Space Exploration

Lead MD: HEOMD
Participating MD(s): SMD, STTR

The exploration of space requires the best of the nation's technical community to provide the technologies that will enable human and robotic exploration beyond Low Earth Orbit (LEO): to visit asteroids, to extend man’s reach to Mars, and for increasingly ambitious robotic missions such as a Europa Lander. Autonomous Systems technologies provide the means of migrating mission control from Earth to spacecraft, habitats, and robotic explorers. This is enhancing for missions in the Earth-Lunar neighborhood and enabling for deep space missions. Long light-time delays, for example up to 42 minutes round-trip between Earth and Mars, require time-critical control decisions to be closed on-board autonomously through automation, augmented for human missions by astronaut-automation teaming, rather than through round-trip communication to Earth mission control.

Long-term crewed spacecraft and habitats, such as the International Space Station, are so complex that a significant portion of the crew's time is spent keeping it operational even under nominal conditions in low-Earth orbit, while still requiring significant real-time support from Earth. The considerable challenge is to migrate the knowledge and capability embedded in current Earth mission control, with tens to hundreds of human specialists ready to provide instant knowledge, to on-board automation that teams with astronauts to autonomously manage spacecraft and habitats. For outer planet robotic explorers, the opportunity is to autonomously and rapidly respond to dynamic environments in a timely fashion. The autonomous agent subtopic addresses this challenge by soliciting proposals that leverage the growing field of cognitive computing to advance technology for deep-space autonomy.

The technology challenge for autonomous crewed systems in off-nominal conditions is even more critical. In the majority of Apollo lunar missions, Earth mission control was needed to resolve critical off-nominal situations ranging from unexplained computer alarms on Apollo 11 to the oxygen tank explosion on Apollo 13 that required executing an 87-hour free return abort trajectory around the moon and back to Earth. Through creative use of Lunar Module assets, Apollo 13 had sufficient resiliency to keep the three astronauts alive despite loss of the oxygen tank and many of the capabilities of the service module. In contrast to a lunar mission, a free return abort trajectory around Mars and back to Earth is on the order of two years – requiring a leap in resiliency. To prevent Loss of Mission (LOM) or Loss of Crew (LOC) in deep space missions, spacecraft and habitats will require long-term resiliency to handle failures that lead to loss of critical function or unexpected expenditure of consumables. Long communication delays or accidents that cause loss of communication will require that the initial failure response be handled autonomously. The subtopic on resilient autonomous systems solicits technology for the design and quantification of resiliency in long-duration missions. The subtopic on sustainable habitats solicits technology for long-term system health management that goes beyond short-term diagnosis technology to include advances machine learning and other prognostic technologies. Enhancing the capability of astronauts is also critical for future long-duration deep space missions. Augmented reality technology can guide astronauts in carrying out procedures through various sensory modalities. The augmented reality subtopic within the STMD Robotics area is very relevant to autonomous systems technologies, and proposers are encouraged to review that subtopic description.

Machine learning could become an increasingly important aspect of space exploration, from finding novel patterns in the science data transmitted from robotic spacecraft, to the operation of sustainable habitats. The sustainable habitat subtopic calls for machine learning technology in order to substantially improve diagnostic and prognostic performance for integrated systems health management. In addition, STTR subtopics related to machine learning are very relevant to autonomous systems technologies.

H6.02 Resilient Autonomous Systems (SBIR)
Lead Center: ARC
Participating Center(s): JPL, JSC, MSFC
Related Subtopic Pointer(s): A2.02, A3.02, H6.01, T4.01

Future human spaceflight missions will place crews at large distances and light-time delays from Earth, requiring novel capabilities for crews with limited ground support to manage spacecraft, habitats, and supporting equipment to prevent Loss of Mission (LOM) or Loss of Crew (LOC) over extended duration missions. In particular, these capabilities are needed to handle faults leading to loss of critical function or unexpected expenditure of consumables. Expanded flight control functionality will be on-board spacecraft with significant automation, autonomy, and decision support software. The increasingly complex interconnectivity of these elements introduces new vulnerabilities within space systems that are sometimes impossible to predict. In that context, one key property of the respective system is its resilience to unforeseen events.

Resilience, as defined by the U.S. National Academy of Sciences [1] (NAS), is the ability to plan and prepare for, absorb, recover from, and more successfully adapt to adverse events. This definition encompasses principles such as robustness, redundancy, modularity, and adaptability

To enable resilient behavior of a system (such as a vehicle, a habitat, a rover, etc.), "resilience" needs to be built-in during the design phase of the system development. To that end, the operational states of a system's component need to be considered in conjunction with the intended function of the component and its possible failure modes throughout the vehicle's life cycle. Where possible, critical failures are eliminated during the design stage. For failure modes that cannot be eliminated, a mechanism needs to be devised that considers how to have optimal state awareness during operations and to mitigate the fault. Mitigation can be accomplished through fault avoidance, fault masking, or Fault Detection, Identification, and Recovery (FDIR). For the latter, system reconfiguration leveraging functional redundancies is of particular interest. Since a vehicle is made up of many components, a system-of-system's approach needs to be considered in a multi-objective optimization context to account for interdependencies and to realize possible mutually beneficial mitigation solutions for resiliency.

Proposals to this subtopic should specify innovation and approaches toward two goals:

- Development of methods and tools that allow the assessment and optimization of system resilience during its conceptual design stage, while simultaneously maximizing reliability and safety.
- Development of measures and metrics that quantify the degree of resilience of a system with respect to a mission ConOps and hazard analysis.

Resilience measures and metrics must be general enough to support broad applications, yet precise enough to measure system-specific qualities. Such metrics are necessary to make resource and operations decisions. Risk metrics tend to assess risks to individual components, ignoring system functionality as the result of interacting components. Resilience measures and metrics also ideally need to account for uncertainty in the planned operation of the system, and focus on integrating statistical methods for uncertainty propagation into resilience-based design. Rather than the static view of systems and networks in risk assessment, resilience adopts a dynamic view. This means resilience metrics must also consider the ability of a system to plan, prepare, and adapt as adverse events occur, rather than focus entirely on threat prevention and mitigation. Finally, resilience depends upon specific qualities that risk assessment cannot quantify, such as system flexibility and interconnectedness.

Proposed solutions are expected to have characteristics including, but not limited to:

- Life-cycle models that encapsulate cost/benefit of envisioned design solution and that can be used to inform about the resilience of the system.
    - Models may need to be built at the appropriate fidelity level to capture relevant fault behavior.
    - Models may need to assess behavior and consequences during degraded (or faulted) state.
    - Models should also be able to assess mitigation actions that are part of an integrated health management approach.
- Design optimization methodology that can systematically incorporate health management solutions.
    - Methods that integrate optimal decision-making into the design concept.
    - Methods that make use of both system health models and observations to provide the best decision given the information available.
    - Methodology to allows bi-directional exchange between a model and the analysis tool.
    - Methods that systemically include desired levels of resilience in the design optimization process.

Desired, but not necessary:

- Uncertainty management:
    - Identify the various sources of uncertainty that affect system performance, and quantify their combined effect on both system failure and resilience.
    - Systematically incorporate uncertainty in the design process, thereby incorporating both resilience and likelihood of failure directly during the design stage.

This SBIR work aims to generate a practical toolkit for space systems that can deliver solutions with assured levels of performance, reliability and resilience. Emphasis is on the design for resilience methodology, not on delivering entire systems.

Metrics for success include:

- Development of generic quantitative measures and metrics that evaluate system resilience, and their application to space relevant systems or subsystems.
- Demonstrated improvement of resilience over baseline design for at least two different space relevant systems or subsystems (In-space applications are preferred, but terrestrial analogues will be considered).
- Consideration of at least 3 different fault modes.
- Software tools must be able to accept other systems or subsystems through appropriate interface.

SBIR work is expected to deliver mainly software in the form of tools used during the design stage and also prototype software that would manage resiliency during autonomous operations. For the latter, the SBIR effort should analyze sensors, computational hardware, and software stack.

Proposals must demonstrate mission operations risk reduction through appropriate metrics.

Deliverables: tools developed, algorithms and any data generated in simulations or experiments.

Below are a few links to documents on resilience that may be useful to understand the context:

- Resilience Engineering and Quantification for Sustainable Systems Development and Assessment: Socio-technical Systems and Critical Infrastructure - https://www.irgc.org/wp-content/uploads/2016/04/Haering-et-al.-Resilience-Engineering-and-Quantification.pdf.
- The New Resilience Paradigm - Essential Strategies for a Changing Risk Landscape - https://www.irgc.org/wp-content/uploads/2016/04/Fiksel-The-New-Resilience-Paradigm.pdf.

References:

Kash Barker, Jose Emmanuel Ramirez-Marquez, Claudio M. Rocco, “Resilience-based network component importance measures”, Reliability Engineering and System Safety 117 (2013) pp.89–97.

Daniel A. Eisenberg, Igor Linkov, Jeryang Park, Matthew E. Bates, Cate Fox-Lent, Thomas P. Seager**, Resilience Metrics: Lessons from Military Doctrines.** http://www.thesolutionsjournal.org/node/237200.

[1] Committee on Increasing National Resilience to Hazards and Disasters; Committee on Science, Engineering, and Public Policy (COSEPUP); Policy and Global Affairs (PGA); The National Academies. Disaster Resilience: A National Imperative. The National Academies Press. http://www.nap.edu/catalog.php?record_id=13457 (2012).

H6.03 Spacecraft Autonomous Agent Cognitive Architectures for Human Exploration (SBIR)
Lead Center: ARC
Participating Center(s): JSC, MSFC
Related Subtopic Pointer(s): H6.01

This subtopic develops intelligent autonomous agent cognitive architectures that are open and modular such that they can feasibly be certified for use on deep space missions to interact both with the mission control operators, the crew, and most if not all of the spacecraft subsystems. With such a cognitive agent that has access to all onboard data and communications, the agent could continually integrate this dynamic information and advise the crew and mission control accordingly by multiple modes of interaction including text, speech, and animated images. This agent could respond to queries and recommend to the crew courses of action and direct activities that take into account all known constraints, the state of the systems, availability resources, risk analyses, and goal priorities.

Future human spaceflight missions will place crews at long distances from Earth causing significant communication lag due to the light distance as well as occasional complete loss of communication with Earth. Novel artificial intelligence capabilities augmenting crews will be required for them to autonomously manage spacecraft operations and interact with Earth mission control under these conditions, including spacecraft and systems health, crew health, maintenance, consumable management, payload management, training, as well as activities such as food production and recycling.

Autonomous agents with cognitive architectures would be able to interface directly with the crew as well as with the onboard systems and mission control, thus reducing the cognitive loads on the crew as well as performing many tasks that would otherwise require scheduling crew time. In addition, this cognitive computing capability is necessary in many circumstances to respond to off-nominal events that overload the crew; particularly when the event limits crew activity, such as high-radiation or loss of atmospheric pressure events.

In deep space, crews will be required to manage, plan, and execute the mission more autonomously than is currently done on the International Space Station (ISS); which from Low Earth Orbit has instantaneous ground support. NASA expects to migrate significant portions of current operations functionality from Earth flight control to deep-space spacecraft to be performed autonomously. These functionalities will be performed jointly by the crew and cognitive agents supervised by the crew; so, the crew is not overburdened. Cognitive agents that can effectively communicate with the crew could perform tasks that would otherwise require crew time by providing assistance, directly operating spacecraft systems, providing training, performing inspections, and providing crew consulting among other tasks.

Due to the complexity of such cognitive agents and the need for them to be continually updated, their software architecture is required to be modular. A requirement for these cognitive software architectures is that modules can dynamically be added, removed, and enhanced. Types of modules would likely include a smart executive, state estimator, planner/scheduler, diagnostics and prognostics, goal manager, etc. Other modules that may be supported include a dialog manager, risk manager, image recognition, instructional drawing, crew task manager, etc. This type of modular cognitive architecture is consistent with that proposed by Prof. Marvin Minsky in "The Society of Mind", 1988, and subsequent proposals and realizations of cognitive agents. Recent venues for cognitive architectures include: ICCM (http://iccm-conference.org/2017/) and AAAI-17 Special Track on Special Track on Cognitive Systems http://www.aaai.org/Conferences/AAAI/2017/aaai17cognitive.php.

Due to NASA's need for fail-safe capabilities, such as continued functionality during high-radiation events, the cognitive architecture will be required to be capable of supporting multiple processes executing on multiple processors, in order to meet the expected computational loads as well as be robust to processor failure. Cognitive architectures capable of being certified for crew support on spacecraft are also required to be open to NASA with interfaces open to NASA partners who develop modules that integrate with other modules on the cognitive agent in contrast to proprietary black-box agents. Note that a cognitive agent suitable to provide crew support on spacecraft may also be suitable for a variety of Earth applications, but the converse is not true; thus, requiring this NASA investment.

The emphasis of proposed efforts is expected to be on analyzing and demonstrating the feasibility of various configurations, capabilities, and limitations of a cognitive architecture suitable for crew support on deep space missions. The software engineering of a cognitive architecture is to be documented and demonstrated by implementing a prototype goal-directed cognitive agent that interacts with simulated spacecraft systems and humans.

For Phase I, a preliminary cognitive architecture, preliminary feasibility study, a cognitive agent prototype that supports a human operating a simulated complex system that illustrates a candidate cognitive agent architecture, and a detailed plan to develop a comprehensive cognitive architecture feasibility study are expected. For Phase II, it is expected that the proposed detailed feasibility study plan is executed.

In Phase II it is expected that a comprehensive cognitive architecture will be generated, along with a demonstration of an agent prototype that instantiates the architecture. The agent prototype should interact with a spacecraft simulator and humans executing a plausible HEOMD design reference mission beyond cis-lunar (e.g., Human Exploration of Mars Design Reference Mission: https://www.nasa.gov/pdf/373665main_NASA-SP-2009-566.pdf). Phase II deliverables are also expected to include a comprehensive feasibility study report, and a detailed plan to develop a fully instantiated robust cognitive architecture suitable for proposing to NASA and other organizations interested in funding a flight capability. A Phase II prototype suitable for a compelling flight experiment or simulation interfacing with the ISS or a spacecraft-relevant robotic system is encouraged.

S5.05 Fault Management Technologies (SBIR)
Lead Center: ARC
Participating Center(s): JPL, MSFC

As science missions are given increasingly complex goals and have more pressure to reduce operations costs, system autonomy increases. Fault Management (FM) is one of the key components of system autonomy. FM consists of the operational mitigations of spacecraft failures. It is implemented with spacecraft hardware, on-board autonomous software that controls hardware, software, information redundancy, and ground-based software and operations procedures.

Many recent Science Mission Directorate (SMD) missions have encountered major cost overruns and schedule slips during test and verification of FM functions. These overruns are due to a lack of understanding of FM functions early in the mission definition cycles and to FM architectures that do not provide attributes of transparency, verifiability, fault isolation capability, or fault coverage. The NASA FM Handbook is under development to improve the FM design, development, verification and validation and operations processes. FM approaches, architectures, and tools are needed to improve early understanding of needed FM capabilities by project managers and FM engineers and to improve the efficiency of implementing and testing FM.

Specific objectives are to:

- Improve the ability to predict FM system complexity and estimate development and operations costs.
- Enable cost-effective FM design architectures and operations.
- Determine completeness and appropriateness of FM designs and implementations.
- Decrease the labor and time required to develop and test FM models and algorithms.
- Improve visualization of the full FM design across hardware, software, and operations procedures.
- Determine extent of testing required, completeness of verification planned, and residual risk resulting from incomplete coverage.
- Increase data integrity between multi-discipline tools.
- Standardize metrics and calculations across FM, SE, S&MA and operations disciplines.
- Increase reliability of FM systems.

Expected outcomes are better estimation and control of FM complexity and development costs, improved FM designs, and accelerated advancement of FM tools and techniques.

The approach of this subtopic is to seek the right balance between sufficient reliability and cost appropriate to the mission type and risk posture. Successful technology development efforts under this subtopic would be considered for follow-on funding by, and infusion into, SMD missions. Research should be conducted to demonstrate technical feasibility and NASA relevance during Phase I and show a path toward a Phase II prototype demonstration.

Offerors should demonstrate awareness of the state-of-the-art of their proposed technology, and should leverage existing commercial capabilities and research efforts where appropriate.

Specific technology in the forms listed below is needed to increase delivery of high quality FM systems. These approaches, architectures and tools must be consistent with and enable the NASA FM Handbook concepts and processes:

- *FM Design Tools* - System modeling and analyses significantly contributes to the quality of FM design; however, the time it takes to translate system design information into system models often decreases the value of the modeling and analysis results. Examples of enabling techniques and tools are modeling automation, spacecraft modeling libraries, expedited algorithm development, sensor placement analyses, and system model tool integration.
- *FM Visualization Tools* - FM systems incorporate hardware, software, and operations mechanisms. The ability to visualize the full FM system and the contribution of each mechanism to protecting mission functions and assets is critical to assessing the completeness and appropriateness of the FM design to the mission attributes (mission type, risk posture, operations concept, etc.). Fault trees and state transition diagrams are examples of visualization tools that could contribute to visualization of the full FM design.
- *FM Operations Approaches* - The goal of current FM processes is to preserve the asset, by safing the vehicle and relying on mission operations to determine how to proceed. But as greater autonomy is required - flying through failures in order to complete science objectives that require timely operations, for example – the spacecraft must be able to make decisions about how to recover from failures or degradations and continue the mission. FM designs must enable flexible operations that can integrate on-board and mission operations decision-making.
- *FM Verification and Validation Tools* - As complexity of spacecraft and systems increases, the extensiveness of testing required to verify and validate FM implementations can be resource intensive. Automated test case development, false positive/false negative test tools, model verification and validation tools, and test coverage risk assessments are examples of contributing technologies.
- *FM Design Architectures* - FM capabilities may be implemented through numerous system, hardware, and software architecture solutions. The FM architecture trade space includes options such as embedded in the flight control software or independent onboard software; on board versus ground-based capabilities; centralized or distributed FM functions; sensor suite implications; integration of multiple FM techniques; innovative software FM architectures implemented on flight processors or on Field Programmable Gate Arrays (FPGAs); and execution in real-time or off-line analysis post-operations. Alternative architecture choices such as model-based approaches could help control FM system complexity and cost and could offer solutions to transparency, verifiability, and completeness challenges.
- *Multi-discipline FM Interoperation* - FM designers, Systems Engineering, Safety and Mission Assurance, and Operations perform analyses and assessments of reliabilities, failure modes and effects, sensor coverage, failure probabilities, anomaly detection and response, contingency operations, etc. The relationships between multi-discipline data and analyses are inconsistent and misinterpreted. Resources are expended either in effort to resolve disconnects in data and analyses or worse, reduced mission success due to failure modes that were overlooked. Solutions that address data integrity, identification of metrics, and standardization of data products, techniques and analyses will reduce cost and failures.

All submissions must show how proposed technologies are relevant to SMD missions and objectives. For further information on SMD Science Strategy go to: https://science.nasa.gov/about-us/science-strategy.

T4.03 Coordination and Control of Swarms of Space Vehicles (STTR)
Lead Center: JPL
Related Subtopic Pointer(s): Z8.02

This subtopic is focused on developing and demonstrating technologies for coordination and autonomous control of teams and swarms of space systems including but not limited to spacecraft and planetary rover teams in a dynamic environment.

Possible areas of interest include but are not limited to:

- Coordinated task planning, operation, and execution.
- Relative localization in space and on planet surface.
- Close proximity operations of spacecraft swarms including sensors required for collision detection and avoidance.
- Fast, real-time, coordinated motion planning in areas densely crowded by other agents.
- Human-Swarm interaction interfaces for controlling the multi-agent system as an ensemble.
- Distributed fault detection and mitigation due to hardware failures or compromised systems.
- Communication-less coordination by observing and estimating the actions of other agents in the multi-agent system.

Phase I awards will be expected to develop theoretical frameworks, algorithms, software simulation and demonstrate feasibility (TRL 2-3). Phase II awards will be expected to demonstrate capability on a hardware testbed (TRL 4-6).

T13.01 Intelligent Sensor Systems (STTR)
Lead Center: SSC
Participating Center(s): KSC, MSFC
Related Subtopic Pointer(s): A1.03, A2.01, A1.08, S1.09, Z11.01

This subtopic area seeks to develop advanced instrumentation technologies which can be embedded in systems and subsystems. Embedded sensor systems have the potential for substantial reduction in time and cost of propulsion systems development, with substantially reduced operational costs and evolutionary improvements in ground, launch and flight system operational robustness. The technologies developed would be capable of addressing multiple mission requirements for remote monitoring such as vehicle health monitoring. The goal is to provide a highly flexible instrumentation solution capable of monitoring remote or inaccessible measurement locations. All this while reducing substantially or eliminating cabling. Highly desirable to be integrated into process control for highly autonomous system operation including the ability to detect present conditions and apply appropriate control system reactions.

Rocket propulsion development is enabled by rigorous ground testing in order to mitigate the propulsion system risks that are inherent in spaceflight. Test articles and facilities are highly instrumented to enable a comprehensive analysis of propulsion system performance. This subtopic seeks to develop advanced instrumentation technologies which can be embedded in systems and subsystems. The goal is to provide a highly flexible instrumentation solution capable of monitoring remote, hazardous or inaccessible measurement locations. All this while reducing or completely eliminating cabling and auxiliary power. It is focused on near-term products that augment and enhance proven, state-of-the-art propulsion test facilities and new ones to be developed. Rocket propulsion test facilities within NASA provide excellent test beds for testing and using the innovative technologies discussed above. The technologies developed would be capable of addressing multiple mission requirements for remote monitoring such as vehicle health monitoring.

Intelligent sensor systems have the potential for substantial reduction in time and cost of propulsion systems development, with substantially reduced operational costs and evolutionary improvements in ground, launch and flight system operational robustness. Sensor systems should provide an advanced diagnostics capability to monitor test facility parameters including simultaneous heat flux, temperature, pressure, strain and near-field acoustics. Applications encompass remote monitoring of vacuum lines, gas leaks and fire; where the use of wireless/self-powered sensors to eliminate power and data wires would be beneficial.

Sensor technologies should be capable of being embedded in structures and systems that are smaller, more energy efficient, and allow for more complete and accurate health assessments including structural health monitoring for long-duration missions. Structural health monitoring is one of the top technical challenges. Nanotechnology enhanced sensors are desired where applicable to provide a reduction in scale, increase in performance, and reduction of power requirements. Specific technology needs include the following:

- Sensor systems should have the ability to provide the following functionality:
    - Measurement.
    - Measure of the quality of the measurement.
    - Measure of the health of the sensor.
- Sensors are needed with capability to function reliably in extreme environments, including rapidly changing ranges of environmental conditions, such as those experienced in ground test, launch environment and space. These ranges may be from extremely cold temperatures, such as cryogenic temperatures, to extremely high temperatures, such as those experienced near a rocket engine plume. Collected data must be time stamped to facilitate analysis with other collected data sets.
- Sensor systems should be self-contained to collect information and relay measurements through various means by a sensor-web approach to provide a self-healing, auto-configuring method of collecting data from multiple sensors, and relaying for integration with other acquired data sets.
- Sensor technologies shall be capable of measuring pressure and temperature with cryogenic and gaseous fluid flow within metal piping.
- Sensor systems should enable the ability to detect anomalies, determine causes and effects, predict future anomalies, and provides an integrated awareness of the health of the system to users (operators, customers, management, etc.).
- The proposed innovative systems must lead to improved safety, reduced test, and space flight costs by allowing for the real-time analysis of data, information, and knowledge through efficient interfaces to enable integrated awareness of the system condition by users.
- The system provided must interface with existing data acquisition systems and the software used by such systems.
- The system must provide NIST traceable measurements.
- The system design should consider an ultimate use of space flight sensor systems, which could be used for multi-vehicle use.

Focus Area 4: Robotic Systems for Space Exploration

Lead MD: STMD
Participating MD(s): SMD, STTR

This focus area includes development of robotic systems technologies (hardware and software) to improve the exploration of space. Robots can perform tasks to assist and off-load work from astronauts. Robots may perform this work before, in support of, or after humans. Ground controllers and astronauts will remotely operate robots using a range of control modes, over multiple spatial ranges (shared-space, line of sight, in orbit, and interplanetary) and with a range of time-delay and communications bandwidth. Technology is needed for robotic systems to improve transport of crew, instruments, and payloads on planetary surfaces, on and around small bodies, and in-space. This includes hazard detection, sensing/perception, active suspension, grappling/anchoring, legged locomotion, robot navigation, end-effectors, propulsion, and user interfaces.

In the coming decades, robotic systems will continue to change the way space is explored. Robots will be used in all mission phases: as independent explorers operating in environments too distant or hostile for humans, as precursor systems operating before crewed missions, as crew helpers working alongside and supporting humans, and as caretakers of assets left behind. As humans continue to work and live in space, they will increasingly rely on intelligent and versatile robots to perform mundane activities, freeing human and ground control teams to tend to more challenging tasks that call for human cognition and judgment.

Innovative robot technologies provide a critical capability for space exploration. Multiple forms of mobility, manipulation and human-robot interaction offer great promise in exploring planetary bodies for science investigations and to support human missions. Enhancements and potentially new forms of robotic systems can be realized through advances in component technologies, such as actuation and structures (e.g., 3D printing). Mobility provides a critical capability for space exploration. Multiple forms of mobility offer great promise in exploring planetary bodies for science investigations and to support human missions. Manipulation provides a critical capability for positioning crew members and instruments in space and on planetary bodies, it allows for the handling of tools, interfaces, and materials not specifically designed for robots, and it provides a capability for drilling, extracting, handling and processing samples of multiple forms and scales. This increases the range of beneficial tasks robots can perform and allows for improved efficiency of operations across mission scenarios. Manipulation is important for human missions, human precursor missions, and unmanned science missions. Sampling, sample handling, transport, and distribution to instruments, or instrument placement directly on in-place rock or regolith, is important for robotic missions to locales too distant or dangerous for human exploration.

Future space missions may rely on co-located and distributed teams of humans and robots that have complementary capabilities. Tasks that are considered "dull, dirty, or dangerous" can be transferred to robots, thus relieving human crew members to perform more complex tasks or those requiring real-time modifications due to contingencies. Additionally, due to the limited number of astronauts anticipated to crew planetary exploration missions, as well as their constrained schedules, ground control will need to remotely supervise and assist robots using time-delayed and limited bandwidth communications. Advanced methods of human-robot interaction over time delay will enable more productive robotic exploration of the more distant reaches of the solar system. This includes improved visualization of alternative future states of the robot and the terrain, as well as intuitive means of communicating the intent of the human to the robotic system.

S4.02 Robotic Mobility, Manipulation and Sampling (SBIR)
Lead Center: JPL
Participating Center(s): AFRC, ARC, GSFC, JSC
Related Subtopic Pointer(s): S1.11, S4.04, S4.05, S4.06

Technologies for robotic mobility, manipulation, and sampling are needed to enable access to sites of interest and acquisition and handling of samples for in-situ analysis or return to Earth from planets and small bodies including Mars, Venus, comets, asteroids, and planetary moons. Application to Ocean Worlds is of increasing importance.

Mobility technologies are needed to enable access to steep and rough terrain for planetary bodies where gravity dominates, such as the Moon and Mars. Wheeled, legged, and aerial solutions are of interest. Wheel concepts with good tractive performance in loose sand while being robust to harsh rocky terrain are of interest. Technologies to enable mobility on small bodies and access to liquid bodies below the surface such as in conduits and deep oceans are desired, as well as associated sampling technologies. Manipulation technologies are needed to deploy sampling tools to the surface and transfer samples to in-situ instruments and sample storage containers, as well as hermetic sealing of sample chambers. Sample acquisition tools are needed to acquire samples on planetary and small bodies through soft and hard materials, including ice. Minimization of mass and ability to work reliably in the harsh mission environment are important characteristics for the tools. Design for planetary protection and contamination control is important for sample acquisition and handling systems.

Component technologies for low-mass and low-power systems tolerant to the in-situ environment are of particular interest. Technical feasibility should be demonstrated during Phase I and a full capability unit of at least TRL 4 should be delivered in Phase II. Proposals should show an understanding of relevant science needs and engineering constraints and present a feasible plan to fully develop a technology and infuse it into a NASA program. Specific areas of interest include the following:

- Surface and subsurface mobility and sampling systems for planets, small bodies, and moons.
- Small body anchoring systems.
- Low mass/power vision systems and processing capabilities that enable fast surface traverse.
- Electro-mechanical connectors enabling tool change-out in dirty environments.
- Tethers and tether play-out and retrieval systems.
- Miniaturized flight motor controllers.
- Sample handling technologies that minimize cross contamination and preserve mechanical integrity of samples.

Z5.01 Augmented Hybrid and Virtual Reality (XR) Technology for Human & Robotics Exploration (SBIR)
Lead Center: JSC
Participating Center(s): AFRC, JPL, KSC

Within the ISS Program, maintenance requires well trained crew members and is labor intensive, expensive and inefficient. NASA uses paper and electronic procedures to direct crew through complex maintenance procedures for all on-board systems. Developing and executing procedures are still time consuming and tedious tasks, and substantial training is needed to understand the technical details for troubleshooting defective components, and the performance of critical maintenance and repairs. *X-R* based technology systems could have the potential to support future human exploration missions by providing the type of guidance normally associated with an expert human trainer. The capabilities of envisioned future *X-R* based systems will augment the ability of the crew while being simple and highly intuitive to use.

On board maintenance is one of the potential areas in which *X-R* technology can be a game changing technology. Other areas such as physical and mental health support for long duration mission isolation from family and friends, mission planning, mission data visualization, are also to be considered in the context of this topic.

The objective of this subtopic is to develop and mature *X-R* technology (system/ software) and to impact all aspects of mission operations including planning, execution, training and crew health countermeasures, in order to enable human exploration beyond LEO.

Proposal are sought to address the following Technology Areas:

- TA-4 TABS 4.4 Human Systems Interface: augmenting the natural environment with precise visual cues as well as with audible and tactile alerts to fully engage and guide the human operator through lengthy and complex spaceflight procedures.
- TA-4 TABS 4.5 Autonomy: using *XR* technology to enable crew autonomous operation and reduce dependency for ground support.
- TA-6 TABS 6.3 Human Health and Performance: using *X-R* technology to enhance situational awareness and to reduce cognitive overload while performing complex task.
- TA-7 TABS 7.5 Mission Operations & Safety: using *X-R* technology to reduce human error, improve operational efficiency and mission timeline while reducing prior training requirements.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II system/software demonstration and delivering a demonstration system/software package for NASA testing.

Z5.02 Robotic Systems - Mobile Manipulation (SBIR)
Lead Center: JSC
Participating Center(s): ARC, GRC, KSC
Related Subtopic Pointer(s): S4.04, S4.05

NASA seeks innovative robotics solutions for upcoming missions to lunar orbit and the lunar surface. This targeted call seeks unique combinations of mobile manipulation, defined as work systems able to position themselves and then perform work with limbs. This combination of mobility and manipulation is a technical challenge, with static manipulation systems or mobile systems poorly suited to perform work being more common. The intent for this subtopic is to stimulate new solutions to the challenges of mobile manipulation, capturing recent advances in robotics technology in numerous terrestrial sectors that are relevant to space exploration. Broader topics of interest include perception, mobility for extreme terrain, autonomous control, human-robot interaction and dexterous manipulation. Lunar surface challenges involve mobile manipulation in soft soils, extreme thermal conditions, and sustained periods of no or low communication with Earth. Challenges in lunar orbit involve mobile manipulation in zero gravity, positioning work systems for preventive maintenance, logistics handling and contingency operations of a dormant spacecraft with reduced communication. Human interaction with these robotic systems will be limited due to communication blackout periods and time delay, and must be optimized for both mobility phases and manipulation phases of work. These lunar missions require low mass, low power and low volume solutions. All command and control approaches for human interaction should assume limited communication capabilities, requiring supervision of autonomous systems. Surface systems must be robust despite challenges of dust and thermal cycles. Orbital systems must be safe around human crew members and able to work with spacecraft interfaces intended for humans. Technologies proven in near term lunar missions must be scalable for future Mars exploration.

Z5.03 Payload Technologies for Free-Flying Robots (SBIR)
Lead Center: ARC
Participating Center(s): JPL, JSC

The objective of this subtopic is to develop technology that can be integrated as payloads (software and/or hardware) on free-flying robots, which operate in human environments and/or assist humans. Current free-flyers include space robots, micro UAVs, quadcopters, etc. Applications of free-flying robots to space exploration include:

- Supporting the caretaking of human spacecraft and habitats by autonomously performing critical maintenance and monitoring functions.
- Supporting astronaut activity (intravehicular or extravehicular) with survey, preparation, real-time support (e.g., tool/sample delivery), and follow-up work.

On the International Space Station (ISS), for example, the SPHERES robots have shown how free-flying robots can perform environment surveys, inspection, and crew support. In addition, STMD is currently developing the "Astrobee" free-flying robot to perform mobile camera, mobile sensor, and microgravity robotics testing on the ISS starting in mid-2018. Proposals are sought to create payloads that can be integrated with small-scale free-flying robots, including the following areas (in order of interest):

- *Human-Robot Interfaces* - Payloads that facilitate communication and coordination between humans (local and remote) and AFFs. This includes displays (3D screens, projectors, etc.), signaling devices (light indicators, sound generation, etc.), and human monitoring (activity recognition, gaze/motion tracking, etc.).
- *Operational Subsystems* - Payloads that can be used to enhance the performance or the capability of AFFs for future deep-space exploration missions. This includes subsystems for extended AFF operations (power systems, efficient propulsion, etc.), supporting crew (e.g., mobile health monitoring), routine maintenance, emergency response, and other use cases.
- *Sensors* - Compact sensors relevant to the scenarios listed above, including functions such as interior environment monitoring, interior/exterior structural inspection, free-flying navigation, 3D environment modeling, etc.
- *End Effectors* - Small, lightweight mechanisms that can be used for docking/perching, prodding/pushing, tool carrying, etc. This may include deployable structures, universal end-effectors (e.g., jamming granular gripper), devices incorporating gecko or electrostatic adhesion, and devices that can interact with handles, storage lockers, and small IVA tools. Note: complete robot manipulator arms are NOT being solicited.

Proposers are encouraged to target the development of these payload technologies to the Astrobee free-flying robot. For Astrobee, payloads should ideally be less than 1 kg in mass, consume less than 5 W electrical power (5 VDC @ 1 A), interface via USB 2.0, and stow within a 10x10x10 cm volume. Payloads that exceed these specifications may still target Astrobee, but may require special accommodations. Proposals must describe how the technology will make a significant improvement over the current state of the art, rather than just an incremental enhancement, for a specific free-flying robotic application.

T4.01 Information Technologies for Intelligent and Adaptive Space Robotics (STTR)
Lead Center: ARC
Participating Center(s): JPL, JSC
Related Subtopic Pointer(s): H6.02

The objective of this subtopic is to develop information technologies (algorithms, avionics, and software) that enable robots to better support space exploration. Improving robot information technology is critical to improving the capability, flexibility, and performance of future NASA missions. In particular, the NASA "Robotics and Autonomous

Systems" technology roadmap (T04) indicates that extensive and pervasive use of robots can significantly enhance future exploration missions that are progressively longer, complex, and operate with fewer ground control resources.

The performance of space robots is directly linked to the quality and capability of the information technologies that are used to build and operate them. Thus, proposals are sought that address the following technology needs:

- Advanced robot user interfaces that facilitate distributed collaboration, geospatial data visualization, summarization and notification, performance monitoring, and physics-based simulation. The primary objective is to enable more effective and efficient interaction with robots remotely operated with discrete commands or supervisory control. Note: proposals to develop user interfaces for direct teleoperation (manual control) are not being solicited and will be considered non-responsive.
- Navigation systems for mobile robot (free-flying and wheeled) operations in man-made (inside the International Space-Station) and unstructured, natural environments (Earth, Moon, Mars). Emphasis on multi-sensor data fusion, obstacle detection, and localization. The primary objective is to radically and significantly increase the performance of mobile robot autonomous navigation through new sensors, avionics (including COTS processors for use in space), perception algorithms and software. Proposals for small size, weight, and power (SWAP) systems are particularly encouraged.
- Robot software systems that support system-level autonomy, instrument/sensor targeting, downlink data triage, and activity planning. The primary objective is to facilitate the creation, extensibility and maintenance of complex robot systems for use in the real-world. Proposals that address autonomy for planetary rovers operating in rough terrain or performing non-traditional tasks (e.g., non-prehensile manipulation) are particularly encouraged.

Proposers are encouraged to target the demonstration of these technologies to existing NASA research robots or current projects in order to maximize relevance and potential for infusion.

Deliverables to NASA:

- Identify scenarios, use cases, and requirements.
- Define specifications based on design trades.
- Develop concepts and prototypes.
- Demonstrate and evaluate prototypes in real-world settings.
- Deliver prototypes (hardware and/or software) to NASA.

Focus Area 5: Communications and Navigation

Lead MD: HEOMD

Participating MD(s): SMD

NASA seeks proposals to produce high impact developments in communications and navigation technologies to support future science and exploration missions. Missions are generating ever-increasing data volumes that require increased performance from communications systems while minimizing the impacts to the spacecraft. Similarly, missions have a need for more precise guidance, navigation, and control to meet their mission objectives. This focus area supports development of technologies in RF and optical communications systems; cognitive systems for communications; and ground-based and onboard guidance, navigation and control systems that will provide a significant improvement over the current state of the art.

H9.01 Long Range Optical Telecommunications (SBIR)
Lead Center: JPL
Participating Center(s): GRC, GSFC
Related Subtopic Pointer(s): Z8.02, S2.02, S2.03

The Long Range Optical Communications subtopic seeks innovative technologies in free-space optical communications for increased data volume returns from space missions in multiple domains: >100 gigabit/s cis-lunar (Earth or lunar orbit to ground), >10 gigabit/s Earth-sun L1 and L2, >1 gigabit/s per AU-squared deep space, and >100 megabit/s planetary lander to orbiter.

Proposals are sought in the following specific areas (TRL3 Phase I to mature to TRL4 to 5 in Phase II):

Flight Laser Transceivers:

- Low-mass, high-effective isotropic radiated power (EIRP) laser transceivers: 30 to 100 cm clear aperture diameter telescopes for laser communications. Targeted mass less than 65 kg/square-meter with wavefront errors less than 1/25th of a wavelength at 1550 nm. Cumulative wavefront error and transmission loss not to exceed 3-dB in the far field. Advanced thermal and stray light design so that transceiver can survive direct sun-pointing and operate while pointing 3-degrees from the edge of the sun; wide range of allowable flight temperatures by the optics and structure, at least -20° C to 50° C operational range, wider range is preferred.
- Diffraction limited field-of-view at focal plane of at least 1 milliradian radius, provision for point-ahead implementation from space.
- Beaconless pointing subsystems for operations beyond 3 A.U.: Point 20 to 100 cm lasercomm transmitter aperture to an Earth-based receiver with a 1-sigma accuracy of better than 100 nanoradians with an assumed integrated spacecraft micro-vibration angular disturbance of 150 micro-radians (<0.1 Hz to ~500 Hz) without requiring a dedicated laser beacon transmission from Earth; lowest subsystem mass and power is a primary selection factor.
- Low mass/low power/cold survivable optical transceivers for planetary lander to orbiter links [7]: bi-directional optical terminals with data rates from >100 megabit/second at a nominal link range of 1000 km, with an individual terminal mass <5 kg and operational power < 25W, including a pointing system for at least full hemisphere coverage.
- Terminals shall be capable of operationally surviving >500 cycles of unpowered temperature cycling from -40° C to +40° C and a 100 krad TID. Discussion of acquisition and tracking con-ops and requirements is a must.

Flight Laser Transmitters and Receivers:

- High-gigabit/s laser transmitter and receiver optical-electronic subsystems: space qualifiable 1550 nm laser transmitter and receiver optoelectronic modulator, detection, and forward-error-correction (FEC) assemblies for data rates from 1 gigabit/s to >200 gigabits/s with power efficiencies better than 10W per gigabit/s and mass efficiencies better than 100 g per gigabit/s.
- Radiation tolerance better than 50 Krad is required.
- Technologies for efficient waveform modulation, detection, and synchronization and on-board low-gap-to-capacity forward-error-correction decoding are of interest.
- Also of interest are hybrid RF-optical technologies.
- Integrated photonic circuit solutions are strongly desired.

- High efficiency (>20% DC-to-optical, including support electronics) space qualifiable (including resilience to photo-darkening) multi-watt Erbium Doped Fiber Amplifier (EDFA) with high gain bandwidth (> 30nm, 0.5 dB flatness) concepts will be considered. Detailed description of approaches to achieve the stated efficiency is a must. High peak-to-average powers for supporting 7-ary to 8-ary pulse position modulation (PPM).
- Space qualifiable wavelength division multiplexing transmitters and amplifiers with 4 to 20 channels and average output power > 20W and peak-to-average power ratios >200 with >10 Gb/s channel modulation capability are also desired.

Narrow Band Pass Optical Filters:

- Flight qualified optical narrow band pass filters with 1 to 2 cm clear aperture and 0.5 1 nm noise equivalent bandwidth with less than 1 dB transmission loss around 1064 nm or optical c-band are also required.

Ground Assets for Optical Communication:

- Large aperture receivers for faint optical communication signals from deep space, subsystem technologies: Demonstrate innovative subsystem technologies for >10 m diameter deep space ground collector capable of operating to within 3 degrees of solar limb with a better than 10 microradian spot size (excluding atmospheric seeing contribution). Desire demonstration of low-cost primary mirror segment fabrication to meet a cost goal of less than $35K per square meter and low-cost techniques for segment alignment and control, including daytime operations.
- 1550 nm sensitive photon counting detector arrays compatible with large aperture ground collectors with integrated time tagging readout electronics for >5 gigaphotons/s incident rate. Time resolution <100 ps 1-sigma and highest possible single photon detection efficiency, at least 50% at highest incident rate, and total detector active area > 0.2 mm^2. Integrated dark rate < 5 megacount/s.
- Cryogenic optical filters for operation at 40K with sub-nanometer noise equivalent bandwidths in the 1550 nm spectral region, transmission losses < 0.5 dB, clear aperture >35 mm, and acceptance angle >40 milliradians with out-of-band rejection of >65 dB from 0.4 to 5 microns.

For all technologies, lowest cost for small volume production (5 to 20 units) is a driver. Research must convincingly prove technical feasibility (proof-of-concept) during Phase I, ideally with hardware deliverables that can be tested to validate performance claims, with a clear path to demonstrating and delivering functional hardware meeting all objectives and specifications in Phase II.

H9.03 Flight Dynamics and Navigation Technology (SBIR)
Lead Center: GSFC
Participating Center(s): MSFC
Related Subtopic Pointer(s): Z7.01

Future NASA missions will require precision landing, rendezvous, formation flying, cooperative robotics, proximity operations (e.g., servicing), and coordinated platform operations. This drives the need for increased precision in absolute and relative navigation solutions, and more advanced algorithms for both ground and onboard guidance, navigation, and control. This subtopic seeks advancements in flight dynamics and navigation technology for applications in Earth orbit, lunar, and deep space that enables future NASA missions. In particular, technology relating to navigation, autonomous onboard guidance, navigation and control, and trajectory optimization are solicited.

Autonomous, On-Board Guidance, Navigation and Control**:**

- Advanced autonomous navigation techniques including devices and systems that support significant advances in independence from Earth supervision while minimizing spacecraft burden by requiring low power and minimal mass and volume.
- Onboard trajectory planning and optimization algorithms, for real-time mission re-sequencing, on-board computation of large divert maneuvers (TA 5.4.2.3, TA 5.4.2.5, TA 5.4.2.6, TA 9.2.6) primitive body/lunar proximity operations and pinpoint landing (TA 5.4.6.1).
- Rendezvous targeting (TA 4.6.2.1) Proximity Operations/Capture/ Docking Guidance (TA 4.6.2.2).

Advanced Techniques for Trajectory Optimization**:**

- Tools and techniques for distributed space missions including constellations and formations (TA 11.2.6).
- Low-thrust trajectory optimization in a multi-body dynamical environment (TA 5.4.2.1).
- Advanced deep-space trajectory design techniques. (TA 5.4.2.7) and rapid trajectory design near small bodies (TA 5.4.5.1).

Additional Scope Clarification

Efforts must demonstrate significant risk or cost reduction, significant performance benefit, or enabling capability. Note that implementation of well understood GN&C algorithms into hardware/software, and high TRL activities, are not in scope.

Proposals that leverage state-of-the-art capabilities already developed by NASA, or that can optionally integrate with those packages, such as the General Mission Analysis Tool (http://sourceforge.net/projects/gmat/), Goddard Enhanced Onboard Navigation System (GEONS) (https://software.nasa.gov/software/GSC-14687-1), GPS-Inferred Positioning System and Orbit Analysis Simulation Software, (http://gipsy.jpl.nasa.gov/orms/goa/), Optimal Trajectories by Implicit Simulation (http://otis.grc.nasa.gov/) , and Navigator (http://itpo.gsfc.nasa.gov/wp-content/uploads/gsc_14793_1_navigator.pdf), or other available hardware and software tools are encouraged. Proposers who contemplate licensing NASA technologies are highly encouraged to coordinate with the appropriate NASA technology transfer offices prior to submission of their proposals.

Phase I research should be conducted to demonstrate technical feasibility, with preliminary software being delivered for NASA testing, as well as show a plan towards Phase II integration. For proposals that include hardware development, delivery of a prototype under the Phase I contract is preferred, but not necessary. Phase II new technology development efforts shall deliver components at the TRL 5-6 level with mature algorithms and software components complete and preliminary integration and testing in an operational environment.

H9.05 Transformational/Over-the-Horizon Communications Technology (SBIR)
Lead Center: GRC
Participating Center(s): GSFC

The proposer is expected to identify new ideas, create novel solutions and execute feasibility demonstrations. Emphasis for this subtopic is on the far-term (≈10yrs.) insofar as mission insertion and commercialization but it is expected that the proposer proves fundamental feasibility via prototyping within the normal scope of the SBIR program. The over-the-horizon communications technology development will focus research in the following areas:

- Systems optimized for energy efficiency (information bits per unit energy).
- Advanced materials; smart materials; electronics embedded in structures; functional materials; graphene-based electronics/detectors.

- Technologies that address flexible, scalable digital/optical core processing topologies to support both RF and optical communications in a single terminal.
- Nanoelectronics and nanomagnetics; quantum logic gates; single electron computing; superconducting devices; technologies to leapfrog Moore's law.
- Quantum communications, methods for probing quantum phenomenon, methods for exploiting exotic aspects of quantum theory.
- Human/machine and brain-machine interfacing; the convergence of electronic engineering and bio-engineering; neural signal interfacing.

The research should be conducted to demonstrate theoretical and technical feasibility during the Phase I and Phase II development cycles and be able to demonstrate an evolutionary path to insertion within approximately 10 years. Delivery of a prototype of the most critically enabling element of the technology for NASA testing at the completion of the Phase II contract is expected.

Phase I deliverables shall include a final report describing theoretical analysis and prototyping concepts. The technology should have eventual commercialization potential. For Phase II consideration, the final report should include a detailed path towards Phase II prototype hardware.

S3.04 Guidance, Navigation and Control (SBIR)
Lead Center: GSFC
Participating Center(s): ARC, JPL, LaRC, MSFC
Related Subtopic Pointer(s): Z7.01

NASA seeks innovative, groundbreaking, and high impact developments in spacecraft guidance, navigation, and control technologies in support of future science and exploration mission requirements. This subtopic covers mission enabling technologies that have significant Size, Weight and Power, Cost, and Performance (SWaP-CP) improvements over the state of the art COTS in the areas of Spacecraft Attitude Determination and Control Systems, Absolute and Relative Navigation Systems, and Pointing Control Systems, and Radiation-Hardened GN&C Hardware.

Component technology developments are sought for the range of flight sensors, actuators, and associated algorithms and software required to provide these improved capabilities. Technologies that apply to most spacecraft platform sizes will be considered.

Advances in the following areas are sought:

- *Spacecraft Attitude Determination and Control Systems* - Sensors and actuators that enable <0.1 arcseond level pointing knowledge and arcsecond level control capabilities for large space telescopes, with improvements in size, weight, and power requirements.
- *Absolute and Relative Navigation Systems* - Autonomous onboard flight navigation sensors and algorithms incorporating both spaceborne and ground-based absolute and relative measurements. For relative navigation, machine vision technologies apply. Special considerations will be given to relative navigation sensors enabling precision formation flying, astrometric alignment of a formation of vehicles, robotic servicing and sample return capabilities, and other GN&C techniques for enabling the collection of distributed science measurements.
- *Pointing Control Systems* - Mechanisms that enable milli-arcsecond class pointing performance on any spaceborne pointing platforms. Active and passive vibration isolation systems, innovative actuation feedback, or any such technology that can be used to enable other areas within this subtopic applies.

- *Radiation-Hardened Hardware:* GN&C sensors that could operate in a high radiation environment, such as the Jovian environment.
- *Fast light Gyroscopes and Accelerometers* - In conventional ring laser gyros, precision increases with cavity size and measurement time. Fast-light media, however, can be used to increase gyro precision without having to increase size or decrease measurement frequency, thereby increasing the time for standalone spacecraft navigation. (The increased precision also opens up new science possibilities such as measurements of fundamental physical constants, improving the sensitivity-bandwidth product for gravity wave detection, and tests of general relativity.) Prototype fast-light gyros are sought that can be implemented in a compact rugged design that is tolerant to variations in temperature and G-conditions, with the ultimate goal of demonstrating decreased angular random walk.

Phase I research should be conducted to demonstrate technical feasibility as well as show a plan towards Phase II integration and component/prototype testing in a relevant environment. Phase II technology development efforts shall deliver component/prototype at the TRL 5-6 level consistent with NASA SBIR/STTR Technology Readiness Level (TRL) Descriptions. Delivery of final documentation, test plans, and test results are required. Delivery of a hardware component/prototype under the Phase II contract is preferred.

Proposals should show an understanding of one or more relevant science or exploration needs and present a feasible plan to fully develop a technology and infuse it into a NASA program.

Focus Area 6: Life Support and Habitation Systems

Lead MD: HEOMD
Participating MD(s): STTR

The Life Support and Habitation Systems Focus Area seeks key capabilities and technology needs encompassing a diverse set of engineering and scientific disciplines, all which provide technology solutions that enable extended human presence in space. Functions include Environmental Control and Life Support Systems (ECLSS), Extravehicular Activity (EVA) Systems, Advanced Food Technology and Biological Life Support.

Habitation systems encompass process technologies, equipment and monitoring functions necessary to provide and maintain a livable environment within the pressurized cabin of crewed spacecraft, including human accommodations, atmosphere revitalization, water recycling, waste management and resource recovery. Vehicle outfitting provides the equipment necessary for the crew to perform mission tasks as well as provide a comfortable and safe habitable volume. A capability for integrated system health management for these sustainable habitats is of interest. Providing cost effective, efficient and reliable carbon dioxide removal for human space applications has been a challenge, with improvements applicable to both Spacecraft ECLSS and EVA portable life support systems. Furthermore, as we consider human missions to planetary surfaces, such as to Earth's moon and to the surface of Mars, new technologies may be required that are compatible with attributes of these environments, including partial gravity or reduced pressure atmosphere. Needs for EVA also include development of tinting and coatings for spacesuit visors and considerations for commercial space suit systems.

For future crewed missions beyond low-Earth orbit (LEO) and into the solar system, regular resupply of consumables and emergency or quick-return options will not be feasible. Technologies are of interest that enable long-duration, safe and sustainable deep-space human exploration with advanced extra-vehicular capability. Special emphasis is placed on developing technologies that will fill existing gaps, reduce requirements for consumables and other resources, including mass, power, volume and crew time, and which will increase safety and reliability with respect to the state-of-the-art. Biological systems, including plant growth systems and microbial bioreactors may be useful to regeneratively recycle wastes into consumables, including fresh foods, chemicals and new materials for in situ manufacturing. A system for preparing fresh fruits and vegetables for use in meals is also of interest, including washing and disinfection.

Please refer to the description of each subtopic for further detail to guide development of proposals.

H3.01 Process Technologies for Water Recycling in Space (SBIR)
Lead Center: MSFC
Participating Center(s): ARC, GRC, JPL, JSC, KSC

Water Processors for Planetary Surface Systems
NASA seeks concepts for the development of water systems on a planetary surface that take advantage of the partial gravity on Mars or the lunar surface while implementing robust technologies with minimal consumables. The technologies should focus on the following potential waste streams: urine, humidity condensate, Sabatier product water, waste hygiene, and waste laundry water. Consideration should be given to planetary protection, for both forward and backward contamination. Technologies must be compatible with a delivery schedule to Mars (6-12-month transit) in which the system will be dormant, operational periods exceeding 500 days, followed by dormancy periods between uses for 2 or more years.

Total Organic Carbon Analyzer for Exploration Missions
Over the past 10+ years, we've learned the importance of real-time on-board monitoring of total organic carbon (TOC) in product water from the ISS wastewater recycling system (Water Processor Assembly - WPA). TOC along with conductivity provides a means to predict when multi-filtration beds require replacement. This data allows controllers and engineers to monitor both impending break through and recovery of upsets in water quality once appropriate remedial action is taken. Having measurement of TOC helps to optimize the life of consumable WPA elements. The hardware for monitoring TOC on the ISS is called the "Total Organic Carbon Analyzer" or TOCA. The Size, Weight and Power (SWaP) of TOCA is as follows: 67 L, 34 kg, and 64 W. Water recycling and therefore a TOCA will be required on future long duration gateway/deep space missions. The ISS TOCA design is simply too large for exploration vehicles and habitats. Any design effort toward an advanced TOCA should reduce the SWaP of the ISS TOCA by at least an order of magnitude. New technology development is sought in measuring TOC and conductivity in a miniaturized, automated system that can be plumbed into the WPA. Ideally, the TOCA requires no hazardous reagents, has long-term calibration stability, and requires very little crew time to operate and maintain. TOCA functionality is one of the critical water monitoring needs for future spacecraft based on the requirements assessment. Studies are currently being performed to explore alternative oxidation and detection techniques, as well as system simplifications and repackaging to shrink its size. In-line measurement is desired as a capability above the SOA, but it is not critical.

Silver-based Microbial Check Valve
NASA has interest in in-line microbial check valve (MCV) technologies for spacecraft potable water systems. The MCV should add 300 to 500 ug/L of silver to the water at a flow rate of 0.1 to 0.15 L/min to maintain the microbial control of the system in accordance with typical spacecraft potable water specifications. In addition, the device should be able to operate at ambient temperature, pH ranges between 4.5 - 9.0, and system pressures up to 30 psig. In addition, the MCV should prevent the passage and/or grow through of microbes across the MCV device when there is no flow. The MCV device should be capable of easy installation and be maintainable. The devices should also be small, robust, lightweight, and have minimal power and consumable mass requirements. In addition, candidate technologies should be microgravity compatible, have no adverse effects on the potability of the drinking water system, and not require removal of the imparted biocide prior to crew consumption. Of particular interest are microbial check valve technologies that are either silver-based and/or fully compatible with ionic silver disinfection strategies. Finally, MCV

technologies should also be capable of providing continuous, stable and autonomous operation, and be fully functional following periods of long-term system dormancy – up to 1 year.

H3.02 Waste Management and Resource Recovery (SBIR)
Lead Center: JSC
Participating Center(s): ARC, GRC, KSC, MSFC

There are two areas of focus in this subtopic:

Collection and Recovery of High TOC Water from Feces and Trash
Wet trash contains ~25% and feces contains ~75% water by mass that is currently not recovered on ISS. Currently wet trash and feces are collected and stored in relatively impermeable containers for short term storage (1-3 months) and disposed of in departing logistics vehicles. There have been crew comments about odor generation during storage. Trash and fecal material must be stabilized for Mars transit and surface missions. Drying and thermal processing of trash can reduce odor generation and prevent microbial proliferation. Past Heat Melt Compactor (HMC) technology development has indicated >80 volatile compounds elute from trash and recovered water can exceed 3,500 ppm total organic carbon (TOC). Innovations are requested for technologies that can recover water from a gas stream with a wide range of volatile gas contaminants for long periods. Technologies must be able to recover >80% of the gas stream water content. Captured water should have minimal free gas and should be below 2% by volume for eventual delivery to a waste water tank. Purification of the water is not requested. Technologies must be able to accommodate a wide range of condensable and non-condensable mass flow rates as trash/fecal processing systems dry and process the material. Water recovery from a variety of processes (i.e., HMC, Trash to Gas, freeze drying) should be accommodated directly or with an assumed regenerative heat exchanger to recover energy prior to phase separation. Process gas temperatures will range from -80° C to 200° C and 6-110 kPa absolute. Condensable gas will range from 0-100% by volume with a maximum water flow rate of 15 g/min. Air cooling using cabin air 18-30° C is preferred but water cooling is acceptable. Systems must be capable of microgravity operation over a 6-month transit to Mars, an 18-month dormancy period, and 6-month operation on return to Earth with minimal crew maintenance. It is highly desirable that maintenance items consider fabrication by on-demand manufacturing (i.e., additive manufacturing and post finishing). Technologies must consider accumulation of organics and microbial proliferation between normal waste processing cycles and extended dormancy and any change in performance should be characterized. Technologies shall demonstrate comparison to previous SOA condensing heat exchangers.

Low Consumable Low Residual Waste Gasification
Past trash gasification technologies focused on producing gases (methane, water, oxygen, or CO_2) for secondary purposes using supplemental oxygen, water, or other consumables. The current request focuses on the minimal total mass (combined consumables and residual mass). Recent trash storage vs processing trade studies have indicated trash jettison during the transit results in the lowest total vehicle mass. It is possible to reduce overall vehicle mass by ~6% (10,800 kg) via trash jettison. Approximately 70% of the savings is due to reduced chemical propulsion fuel and tankage for orbit departures and insertions. Innovations are requested for technologies that can convert trash to gas suitable for venting to the space craft exterior for the purpose of reducing vehicle mass. Technologies must be capable of processing the wide range of crew logistical trash and metabolic waste. Processing technologies must decompose at least a portion of the hydrocarbon waste. Technologies that only recover water are not requested. Residuals material plus processing consumables (lost gas, oxygen, water, and carrier gases) must be less than 10% of the starting trash material. Processes must be capable of serial waste loading, processing, and residual removal without complete shutdown. Systems must be capable of microgravity operation over a 6-month transit to Mars, an 18-month dormancy period, and 6-month operation on return to Earth with minimal crew maintenance. It is highly desirable that maintenance items consider fabrication by on-demand manufacturing (i.e., additive manufacturing and post finishing). Technologies must consider containment of high pressure/temperature/hazardous gases for crew safety and operational robustness. Characterization of produced gases is required with emphasis on identification of condensable

gases and acid/caustic gases that can adversely affect exterior glass and metallic vehicle surfaces. Technologies shall demonstrate comparison to previous state-of-the-art Trash to Gas (TtG) systems. If water is recovered (desirable but not required) chemical contaminants within the recovered water should be characterized.

H4.01 Advanced Space Suit Portable Life Support System (PLSS) (SBIR)
Lead Center: JSC

NASA plans to continue using the current EMU/spacesuit for the life of ISS. However, with the anticipation of a replacement suit for ISS or other future mission, the plan for an Advanced EMU is underway. Technology gaps remain for the PLSS. The following is a list of technology focus areas specifically for the Advanced PLSS:

- *Continuous trace contaminant removal capability* - Activated charcoal is the state of the art and provides a logistics impact to future missions. The primary trace contaminants to remove include ammonia (NH_3), carbon monoxide (CO), formaldehyde (CH_2O), and methanethiol (also known as methyl mercaptan) (CH_3SH). The minimum objective would be to remove all of the significant compounds that threaten to exceed the 7-day SMAC[2] during an EVA. For continuous removal, the most advantageous integration with the current state of the art CO_2/H_2O removal system would be integrated such that regeneration or desorption occurs with a pressure swing from 4.3 psia to <1 torr over a ~2min period half-cycle at temperatures in the 60-80° F range. A small amount of heat flux is available from the cross-coupled adsorbing bed; additional heat input requirements from resistance heaters, etc. would negatively impact the system trade the more significant the value becomes.
- *Small, oxygen compatible gas flow meter for suit operations* - Small, oxygen compatible gas flow meter for suit operations: The current state of the art for flow measurement on the ISS EMU space suit is a flapper valve attached to a microswitch which is limited to a single set-point. The accurate measurement ranges required for the sensor are 2-8 acfm +/- 1% with a pressure drop of less than 0.68 in-H_20 in a 100% oxygen (O_2) environment (traces of NH_3, H_2O, CO_2); suit pressure from 3.5-25 psia, temperature from 50-90° F, relative humidity (RH) 0-50%, and CO_2 from 0-15mmHg. This flow meter needs to fit within a volume/shape factor of approximately 2.5 in x 1.5in x 3in or less including fluid ports and electrical connectors; if added as an in-line flow, 1 in inlet/outlet porting will be necessary. Operating life objective is 8 years without calibration and 5000 hours of powered operation.
- *Small hermetic micro switch* - Current state of the art is 3-5 times larger than needed. Honeywell MicroSwitch HM-1 series is a typical state of the art. Combining Single Pole Double Throw (SPDT) circuits that add additional toggle mechanisms would further grow the size of the switch. Hermetic is defined as leakage <10-8 atm-cc/sec. Switching currents for these switches are signal level at <500mA.
- *Multi-gas monitoring within the suit* - Multi-gas monitoring: Advanced suit could benefit from measuring Oxygen (O_2), carbon dioxide (CO_2), water (H_2O), ammonia (NH_3), carbon monoxide (CO), formaldehyde (CH_2O), methanethiol (also known as methyl mercaptan) (CH_3SH), etc. The measurement of trace contaminants becomes even more important if an alternate approach (e.g., pressure or temperature swing adsorption) to the traditional activated charcoal cartridge is used. There is a need to measure the following major constituents and trace contaminants ranges in the gas stream across a total pressure range of 3.5 – 23.5 psia and temperature range of 35-125F: O_2 = 20-100%; CO_2 = 0-30 torr over 3.5-23.5 psia; H_2O = 5-90% RH; NH_3 = 0-50 ppm; CO = 0-400 ppm; CH_2O = 0-5 ppm; and CH_3SH = 0-5 ppm.
- *Power* - Current state of the art is lithium-ion batteries with cell level energy densities of 200 W-h/kg but packaged energy densities of ~130W-h/kg after addressing mitigation for thermal runaway. Safe, high-energy density power sources are needed which are rechargeable post-EVA.
- *Heat Transport Improvements* - Several improvements are needed in this focus area including:
    - Improvement in the Liquid Cooling and Ventilation Garment (LCVG) state of the art.

  - Improvement in the UA such that warmer water can be used to sink the waste heat from the human and hence reduce the evaporator size.
  - Drastically alter the human-to-cooling loop interfaces such as a fluid-filled suit with directly pumped cooled water.
  - Alter the Thermal Micrometeoroid Garment (TMG) such that the emissivity/absorptivity can be dynamically altered to improve thermal.
- *Human-Machine Interface Improvements* - Current state of the art for this focus area includes mechanical switches and a 16 x 2 Liquid Crystal Display (LCD). Low power, wide thermal range, rad tolerant high definition graphics displays that can be integrated with the suit soft goods or hard goods such as heads-displays.

These technology gaps were detailed during the 2017 SBIR/STTR Industry Day (https://sbir.nasa.gov/events/sbir-industry-day).

Phase I Products - By the end of Phase, it would be beneficial to have a concept design for infusion into the Advanced PLSS. Testing of the concept is desired at this Phase.

Phase II Products - By the end of Phase II, a prototype ready for system-level testing in the PLSS or in a representative loop of the PLSS is desired.

H4.02 Controllable, Tinting, Polycarbonate Compatible Coatings for Advanced EVA Spacesuit Visor (SBIR)
Lead Center: JSC

For the next generation of NASA's space suits, being able to enable an architecture for microgravity and planetary capabilities is required. To support these future missions, we will need support hardware to be designed, such as a new extravehicular visor assembly (EVVA) to protect the astronaut's eyes from the damaging UV rays of the sun. The EMU has an EVVA that is a sun visor that can be manually deployed by the crew members. This changes the radiation protection from just UV via the clear helmet to a reflective visor that blocks visible light and IR via the gold visor. Unlike the EMU EVVA design, the new EVVA will need to integrate with the exploration space suit helmet bubble, which is a 10"x13" hemi-ellipsoid dome. We feel that in this new design we have a unique opportunity to integrate the new technologies in the field of actively controlled coatings that affect tint-ability, UV protection, and optimized transmittance through our EVVA. Focus areas of coating technology that appeal to the team are electrochromics and solar variable reflectance, but we are open to other novel solutions.

The goal at the end of Phase I SBIR is to have a tabletop prototype helmet bubble that is coated with a controllable tint that would demonstrate the technology needed to replace the EVVA reflective visor.

Phase I Performance Targets:

- Transmittance requirements in off state: 450 nm N/A, 550 nm 70% min, 1100 N/A.
- Transmittance requirements in on state: 450 nm 10+/-4%, 550 16+/-4%, and 1100 nm 10% max.
- Cannot hinder visibility in a failed state.
- Must be thermally stable in the space environment.
- Concepts of how to make it operable with a gloved hand.
- If required, low power consumption.

Phase II would require the coating to meet the same requirements as seen in Phase I, but to deliver a full helmet bubble prototype that could interface with NASA's Z-2 spacesuit for a suited demonstration. Examples of Phase II performance targets would include ability to autosense UV/light with the ability to turn on/off the coating automatically, integrating a scratch resistant coating, a packaged power supply (if needed) that is dust resistant and tolerant to the space environment, and packaged controls for the crew member that are operable with a gloved hand.

H4.03 Mass Produced, Minimal Capability, Disposable EVA Life Support System (SBIR)
Lead Center: JSC

NASA's plans for Exploration EVA Operational Concepts and Architectures currently lead to conceptual design solutions optimized for relatively long EVA's and extensive re-use of the PLSS over the course of many missions. From an economics perspective, that is one way to solve the question of "value" – by amortizing the development and manufacturing cost of a relatively small amount of production units across a relatively long period of use (many years, many EVAs or many separate missions).

However, it is possible that alternative ways of solving the Suit and PLSS problems, including cost, could be acceptable – by reducing the capability inside the EVA PLSS to a point where it might only enable a relatively short EVA (perhaps ~2 hours instead of ~8) and relatively few EVAs (perhaps ~10 instead of ~100) one might be able to construct a schematic and design that was affordably "mass produced".

Embracing innovative suit garment technologies and concepts such as novel material layups, self-healing/self-repair bladders and restraints, Shape Memory Alloy (for adjustable sizing and fit geometry, ballistic projectile mitigation (for secondary eject from MMOD strikes on nearby natural surfaces), electrochromics, Mechanical Counter Pressure (MCP) concepts, and hybrid designs and manufacturing approaches may lead to cost effective suits that could inform NASA future plans as well as support future commercial space needs. Ultimately, concepts, technologies and design solutions leading to the capability of "low-cost customization" is vital to NASA's future exploration capabilities in many ways.

The potential benefits of these approaches could include the ability to more regularly incorporate emerging technologies and minor feature updates to continuous reduction of cost through refinement and modernization of the production system. Such an approach might also stimulate or otherwise support the adoption of EVA as a viable, cost effective feature in commercial spaceflight systems for non-NASA customers.

Design solutions might look significantly different from current/historic EVA PLSS and suit designs, including features similar to the emergency breathing systems used for short periods by firefighters, first responders and Hazardous Material teams. Parallels with such terrestrial applications offer opportunities for existing commercial product lines to be adapted or modified for the "hazardous environment" of EVA and could further grow existing sectors of the economy. Such innovative design solutions would also provide NASA technical data that NASA could then integrate into analysis of alternative "Mission Design" scenarios where the total spaceflight architectural impact of mass, volume, reliability, spares and contingency scenarios are assessed. These types of analysis currently only use the conventional PLSS design solution parameters as inputs, but running the same models by adapting Operational Concepts to use a "mass produced" EVA PLSS might reveal surprising alternative approaches that NASA should be aware of.

Phase I products:

- A paper report on the concept highlighting the design's minimal capabilities.
- A manufacturability analysis explaining why it is mass-producible at an extremely low cost (including an estimate of the number of units needed to achieve a minimal unit price).
- A comparison of the proposed concept with existing commercially available terrestrial life support systems such as firefighter breathing apparatus':

  - The comparison highlights commonality or differences in the technical design and the economies of scale found in available terrestrial life support systems and the proposed concept.
  - This information should clearly support the manufacturability analysis by providing evidence to the costs of existing product lines and why those are relevant analogies to the proposal.
- Prototype suit subsystem manufacture, up to and including a full suit, which could be used in testing.

Phase II would require the product development, further characterization of the limits of the design's performance and additional financial analysis on the cost of mass production.

H6.01 Integrated System Health Management for Sustainable Habitats (SBIR)
Lead Center: ARC
Participating Center(s): GRC, JSC, LaRC
Related Subtopic Pointer(s): H6.02, H6.03

Habitation systems provide a safe place for astronauts to live and work in space and on planetary surfaces. They enable crews to live and work safely in deep space, and include integrated life support systems, radiation protection, fire safety, and systems to reduce logistics and the need for resupply missions. Innovative health management technologies are needed in order to increase the safety and mission-effectiveness for future space habitats on other planets, asteroids, or lunar surfaces. For example, off-nominal or failure conditions occurring in safety-critical life support systems may need to be addressed quickly by the habitat crew without extensive technical support from Earth due to communication delays. If the crew in the habitat must manage, plan and operate much of the mission themselves, operations support must be migrated from Earth to the habitat. Enabling monitoring, tracking, and management capabilities on-board the habitat and related EVA platforms for a small crew to use will require significant automation and decision support software.

This subtopic seeks to broaden the scope of traditional caution and warning systems, which are typically triggered by out-of-bounds sensor values, by including machine learning and data mining techniques. These methods aim to reveal latent, unknown conditions while still retaining and improving the ability to provide highly accurate alerts for known issues. The performance targets for known faults and failures will be based upon false alarm rate, missed detection rate, and detection time (first time prior to the adverse event that the algorithm indicates an impending fault/failure). Methods should explore the trade space for ISHM data and processing needs in order to provide guidance for future habitat sensor and computational resource requirements.

Proposals may address specific system health management capabilities required for habitat system elements (life support systems, etc.). In addition, projects may focus on one or more relevant subsystems such as water recycling systems, photovoltaic systems, electrical power systems, and environmental monitoring systems. Proposals that involve the use of existing testbeds or facilities at one of the participating NASA centers (e.g., Sustainability Base at ARC) for technology validation, verification, and maturation are strongly encouraged. Technology Readiness Levels (TRL) of 4 to 6 or higher are sought.

Key features of Sustainability Base that make it relevant to deep space habitat technology are its use of a grey water recycling system and a photovoltaic array. Data logged from other facility management/building automation systems include environmental data (temp, CO_2, etc.) and facility equipment sensors (flowrates, differential pressures, temperatures, etc.). Also, information on power consumption (whole building, plug load, other loads metered at the panel/circuit level) can be made available. These remaining systems, while conventionally "green," have no unique feature that can't be exclusively used for terrestrial purposes. However, the fact that all such systems require less power to support human occupancy can be used as a focal point to serve as a testbed for deep space habitats that will need to operate within finite energy budgets.

Specific technical areas of interest related to integrated systems health management include the following:

- Machine learning and data mining techniques that are capable of learning from operations data to identify statistical anomalies that may represent previously unknown system degradations. Methods should facilitate the incorporation of human feedback on the operational significance of the statistical anomalies using techniques such as active learning.
- Demonstration of advanced predictive capability using machine learning or data mining methods for known system fault or failure modes, within prescribed performance constraints related to detection time and accuracy.
- Prognostic techniques able to predict system degradation, leading to system robustness through automated fault mitigation and improved operational effectiveness. Proposals in this area should focus on systems and components commonly found in space habitats or EVA platforms.
- Innovative human-system integration methods that can convey a wealth of health and status information to mission support staff quickly and effectively, especially under off-nominal and emergency conditions.

H12.04 Wash System to Disinfect Fresh Fruit & Vegetables Grown in Spaceflight (SBIR)
Lead Center: JSC
Participating Center(s): KSC

Fresh fruits and vegetables grown in spaceflight may provide critical nutritional and behavioral benefits, but introduce unacceptable microbiological risk that could lead to foodborne illness. It is critical that a produce disinfection method be identified to prevent foodborne illness. A water wash method would impact vehicle design, and requirements must be determined in time to inform transit vehicle designs. The Pro-San wipes currently used to disinfect space-grown produce require continual up-mass and create trash. Other novel methods that have been investigated, including hydrogen peroxide and cold plasma chambers, generated a noticeable quality reduction during disinfection. Crewmembers will be harvesting and processing produce themselves, and it is imperative that quality is not reduced during disinfection. Some examples of items of interest:

- Development of a water wash system that can directly integrate in a closed loop with the spacecraft water system.
- Use of food grade sanitizers. No soaps or detergents. Residuals should not exceed approved food amounts.
- Systems that disinfect and dry a range of fruit and vegetable amounts (0.25 - 2 kg) and types (leafy greens, tomatoes, radishes, green peppers) in both microgravity and reduced gravity environments.
- Proposals that use the least amount of crew time (both active and passive) will be given greater consideration.
- Proposals that use the least amount of water for both disinfecting and rinsing will be given greater consideration. Note, crew currently receive less than 3 L of water a day each for consumption.
- Demonstrate greater than a 3 log reduction in Aerobic Plate Count, Yeast and Mold, and both *Bacillus cereus* ATCC 14579, a common contaminant on fresh produce, and in *Escherichia coli* ATCC 11775, a non-pathogen used as a surrogate for other gram negative organisms that have been associated with foodborne illness.
- Demonstrate that produce quality is not noticeably reduced from the beginning of the process to the end.
- Systems that are lowest in mass, power, volume, crew time, etc. will be given greater consideration.
- Reliability; capable of operation for up to 2-5 years and withstand launch loads and gravity changes.

Proposals for novel approaches or systems other than a water solution wash system that meet the success criteria may be considered. Note, systems that require pressurized gases or that generate toxic byproducts will not be considered at this time.

Phase I Deliverables - Prototype system design and evaluation. Final report detailing resource use (crew time, water, mass, volume), sanitizer compatibility, microbial reduction achieved and initial quality results.

Phase II Deliverables - Completed first generation unit that integrates with the ECLSS water system and detailed data regarding resource use, microbial testing, and quality evaluations.

T6.01 Innovative Solutions to Carbon Dioxide Removal for Spacecraft, Surface Systems, and EVA Systems (STTR)
Lead Center: JSC
Participating Center(s): ARC, MSFC

Technology advancements in Extra-Vehicular Activity (EVA) and spacecraft cabin life support systems are required to enable forecasted microgravity and planetary human exploration mission scenarios and to support potential extension of the International Space Station (ISS) mission beyond 2020.

Providing cost effective, efficient and reliable carbon dioxide removal for human space applications has been a challenge. The state-of-the-art zeolite-based system currently in use in for closed-loop atmosphere revitalization on the ISS has suffered from the production of fines, resulting in the need for frequent maintenance. Vacuum-based swing bed systems for potential use in the Portable Life Support Systems (PLSS) used in EVA space suits will not be effective in the Mars surface environment due to the partial pressure of carbon dioxide in the Mars atmosphere. Both solutions become less efficient if the inlet partial pressure of CO_2 from the crew environment is reduced. Novel solutions are sought for applications including Spacecraft, Surface Systems, and EVA Systems.

Advanced Extravehicular Mobility Unit (EMU)
Technologies are sought for continuous CO_2 and relative humidity removal capability that can operate within space vacuum and Martian atmospheres (0.6 kPa, or 4.5 torr). Examples of advancements sought include:

- Improvements in sorbent CO_2 and H_2O uptake leading to smaller, more efficient beds.
- Providing for independent control and selectivity for CO_2 and water vapor.
- Consideration for alternative process technologies, including but not limited to metal organic frameworks, ionic liquids, other liquid sorbents and supported structures, or selective permeable membranes.
- Novel systems integration and enhancements, such as using efficient boost compressors that may enable pressure swing operation in the Martian atmosphere, or temperature swing cycles that do not place a large power burden on the EMU.

Systems for Spacecraft Cabin and Surface Systems
Currently state-of-the-art CO_2 removal systems are large and power intensive. Alternative systems have been proposed, including but not limited to, metal organic frameworks, ionic liquids and liquid sorbents, structured or other alternative solid sorbents, selective membranes, electrochemical separation, etc. Many of these novel alternative technologies are at a low TRL and require additional research and development to prove the concepts, especially at the low partial pressures required for use in the cabin environment. Improvements are sought in the following areas:

- Improvements in sorbent CO_2 capacity and selectivity leading to smaller, more efficient components, lower energy consumption and operation at lower CO_2 partial pressures.
- Increases in the robustness of sorbent materials to mechanical stresses, temperature and humidity changes, or poisoning.
- Advanced and novel methods to increase the efficiency of temperature and pressure swing adsorption processes.

- Innovations and improvements in capillary structures and gravity insensitive frameworks for containment and management of ionic liquids and liquid sorbents.

NASA is especially interested in systems that can be incorporated into closed loop life support systems that recycle CO_2 and humidity, and could achieve the following performance targets. These parameters address the full system, including fans, valves, heat exchangers, etc.):

- Removal rate of 4.16 kg/day (a four-person load).
- Operate in an environment with 2.0 mmHg $ppCO_2$ for cabin applications (based on the daily average $ppCO_2$).
- System size ≤0.3 cubic meters for the 4-person load.
- System power use ≤500 watts of power for the 4-person load.
- System mass of ≤100 kilograms for the 4-person load.
- Effectively separate out water vapor (less than 100 ppm water vapor in the CO_2 product is desired).
- Effectively separate out oxygen and nitrogen (less than 1% O_2 and 2% N_2 by volume in the CO_2 product is desired).

Phase I Deliverables - Detailed analysis, proof of concept test data, and predicted performance (mass, volume, thermal performance) addressing inlet partial pressures of CO_2 below and above 2 mmHg, with description of regeneration requirements, especially relationship to Mars atmosphere vacuum. Deliverables should clearly describe and predict performance over the state of the art.

Phase II Deliverables - Delivery of technologically mature components/subsystems that demonstrate functional performance with appropriate interfaces are required. Prototypes should be at least at a 1-crewmember scale.

T7.01 Advanced Bioreactor Development for In Situ Microbial Manufacturing (STTR)
Lead Center: ARC

NASA's future long-duration missions require a high degree of materials recovery and recycling as well as the ability to manufacture required mission resources in situ. While physico-chemical methods offer potential advantages for the production of many products, biological systems are able to manufacture a wide range of materials that are not yet possible with abiotic systems. Microbial systems are currently being developed by academic institutions, industry, and government agencies to produce a wide array of products that are applicable to space missions. Relevant mission resources include, but are not limited to, food, nutrients, pharmaceuticals, polymers, fuels and various chemicals.

While current space-based research involves engineering of organisms to produce targeted compounds as well as the in-situ production of microbial media to support larger scale operations, additional enabling research is needed to develop specialized bioreactors that are highly efficient, reliable, low volume and mass, and that otherwise meet the unique rigors of space.

Advanced bioreactor research and development has been primarily focused on terrestrial applications, particularly pharmaceutical, food and chemical production systems. Some space bioreactor work regarding flight experiments and life support applications has been conducted, such as algal reactors for CO_2/O_2 management. However, little to no effort has been conducted on the bioreactor design and operations that are required to enable in-situ microbial manufacturing. Therefore, innovations are sought to provide:

- Bioreactors that minimize mass, power and volume, maintenance, process inputs and waste production.
- Bioreactors that are capable of operating on the surface of Mars or potentially in-flight scenarios.

- Bioreactors that incorporate novel microbial biomass separation/harvesting/purification methods, materials recycling/recovery and ease of cleaning.
- High-density bioreactors that are capable of producing extremely high levels of microbial biomass and/or product.
- Advanced bioreactor monitoring and control systems, including oxygen, temperature, pH, nutrients.
- Experimental bioreactors that exhibit the ability to scale upwards.
- Bioreactors that maximize reliability, component miniaturization, materials handling ability, gas management and overall performance.

Overall, proposals should focus on advancing bioreactor development for space applications, rather than the production of a particular product or microorganism. The Phase I STTR deliverable should include a Final Report that captures any scientific results and processes as well as details on the technology identified. The Final Report should also include a Feasibility Study which defines the current technology readiness level and proposes the maturation path for further evolution of the system. Opportunities for commercial and government infusion should be addressed. Other potential deliverables include bioreactor system designs, hardware components and prototypes, and system control approaches and software.

T7.02 Space Exploration Plant Growth (STTR)
Lead Center: KSC
Participating Center(s): JSC

Producing food for crew consumption is an important goal for achieving Earth independence and reducing the logistics associated with future exploration missions. NASA seeks innovative technologies to enable plant growth systems for food production for in-space and planetary exploration missions.

- *Regolith to Soil* - Cultivation of crops for a Mars surface mission could be done hydroponically, or in combination with solid media generated from mineral regolith found near the landing site. NASA is interested in testing and developing concepts for generating "soil" media from Mars-like regolith to support food crop growth and allow uptake of essential minerals. Consideration should be given to improving water and nutrient retention characteristics, and remediation of potentially toxic perchlorate compounds common to Mars regolith.
- *CO_2 Control for Plant Chambers* - More advanced plant chambers for space typically manage their internal atmosphere separately, which allows recycling of transpired humidity. But this requires the use of consumable, compressed CO_2 sources for controlling the plant chamber. Cabin air typically has high CO_2 levels and technologies are sought to scavenge or adsorb cabin CO_2 from cabin air and allow careful, controlled additions of the CO_2 to the plant chamber.
- *Cultivation and Growth Systems* - Spacecraft systems are constrained to utilize minimal volume and require minimal crew time for management and operation. Future systems may even require autonomous start-up and operation prior to crew arrival. NASA seeks innovative systems for plant growth and cultivation that are volume efficient, flexible for a range of plant types and sizes (examples: tomatoes, wheat, beans, and potatoes).

Technologies should be adaptive for the entire life cycle (from seeding, to managing plant growth and spacing, through harvest), and reusable across multiple harvests. Concepts need to address integration with watering and nutrient/fertilizer systems (whether soil/media based, hydroponic, or aeroponic). Systems should address whether they are microgravity compatible, surface gravity compatible, or both.

Focus Area 7: Human Research and Health Maintenance

Lead MD: HEOMD

NASA's Human Research Program (HRP) investigates and mitigates the highest risks to astronaut health and performance in exploration missions. The goal of the HRP is to provide human health and performance countermeasures, knowledge, and technologies to enable safe, reliable, and productive human space exploration, and to ensure safe and productive human spaceflight. The scope of these goals includes both the successful completion of exploration missions and the preservation of astronaut health over the life of the astronaut. HRP developed an Integrated Research Plan (IRP) to describe the requirements and notional approach to understanding and reducing the human health and performance risks. The IRP describes the Program's research activities that are intended to address the needs of human space exploration and serve HRP customers. The Human Research Roadmap (http://humanresearchroadmap.nasa.gov) is a web-based version of the IRP that allows users to search HRP risks, gaps, and tasks.

The HRP is organized into Program Elements:

- Human Health Countermeasures.
- Human Factors and Behavioral Performance.
- Exploration Medical Capability.
- Space Radiation.
- ISS Medical Projects.

Each of the HRP Elements address a subset of the risks, with ISS Medical Projects responsible for the implementation of the research on various space and ground analog platforms. HRP subtopics are aligned with the Elements and solicit technologies identified in their respective research plans.

H12.01 Radioprotectors and Mitigators of Space Radiation-induced Health Risks (SBIR)
Lead Center: LaRC
Participating Center(s): JSC

Space radiation is a significant obstacle to sending humans on long duration missions beyond low earth orbit. NASA is concerned with the health risks to astronauts following exposures to galactic cosmic rays (GCR), the high-energy particles found outside Earth's atmosphere. Astronaut health risks from GCR are categorized into cancer, late and early central nervous systems (CNS) effects, and degenerative risks, which includes cardiovascular diseases (CVD) (see references below for more detail).

This subtopic is for biological countermeasures to minimize or prevent adverse health effects from space radiation: chronic, low dose, low dose-rate, mixed field (high LET and low LET) and mission relevant doses (0.25 to 0.5 Gy). Radioprotectors or mitigators are needed that can target common pathways (e.g., inflammation) across cancer, cardiovascular disease, and neurodegeneration. The focus of this subtopic will be to address CVD and late CNS effects through a medical countermeasure that can provide cross-risk mitigation (addressing both CVD and CNS late effects).

This subtopic will consider:

- FDA approved drugs.
- FDA Off-label usage drugs.
- FDA IND Status drugs.

Biological countermeasures under development for acute radiation syndrome or prevention of secondary radiation-induced diseases from radiation therapy may be ideal for this topic and allow the company to expand its product line to space radiation, carbon ion therapy and ground based late effects from nuclear fallout. Additionally, countermeasures must be acceptable for use as a radioprotectant in an otherwise healthy population with consideration given to safety, risks, and benefits of possible long-term usage over the course of a mission and/or post mission timeframe. Benefits should clearly outweigh risks.

The biological countermeasure criteria:

- Medical products and regimens that prevent and/or mitigate adverse health effects due to space radiation with emphasis on broad activity (i.e., multi-tissue).
- Mechanism of action well known.
- Independent of sex.
- Capable of being delivered chronically for the period of the mission (potentially up to 3 years).
- Easily administered; capable of self-administration (e.g., Oral, inhaled).
- Known/potential benefits greater than known potential risks; minimal adverse events.
- No contraindications with other drugs used for treating other symptoms or diseases during the mission.
- Long shelf-life.

Phase I will test radioprotectors or mitigators using mixed radiation fields that must include a low LET source such as gamma combined with high LET radiation such as neutrons or alpha particles to determine efficacy in mixed fields at space relevant doses. This testing can be done at the location of choice. Companies should provide a test plan that will demonstrate the compound being proposed provides protection or mitigation of radiation-induced injury for normal tissues and does not protect cancer cells. A kickoff meeting with NASA is mandatory prior to the start of this award.

Phase II will test effective radioprotectors or mitigators in space radiation simulated environments (HZE) to determine if they are able to minimize or prevent late effects directly related to the development of neurodegeneration or cardiovascular disease. Companies should provide a test plan for in vivo evaluation that describes the expected effect from the compound. Access and funding to support testing in space radiation simulated facilities will be provided for Phase II in addition to the standard award.

The following references discuss the different health effects NASA has identified as areas of concern as a result of space radiation:

- Evidence report on central nervous systems effects - https://humanresearchroadmap.nasa.gov/evidence/reports/CNS.pdf.
- Evidence report on degenerative tissue effects - https://humanresearchroadmap.nasa.gov/evidence/reports/Degen.pdf.
- Evidence report on carcinogenesis - https://humanresearchroadmap.nasa.gov/evidence/reports/Cancer.pdf.

H12.03 Crew Worn Accelerometers in Spaceflight Environment (SBIR)
Lead Center: ARC
Participating Center(s): GRC, JPL, KSC, LaRC, MSFC

NASA needs an all-in-one data collection system to record crewmember dynamics and kinematics during dynamic phases of flight including launch, pad or ascent abort, atmospheric reentry, descent, and landing. These phases of

Soyuz and Commercial vehicle flights are of particular interest due to the sustained vibration (launch), sustained accelerations (launch and reentry), transient accelerations (aborts, descent and landing), and rotational velocities (abort, descent and landing). The sensors must:

- Be self-powered with non-volatile memory (onboard data storage).
- Be able to collect at least 30 minutes of data in a 5-hour time span of launch (including time on the pad).
- Be able to sustain the stresses of launch and then be powered off for 6 months to 1 year (with the possibility of charging and off-loading launch data while in-flight).
- Be capable of collecting ≥1 hour of data in at least an 8-hour period during entry, descent, and landing (including loiter time).
- Have a customizable trigger based on timing or acceleration sensing.
- Be capable of accurately measuring and storing linear accelerations and angular velocities with sufficient temporal resolution to capture the relevant dynamics in each event (linear X, Y, Z axis; ±200g range, 0-3000Hz bandwidth, 10,000 Hz sampling rate; angular X & Z - ±2,000 rad/sec range, 0-300 Hz bandwidth, 5,000 Hz sampling rate, Y - ±5,000 rad/sec range, 0-300 Hz bandwidth, 5,000 Hz sampling rate).
- Be crew-worn without interfering with other crew-worn equipment.
- Meet SAE J211-1 and SAE J2570 specifications.

The data collected will be used to quantify crew loading during each phase of flight and improve NASA's ability to predict dynamic environments through the use of numerical simulation and models. Such sensors could be used to quantify crewmember head and neck dynamics, chest kinematics, and helmet kinematics in relation to the head and neck. These data have not been previously collected during spaceflight and are important to understanding how humans respond to the unique dynamics present in the spaceflight environment.

Focus Area 8: In-Situ Resource Utilization
Lead MD: HEOMD

In Situ Resource Utilization (ISRU) involves any hardware or operation that harnesses and utilizes 'in-situ' resources (natural and discarded) to create products and services for robotic and human exploration. ISRU encompasses a broad range of systems, and is typically divided into six focus areas: Resource Assessment, Resource Acquisition, Resource Processing/Consumable Production, In Situ Manufacturing, In Situ Construction, and In Situ Energy. ISRU products and services can be used to reduce Earth launch mass or lander mass by not bringing everything from Earth, reduce risks to the crew and/or mission by reducing logistics, increasing shielding, and providing increased self-sufficiency, or reduce costs by needing less launch vehicles to complete the mission and/or through the reuse of hardware and lander/space transportation vehicles. Since ISRU can be performed wherever resources may exist, ISRU technologies and systems may need to operate in a variety of environments and gravities, and may need to consider a wide variety of potential resource physical and mineral characteristics. This year's solicitation will focus on critical technologies needed in the areas of Resource Acquisition and Consumable Production for the Moon and Mars.

H1.01 Mars Atmosphere ISRU for Mission Consumables (SBIR)
Lead Center: JSC
Participating Center(s): ARC, GRC, JPL, KSC, MSFC

In-Situ Resource Utilization (ISRU) involves collecting and converting local resources into products that can be used to reduce mission mass, cost, and/or risk of human exploration. ISRU products that provide significant mission benefits with minimal infrastructure required are propellants, fuel cell reactants, and life support consumables. Production of mission consumables from in-situ Mars resources is enabling and critical for human exploration of the Mars surface and for minimizing the number and size of landers and the crew ascent vehicle. Innovative technologies and approaches are sought related to ISRU processes associated with collecting, separating, pressurizing, and processing gases collected from the Mars atmosphere. State of the art (SOA) technologies for these ISRU processes either do not exist, are too small of scale, or are too complex, heavy, inefficient, or consume too much power.

Specific areas of technology interest include the following:

Mars Atmosphere Collection and Separation:

- *Inlet Gas Dust Measurement* - To understand both the dust concentration before filtration as well as the effectiveness of dust filtration techniques, NASA is interested in a dust sensor to measure dust particles in the Mars atmosphere acquired for processing. Measurements need to be made in a flow of carbon dioxide (CO_2) up to 2.5 SLPM at Mars atmosphere pressure. The measurement technique should produce minimal modifications to the flow. The dust sensor needs to discriminate over a minimum of three particle sizing bins from 0.1 to 5.0 micron and detect particle concentrations from a few to hundreds of particles per cubic centimeter. The sensor needs to provide an analog or digital output to allow for remote monitoring and storage of particle counting data.
- *Rapid Cycle Adsorption Pump (RCAP)* - This process operates through adsorption and desorption of carbon dioxide (CO_2). The cycle time between absorption and desorption should be in terms of minutes to minimize adsorption material mass. To achieve this, the proposal must include the thermal management system to perform the adsorption/desorption cycle with a minimum of thermal energy loss. The proposals also must consider all the valving and an active flow device to move the Mars atmosphere through the unit during the CO_2 adsorption cycle.
- *CO_2 Freezing including active cooling (direct cryocooler or cryogenic fluid loop) and thermal management of freezing/heating that minimizes overall electrical energy* - Active cooling is required to achieve a minimum of −123° C (150) K during the freezing process. The design must state and withstand pressures potentially up to 1000 psi during CO_2 feeding.
- *Cryocooler for in-house NASA design that operates at 150 K with a thermal lift in the 200-300 W range* - The cold fingers and flanges must be capable of 1000 psi to handle the liquid CO_2 pressures. The cryocooler would also need to be able to operate under Mars conditions with cooling supplied by the lander system.
- *Separation and storage of nitrogen (N_2) from Mars atmosphere* - Two options can be considered. Option one is separation of N_2 after the CO_2 has been removed at Mars atmosphere pressures based on the use of RCAP or CO_2 Freezing. Option two is separation of N_2 after the Mars atmosphere has been compressed up to 517 KPa (75 psi).

Carbon Dioxide (CO_2) Processing:

- *Microchannel Reverse Water Gas Shift (RWGS)* - The technology must demonstrate a CO_2 conversion efficiency to >50% in a single pass before any separation and recirculation occurs. The technology proposed should include inlet/outlet gas heat exchange and reactor thermal management to minimize thermal energy losses. The proposer needs to define the design and performance aspects associated with operating pressures ranging from a nominal pressure of 103 KPa (15 psi) up to 517 KPa (75 psi).
- *Solid Oxide Electrolysis (SOE)* - The technology must demonstrate a temperature ramp rate of >15° C/min. and redox stable electrodes for the production durations and rates below. The technology must be able to electrolyze dry CO_2, water (H_2O), or a combination of both CO_2 and H_2O. The proposer needs to define the design and performance aspects associated with operating pressures ranging from a nominal pressure of 55 KPa (8 psi) up to 103 KPa (15 psi), and the design impact associated with differential pressures from inside

to outside and across the electrolyte during different phases of operation. In Phase I the technology must demonstrate ≥ 20 thermal cycles, and ≥ 70 thermal cycles for Phase II. The technology proposed should include thermal management of the SOE stack and inlet/outlet gas heat exchange to minimize thermal energy losses. Information and performance of the proposed technology in a second application as a fuel cell using previously produced oxygen and carbon monoxide is also of interest to NASA.

- *Alternative O_2 from CO_2 conversion technologies* - Besides RWGS and SOE, NASA is interested in alternative CO_2 conversion technologies as well. These technologies must exhibit >50% CO_2 to CO conversion in single pass, and the proposer must clearly state benefits in mass, power, volume, operating life, and/or complexity compared to RWGS or SOE.
- *Separation and recirculation of CO_2 from CO_2/CO streams* - Most O_2 to CO conversion processes have a significant amount of unreacted CO_2 in the exhaust stream after a single pass. NASA is interested in technologies that allow the unreacted CO_2 to be separated and recirculated back to the process inlet. RWGS and SOE reactors operate at high temperatures (>650° C) so exhaust gases may be at high temperature. The proposal must include both the recirculation pump and separation technologies required for the separation and recirculation system and define the temperatures, pressures, and separation efficiencies associated with these technologies.
- *Regenerable gas drying* - Oxygen and methane (CH_4) produced from Mars CO_2 must be dried before it is liquefied and stored. Also, hydrogen (H_2) from water electrolysis must be dried before delivery to fuel/chemical production reactors. NASA is interested in regenerable gas drying technologies that can remove water from O_2, H_2, and CH_4 streams. No service should be required for these units prior to completion of the ISRU plants operation. Recuperation of the removed water for subsequent use is highly desired.
- *Humidity Sensor for dry oxygen and methane* - Oxygen and methane produced from Mars CO_2 must be dried before it is liquefied and stored. NASA is interested in technologies for water vapor sensing down to 20 ppmv of water in oxygen and methane streams.
- *Dehydration resistant Proton Exchange Membrane (PEM) for water electrolysis and gas/water separators* - ISRU plants sent to Mars may be required to be for launch and during the cruise and landing phases before the system is activated. NASA is interested in dehydration resistant PEM materials for water electrolyzers and gas/water vapor separator membranes to allow for long term dry storage and delivery of ISRU systems.

Technology work in Phase I and hardware to be delivered at the conclusion of Phase II will be designed and built to operate under lunar polar shadowed crater and/or Mars surface environmental conditions, so thermal management during operation of the proposed technology will need to be specified in the Phase I proposal.

ISRU technologies for Mars missions must operate continuously (day and night) for very long durations (480 days) and at all possible atmosphere pressures, 700 to 1000 Pa (0.1 to 0.14 psi) and surface temperatures, which may reach a high of about 20° C (293 K) at noon, at the equator, to a low of about −153° C (120 K) at the poles, with the potential for significant temperature differences between day and night depending on the season and latitude.

The total production rate for initial human missions to Mars for ascent propellant are 2.2 kg/hour for O_2 production alone and 2.7 kg/hour oxygen and 0.68 hg/hour of methane for oxygen and fuel production. This correlates to approximately needing 6.6 kg/hr CO_2 for O_2 only and 2 kg/hr for O_2/CH_4 production. Since carbon dioxide processing may occur between 55 and 517 KPa (8 and 75 psi) and nominally at 103 KPa (15 psi) depending on the processing technology selected, proposers must state how the technology proposed changes in mass, power, volume, and complexity as a function of CO_2 delivery and process operating pressure. Proposers are allowed to consider the use of multiple units to achieve these production rates, but should justify the number of units proposed based on overall mass, power, thermal, and/or operation duration requirements. Power needed for the proposed technology operation should be differentiated between electrical and thermal, and consideration should be given on how the thermal management system and the Mars environment could minimize the need for electrical-to-thermal energy conversion. Proposals will be evaluated on mass, power, volume, complexity, and technical feasibility.

H2.01 Lunar Resources (SBIR)
Lead Center: KSC
Participating Center(s): GRC, JPL, JSC
Related Subtopic Pointer(s): S1.06, S1.07

Whereas the Moon was once thought to be dry, more recent discoveries indicate that there are a variety of resources that exist on the Moon in an embedded or frozen state in the regolith. When acquired and exposed to higher temperatures and vacuum, these resources will change state into the vapor phase and are known as volatiles. Examples are polar water ice or Hydrogen and Helium 3 embedded in the regolith grains by the sun.

Lunar volatiles are a meaningful first focus area for a space exploration strategy because:

- Use of local space resources, including lunar volatiles, for propellant, life support, etc. will improve the sustainability of human space exploration.
- Technologies and methods for accessing lunar volatiles are relevant to potential future Mars resource utilization.
- Volatiles are of great interest to the science community and provide clues to help understand the solar wind, comets, and the history of the inner solar system.

NASA is interested in this proposal solicitation for small payloads up to 5 kg in mass which are needed to characterize and map the lunar volatiles resources, so that they can be included in a future lunar ISRU strategy, as listed in selective NASA Strategic Knowledge Gaps (SKG) below. This payload may be delivered to the surface of the Moon on a small commercial lunar lander and could be stationary on the lander, mobile on a mobility device, or it may itself be mobile and/or deployable. The Phase I proposal shall indicate the type of lunar surface assets, interfaces and commodities that are required to carry and support the payload. Impactors and other devices that are used or released in lunar orbit are not within the scope of this solicitation.

The goal of this subtopic is to develop the technologies necessary for small payloads delivered to the Moon on a commercial lander to characterize and map the lunar volatiles resources. All proposals need to identify the state-of-the-art of applicable technologies and processes and Technology Readiness Level (TRL) expected at the end of Phase I, with a credible development plan. By the end of Phase I, feasibility of the proposed payload technology should be established with a notional payload packaging concept and evidence that the payload is feasible. If a Phase II is awarded, then further development of the payload technologies and payload packaging shall be required, including a payload prototype delivered to NASA at the end of the two-year project with a goal of achieving TRL 6. Due to the fact that lunar volatiles primarily exist in permanently shadowed craters, the prototype hardware proposed will need to operate under lunar vacuum conditions and either need to be designed to operate and be tested at extremely low temperatures (down to 40 K) or include estimates on thermal management and power to operate under these temperatures. Methods to collect the volatiles without significant loss to sublimation are of high interest. Proposals for innovative technologies and processes must include the design and test of critical attributes or high-risk areas associated with the proposed payload technology or process to achieve the objectives of potential SBIR Phase II proposed Lunar payload hardware. At the end of Phase II, successful payload designs will be considered for funding applied to a commercial lunar lander flight in a potential Phase III award.

Proposals will be evaluated on the basis of feasibility, mass, power, volume, and complexity. All proposals shall identify the SKG(s) from the list below that will be met. Payloads with a proposed mass of greater than 5 kg shall not be considered in this subtopic.

The following information is provided so proposers understand the context and purpose of the small payloads being solicited for a robotic lunar landing mission.

Recent data from NASA's Lunar CRater Observation and Sensing Satellite (LCROSS), and Lunar Reconnaissance Orbiter (LRO) missions indicate that as much as 20% of the material kicked up by the LCROSS impact was volatiles, including water, methane, ammonia, hydrogen gas, carbon dioxide and carbon monoxide. The instruments also discovered relatively large amounts of light metals such as sodium, mercury and possibly even silver.

The following criteria are relevant to this SBIR solicitation, as reported by the Lunar Exploration Analysis Group (LEAG):

Significant uncertainties remain regarding to the distribution of volatiles at the 10 to 100 m resolution scales accessible to near term orbital missions. Data and models are clear that volatiles are distributed unevenly at this scale and mission success scenarios should accommodate this likelihood. We also found that a range of new orbital missions and science support activities could reduce this risk by improving both the empirical data upon which site selections are based upon, and the scientific understanding of polar volatile evolution. Regarding landed experiments, there are several key measurements-- such as compositional variation and soil geotechnical and thermal properties--within the capabilities of small near-term missions that would greatly improve the understanding of polar volatiles; obtaining any of the needed quantities would benefit subsequent missions.

There are sufficient data to support near-term landing site selections – Enhanced hydrogen is widespread across the polar regions and is sometimes concentrated in permanently shadowed regions (PSRs). Data show that average annual surface temperatures below 110K are also widespread, including both PSRs and areas sometimes illuminated. This characteristic allows preservation of shallow buried ice for geologic time. LCROSS demonstrated hydrogen and water do occur at shallow depths at the LCROSS target site PSR. However, arguments derived from lunar surface processes suggest volatiles will be distributed irregularly and high water abundance observed by LCROSS was not consistent with the regional H abundance indicating sampling of a local concentration.

The expected patchy nature of hydrogen distributions constitutes significant risk to missions requiring detection and sampling of hydrogen. Higher resolution definitive hydrogen data would reduce this risk.

LEAG Volatiles Specific Action Team (SAT) Landed Measurements Finding #1
Small near-term missions can provide critical data to resolve important unknowns regarding polar volatile science and resource utilization:

- Lateral and vertical distribution of volatiles.
- Chemical phases that contain volatile elements.
- Geotechnical and thermal properties of polar soils.
- Mobility of volatiles and associated timescale(s).
    - Landed experiments obtaining any of the important quantities are of great science and exploration value.

LEAG Volatiles Specific Action Team (SAT) Landed Measurements Finding #2
Early characterization of the variation in volatile abundance at ISRU and scientifically relevant spatial scales would greatly benefit all future missions:

- Current understanding of the spatial variation of volatile abundance at the scale of landers and small rovers is a major uncertainty. This ignorance is a strong inhibitor for the use of static landers.
- Several studies suggest that near surface volatiles will be very unevenly distributed due to the impact process and other mechanisms.
- A small rover traversing several hundred meters could characterize the variation in volatiles at this scale with simple instrumentation. A rover traverse of several hundred meters to several kilometers is required. The minimum distance for ground truthing is 20 km. Minimum distance to confirm if there are volatiles present is likely to be ~1 km.
- This would provide ground-truth for orbital volatile measurements by beginning to close the gap in scales.

LEAG Volatiles Specific Action Team (SAT) Landed Measurements Finding #3
The physical and chemical forms of abundant volatile elements are critical to understanding the resource and its origins:

- Early measurements should include unambiguous determination of the chemical phase of volatiles present to a depth of one or more meters.
- Measurements should not be restricted to the detection of water, but include other volatile species.
- Profiling is desirable, but a bulk analysis would be of very high value.
- It is necessary to measure the isotopic composition of volatile elements. Both with respect to fundamental volatile science and with respect to assessing quantitatively potential landing-induced contamination of the surface materials.

LEAG Volatiles Specific Action Team (SAT) Landed Measurements Finding #4
Successful exploitation of in-situ resources requires knowledge of the physical (geotechnical) and thermal properties of polar regolith in addition to the volatile abundance:

- The utility of a resource is highly dependent on the cost of extraction that is in turn dependent on the physical and chemical state of the volatile and its refractory matrix.
- The ISRU community should develop specific measurement objectives for geotechnical and temperature dependent properties.
- Thermal analysis of polar soils such as differential scanning calorimetry would greatly enhance the ability to develop ISRU regolith processing strategies, even in a volatile poor polar target:
    - Thermal analysis can also be made sensitive to volatiles found in the LCROSS plume that could cause significant concerns for contamination and degradation of ISRU hardware including H_2S, Hg, and Na.
- Physical and thermal properties of polar regolith should be measured. The potential effect of some volatile compounds such as Hg and Na on instrument degradation should be quantified.

LEAG Volatiles Specific Action Team (SAT) Landed Measurements Finding #8
In addition to ISRU goals, landed experiments should include measurements of current volatile flux to aid understanding volatile transport mechanism:

- Apollo surface experiments revealed a dynamic exosphere and produced a lengthy list of potential volatile atmospheric species.
- Measurements might include:
    - Pressure.
    - Atmospheric species.
    - Flux directions.

- Measurements at PSR contacts to measure the volatile flux into cold traps.

The relevant lunar Strategic Knowledge Gaps (SKG's) for this subtopic are listed below:

- I-C. Regolith 2: Quality/ quantity/distribution/form of H species and other volatiles in mare and highlands regolith (requires robotic precursor missions). Robotic in-situ measurements of volatiles and organics on the lunar surface and eventual sample return of "pristine" samples. Enables prospecting for lunar resources and ISRU. Feeds forward to Near Earth Asteroids (NEA)-Mars. Relevant to the Planetary Science Decadal survey.
- I-D-1. Composition/quantity/distribution/form of water/H species and other volatiles associated with lunar cold traps. Required "ground truth" in-situ measurement within permanently shadowed lunar craters or other sites identified using LRO data. Technology development required for operating in extreme environments. Enables prospecting of lunar resources and ISRU. Relevant to Planetary Science Decadal survey.
- I-D-3 Subsection c: Geotechnical characteristics of cold traps Landed missions to understand regolith densities with depth, cohesiveness, grain sizes, slopes, blockiness, association and effects of entrained volatiles.
- I-D-7 Subsection g: Concentration of water and other volatiles species with depth 1-2 m scales Polar cold traps are likely less than ~2 Ga, so only the upper 2-3 m of regolith are likely to be volatile-rich.
- I-D-9 Subsection I: mineralogical, elemental, molecular, isotopic make up of volatiles. Water and other exotic volatile species are present; must know species and concentrations.
- I-D-10 Subsection j: Physical nature of volatile species (e.g., pure concentrations, inter-granular, globular) Range of occurrences of volatiles; pure deposits (radar), mixtures of ice/dirt (LCROSS), H_2-rich soils (neutron).
- I-E. Composition/volume/distribution/form of pyroclastic/dark mantle deposits and characteristics of associated volatiles. Required robotic exploration of deposits and sample return. Enables prospecting for lunar resources and ISRU. Relevant to Planetary Science Decadal survey.

Focus Area 9: Sensors, Detectors and Instruments

Lead MD: SMD
Participating MD(s): STTR

NASA's Science Mission Directorate (SMD) (http://nasascience.nasa.gov/) encompasses research in the areas of Astrophysics, Earth Science, Heliophysics and Planetary Science. The National Academy of Science has provided NASA with recently updated Decadal surveys that are useful to identify technologies that are of interest to the above science divisions. Those documents are available at the following locations:

- Astrophysics - http://sites.nationalacademies.org/bpa/BPA_049810.
- Planetary - http://sites.nationalacademies.org/ssb/completedprojects/ssb_065878.
- Earth Science - http://science.nasa.gov/earth-science/decadal-surveys/.
- Heliophysics the 2014 technology roadmap can be downloaded here: http://science.nasa.gov/heliophysics/.

A major objective of SMD instrument development programs is to implement science measurement capabilities with smaller or more affordable spacecraft so development programs can meet multiple mission needs and therefore make the best use of limited resources. The rapid development of small, low-cost remote sensing and in situ instruments is essential to achieving this objective. For Earth Science needs, in particular, the subtopics reflect a focus on instrument development for airborne and Unmanned Aerial Vehicle (UAV) platforms. Astrophysics has a critical need for sensitive detector arrays with imaging, spectroscopy, and polarimetric capabilities, which can be demonstrated on ground, airborne, balloon, or suborbital rocket instruments. Heliophysics, which focuses on measurements of the sun and its interaction with the Earth and the other planets in the solar system, needs a significant reduction in the size, mass, power, and cost for instruments to fly on smaller spacecraft. Planetary Science has a critical need for miniaturized instruments with in situ sensors that can be deployed on surface landers, rovers, and airborne platforms. For the 2018 program year, we are restructuring the Sensors, Detectors and Instruments Topic, adding new, rotating out, and retiring some of the subtopics. Please read each subtopic of interest carefully. We continue to emphasize Ocean Worlds and solicit development of in situ instrument technologies and components to advance the maturity of science instruments focused on the detection of evidence of life, especially extant of life, in the Ocean Worlds. The microwave technologies subtopic was split last year into two subtopics one focused on active microwave remote sensing and the second on passive systems such as radiometers and microwave spectrometers. A key objective of this SBIR topic is to develop and demonstrate instrument component and subsystem technologies that reduce the risk, cost, size, and development time of SMD observing instruments and to enable new measurements. Proposals are sought for development of components, subsystems and systems that can be used in planned missions or a current technology program. Research should be conducted to demonstrate feasibility during Phase I and show a path towards a Phase II prototype demonstration. The following subtopics are concomitant with these objectives and are organized by technology.

S1.01 Lidar Remote Sensing Technologies (SBIR)
Lead Center: LaRC
Participating Center(s): GSFC, JPL
Related Subtopic Pointer(s): Z7.01

NASA recognizes the potential of lidar technology in meeting many of its science objectives by providing new capabilities or offering enhancements over current measurements of atmospheric and topographic parameters from ground, airborne, and space-based platforms. To meet NASAs requirements for remote sensing from space, advances are needed in state-of-the-art lidar technology with an emphasis on compactness, efficiency, reliability, lifetime, and high performance. Innovative lidar subsystem and component technologies that directly address the measurement of atmospheric constituents and surface topography of the Earth, Mars, the Moon, and other planetary bodies will be considered under this subtopic. Compact, high-efficiency lidar instruments for deployment on unconventional platforms, such as balloon, small sat, and CubeSat are also considered and encouraged.

Proposals must show relevance to the development of lidar instruments that can be used for NASA science-focused measurements or to support current technology programs. Meeting science needs leads to four primary instrument types:

- *Backscatter* - Measures beam reflection from aerosols to retrieve the opacity of a gas.
- *Ranging* - Measures the return beams time-of-flight to retrieve distance.
- *Doppler* - Measures wavelength changes in the return beam to retrieve relative velocity.
- *Differential absorption* - Measures attenuation of two different return beams (one centered on a spectral line of interest) to retrieve concentration of a trace gas.

Phase I research should demonstrate technical feasibility and show a path toward a Phase II prototype unit. Phase II prototypes should be capable of laboratory demonstration and preferably suitable for operation in the field from a ground-based station, an aircraft platform, or any science platform amply defended by the proposer. For the 2018 SBIR Program, NASA is soliciting the component and subsystem technologies described below:

- Compact and rugged single-frequency continuous-wave and pulsed lasers operating between 290-nm and 2050-nm wavelengths suitable for lidar. Specific wavelengths are of interest to match absorption lines or atmospheric transmission: 290 to 320-nm (ozone absorption), 450 to 490-nm (ocean sensing), 532-nm, 817-nm (water line), 750 to 950-nm (aerosol sensing), 935-nm (water line), 1064-nm, 1570-nm (CO_2 line), 1650-nm (methane line), and 2050-nm (Doppler wind). Architectures involving new developments in diode laser, quantum cascade laser, and fiber laser technology are especially encouraged. Additionally, novel solid-state laser materials are sought for reaching infrared wavelengths of 2500-nm to 10,000-nm. For pulsed lasers two different regimes of repetition rate and pulse energies are desired: from 1-kHz to 10-kHz with pulse energy greater than 1-mJ and from 20-Hz to 100-Hz with pulse energy greater than 100-mJ.

- Optical amplifiers for increasing the energy of pulsed lasers in the wavelength range of 300-nm to 2050-nm. Also, amplifier and modulator combinations for converting continuous-wave lasers to a pulsed format are encouraged. Amplifier designs must preserve the wavelength stability and spectral purity of the input laser.
- Ultra-low noise photoreceiver modules, operating at 1600-nm or 2050-nm wavelength, consisting of the detection device, complete Dewar/cooling systems, and associated amplifiers. General requirements are: large single-element active detection diameter (>100 micron), high quantum efficiency (>85%), noise equivalent power of the order of 10^{-14} W/sqrt(Hz), and bandwidth greater than 10-MHz.
- Novel approaches and components for lidar receivers such as: new approaches for high-efficiency measurement of high spectral resolution lidar (HSRL) aerosol properties at 1064, 532 and/or 355 nm; compact and lightweight Cassegrain telescopes compatible with existing differential absorption lidar (DIAL) and HSRL lidar systems; frequency agile solar blocking filters at 817-nm and/or 935-nm, and scanners for large apertures of telescope of at least 10-cm diameter and scalable to 50-cm diameter.

S1.02 Technologies for Active Microwave Remote Sensing (SBIR)
Lead Center: JPL
Participating Center(s): GSFC

NASA employs active microwave sensors for a wide range of remote sensing applications (for example, see http://www.nap.edu/catalog/11820.html). These sensors include low frequency (less than 10 MHz) radar sounders to G-band (160 GHz) radars for measuring precipitation and clouds, for planetary landing, upper atmospheric monitoring, surface water monitoring, soil moisture and global snow coverage, topography measurement and other Earth and planetary science applications. We are seeking proposals for the development of innovative technologies to support future radar missions and applications. The areas of interest for this call are listed below.

Deployable High-Frequency Antenna Technologies for CubeSats, NanoSats or SmallSats
Novel technologies are sought that enable X, Ku, Ka, W-band deployable antennas for small spacecraft, exceeding an effective deployed area of 3U or 30 cm x 30 cm. Techniques, hardware, electronics, materials, etc. are sought to advance the state of art in deployable high-frequency antennas for CubeSats, NanoSats or SmallSats.

Deployable Low-Frequency Antenna Technologies for CubeSats, NanoSats or SmallSats
Novel technologies are sought that enable HF, VHF, UHF deployable, electrically large antennas (half-wavelength or greater) for small spacecraft. Techniques, hardware, electronics, materials, etc. are sought to advance the state of art in deployable low frequency antennas for CubeSats, NanoSats or SmallSats.

Deployable Cylindrical Parabolic Antenna:

- Up to a four square meter aperture.
- Performance up to 36 GHz desired.

SoOp (Signal of Opportunity) Power Reduction Technologies

Technology to reduce the power consumption of Signal of Opportunity (SoOp) instruments, such as a correlator ASIC with >20 MHz BW, on-board ADCs, and differential delay and Doppler compensation.

V-band Power Amplifiers:

- Frequency: 65-70 GHz.
- Output Power > 1.5W.
- Or >2W over smaller bandwidth 67-69 GHz.

Compact mm-Wave phase array (Active or Passive) for Landing/Hazard Detection:

- Mm-Wave phased array antenna design.
- Low-Power TRMs/Solid State.
- Output Power > 20 dBm.
- Beam width < 8 mrad.

Large Aperture, High Aspect Ratio Antenna Technologies for MicroSats
Novel technologies that enable antenna designs between L and X band with > 4 m^2 effective area aspect ratios > 4:1 stowing volume < 18,000 cm^3.

VHF/P-band Dual-band dual-polarization antenna elements for small satellites or CubeSats:

- Needed for signals-of-opportunity remote sensing.
- Specifications: 137 MHz and 255 MHz.
- ~10% bandwidth, dual polarization.
- Stowable in <1U.
- Deployable in zero gravity (1-G also desired).
- Gain > 0 dBi -Combine into 2-element end-fire array.

VHF/P-band Dual-band Dual-Polarization Antenna Elements for Small Satellites or CubeSats
VHF/P-band Dual-band dual-polarization antenna elements for small satellites or CubeSats are needed for signals-of-opportunity remote sensing. Specifications: 137 MHz and 255 MHz with ~10% bandwidth, dual polarization, stowable in <1U, deployable in zero gravity (1-G also desired), gain > 0 dBi. Combine into 2-element end-fire array.

Deployable Cylindrical Antennas
Deployable cylindrical parabolic antenna with up to a four square meter aperture. Performance up to 36 GHz desired.

Deployable W-band (94 GHz) antenna suitable for CubeSats and SmallSats
Aperture up to 1 square meter desired.

Surface Mount Non-Intrusive Hall Effect Current Sensor:

- Current Sensing: > 10-100 mA.
- Based on Hall Effect.
- Devices should sense current indirectly on PCB without being part of the circuit.

Technologies/Techniques for Super Resolution Radar Imaging
Hardware and algorithms required to apply physics-based super resolution techniques to acquire and/or analyze data.

S1.03 Technologies for Passive Microwave Remote Sensing (SBIR)
Lead Center: GSFC
Participating Center(s): JPL

NASA employs passive microwave and millimeter-wave instruments for a wide range of remote sensing applications from measurements of the Earth's surface and atmosphere to cosmic background emission. Proposals are sought for the development of innovative technology to support future science and exploration missions MHz to THz sensors. Technology innovations should either enhance measurement capabilities (e.g., improve spatial, temporal, or spectral resolution, or improve calibration accuracy) or ease implementation in spaceborne missions (e.g., reduce size, weight, or power, improve reliability, or lower cost). Specific technology innovations of interest are listed below, however other concepts will be entertained:

- Microwave integrated photonic components to demonstrate feasibility and utility for future microwave instruments. Components used in spectrometers, beam forming arrays, correlation arrays and other active or passive microwave instruments are sought.
- A focal plane array antenna design to enable large aperture microwave radiometers (e.g., 6 meters operating at 37 GHz), conical scanning reflector antennas fed by focal plane arrays are needed. Designs are desired for 4,6, or 12-meter apertures operating at 36.5 GHz and 18.7/23.8 GHz.
- Low power RFI mitigating receiver back ends for broad band microwave radiometers. NASA requires a low power, low mass, low volume, and low data rate RFI mitigating receiver back-end that can be incorporated into existing and future radiometer designs. The system should be able to channelize up to 1 GHz with 16 sub bands and be able to identify RFI contamination using tools such as kurtosis.
- Calibration Targets for water vapor radiometers operating in the frequency range from 18 to 37 GHz. Return loss of > 40 dB and relative emission characterized over physical temperature to 0.1%.
- Components for addressing gain instability in LNA based radiometers from 100 and 600 GHz. NASA requires low insertion loss solutions to the challenges of developing stable radiometers and spectrometers operating above 100 GHz that employ LNA based receiver front ends. This includes noise diodes with ENR>10dBm with better than ≤ 0.01 dB/° C thermal stability, Dicke switches with better than 30 dB isolation, phase modulators, and low loss isolators along with fully integrated state-of-art receiver systems operating at room and cryogenic temperatures.
- Technology for low-power, rad-tolerant broad band spectrometer back ends for microwave radiometers. Includes: digitizers starting at 20 Gsps, 20 GHz bandwidth, 4 or more bit and simple interface to FPGA; ASIC implementations of polyphase spectrometer digital signal processing with ~1 Watt/GHz.
- 5-GHz bandwidth polarimetric-spectrometer with 512 channels. Two simultaneously sampled ADC inputs. Spectrometer filterbanks and either polarization combiners or cross correlators for computing all four Stokes parameters (any Stokes vector basis is acceptable: e.g., IQUV, vhUV, vhpmlr). Kurtosis detectors on at least the two principal channels. Rad-hard and minimized power dissipation.
- Local Oscillator technologies for THz instruments. This can include: GaN based frequency multipliers that can work in the 200-400 with better than 30% efficiency GHz range (output frequency) with input powers up to 1 W. Graphene based devices that can work as frequency multipliers in the frequency range of 1-3 THz with efficiencies in the 10% range and higher.
- Low DC power correlating radiometer front-ends and low 1/f-noise detectors for 100-700 GHz. Correlating radiometers and low 1/f-noise tunnel diode detectors have been demonstrated at frequencies below 100 GHz. 180 GHz correlating radiometer with high DC power LO system demonstrated.
- A radiometer-on-a-chip of either a switching or pseudo-correlation architecture with internal calibration sources is needed. Designs with operating frequencies at the conventional passive microwave bands of 36.6 GHz (priority) and 19.7/22.3 GHz enabling dual-polarization inputs. Interfaces include, waveguide input,

power, control, and digital data output. Design features allowing subsystems of multiple (10's of) integrated unites to be efficiently realized.

- GaAs based Schottky diode with low junction capacitance and finger inductance to operate in the 2-5 THz. The diodes should be integrated with waveguide coupling probes and other circuitries to develop 2-5 THz harmonic-mixers with low conversion loss and noise temperature.

S1.04 Sensor and Detector Technology for Visible, IR, Far IR and Submillimeter (SBIR)
Lead Center: JPL
Participating Center(s): ARC, GSFC, LaRC
Related Subtopic Pointer(s): S2.01, S2.04

NASA is seeking new technologies or improvements to existing technologies to meet the detector needs of future missions, as described in the most recent decadal surveys:

- Earth science - (http://www.nap.edu/catalog/11820.html).
- Planetary science - (http://www.nap.edu/catalog/10432.html).
- Astronomy and astrophysics - (http://www.nap.edu/books/0309070317/html/).

In pixel digital readout integrated circuit (DROIC) for high dynamic range infrared focal plane arrays to circumvent the limitations in charge well capacity, by using in-pixel digital counters that can provide orders of magnitude larger effective well depth, thereby affording longer integration times. Longer integration times provide improved signal-to-noise ratio and/or higher operating temperature, which reduces cooler capacity, resulting in savings in size, weight, power and cost.

Compact, low power, ASICs for readout of Kinetic Inductance Detector arrays **each with a low operating power and capable of operation at both room temperature and cryogenic temperatures to perform one of the following functions.**

- 8192 point FFT processor with 5 bits of depth using a polyphase oversampling or a Hanning window. Input format would be SERDES (2-4Gsamples/sec) and output format USB2.0 or similar and Power <=2W.
- >10bit ADC at >1GHz sampling rate with >2000 bands, ~5kHz bandwidth, power <0.3W.

Two-dimensional row and column, cryogenic, multiplexing readout system for hybridization to two dimensional Far IR and Submillimeter bolometer arrays. Of particular interest are SQUID based systems with a first stage operating at sub-Kelvin temperatures and compatible with 32X40 detector array format.

New or improved technologies leading to measurement of trace atmospheric species (e.g., CO, CH_4, N_2O) or broadband energy balance in the IR and far-IR from geostationary and low-Earth orbital platforms. Of particular interest are new direct detectors or heterodyne detectors technologies made using high temperature superconducting films (YBCO, MgB_2) or engineered semiconductor materials, especially 2Dimensional Electron Gas (2DEG) and Quantum Wells (QW). Candidate missions are thermal imaging, LANDSAT Thermal InfraRed Sensor (TIRS), Climate Absolute Radiance and Refractivity Observatory (CLARREO), BOReal Ecosystem Atmosphere Study (BOREAS), Methane Trace Gas Sounder or other infrared earth observing missions.

Development of a robust wafer-level integration technology that will allow high-frequency capable interconnects and allow two dis-similar substrates (i.e., Silicon and GaAs) to be aligned and mechanically 'welded' together. Specially develop ball grid and/or Through Silicon Via (TSV) technology that can support submillimeter-wave arrays. Initially the technology can be demonstrated at 1-inch die level but should be do-able at 4-inch wafer level.

Single photon avalanche diode or silicon photomultiplier photon-counting detector technology for high-speed, non-imaging lidar applications. Detector(s) (single or array) to provide ≥ 10E10 ph/s linear counting dynamic range, < 5x10E5 dark count rate at non-cryogenic temperatures, > 30% detection efficiency at 532 nm.

Space qualify a commercial 2k x 2k polarization camera for a solar coronograph for low Earth orbit and Earth-Sun lagrange point environments.

Higher power THz local oscillators and backend electronics for high resolution spectroscopy for astrophysics. Local Oscillator capable of spectral coverage 2-5 THz; Output power up to >2 mW; Frequency agility with > 1GHz near chosen THz frequency; Continuous phase-locking ability over the THz laser tunable range with <100 kHz line width. Backend ASIC capable of binning >1GHz intermediate frequency bandwidth into 0.1-0.5 MHz channels with low power dissipation <0.5W.

Development of an un-cooled broadband photon detector with average QE>50% over the spectral range from 3um to 50um. The Detectivity D* must be greater than $5x10^9$. The detector may have electrically tunable spectral range.

S1.05 Detector Technologies for UV, X-Ray, Gamma-Ray and Cosmic-Ray Instruments (SBIR)
Lead Center: JPL
Participating Center(s): GSFC, MSFC

This subtopic covers detector requirements for a broad range of wavelengths from UV through to gamma ray for applications in Astrophysics, Earth Science, Heliophysics, and Planetary Science. Requirements across the board are for greater numbers of readout pixels, lower power, faster readout rates, greater quantum efficiency, and enhanced energy resolution.

The proposed efforts must be directly linked to a requirement for a NASA mission. These include Explorers, Discovery, Cosmic Origins, Physics of the Cosmos, Solar-Terrestrial Probes, Vision Missions, and Earth Science Decadal Survey missions. Details of these can be found at the following URLs:

- General Information on Future NASA Missions - (http://www.nasa.gov/missions).
- Future planetary programs - (https://solarsystem.nasa.gov/2013decadal/).
- Earth Science Decadal missions - (http://www.nap.edu/catalog/11820.html).
- Helio Probes - (http://solarsystem.nasa.gov/2013decadal/).
    - https://solar-orbiter.cnes.fr/en/SOLO/GP_spice.htm.
    - http://foxsi.ssl.berkeley.edu/.
- X-ray Astrophysics - (http://sites.nationalacademies.org/bpa/BPA_049810).
    - http://wwwastro.msfc.nasa.gov/xrs/.
    - http://x-ifu.irap.omp.eu/.

Specific technology areas are:

- Significant improvement in wide band gap semiconductor materials, such as AlGaN, ZnMgO and SiC, individual detectors, and detector arrays for operation at room temperature or higher for missions such as GEO-CAPE, NWO, ATLAST and planetary science composition measurements.
- Highly integrated, low noise (< 300 electrons rms with interconnects), low power (< 100 uW/channel) mixed signal ASIC readout electronics as well as charge amplifier ASIC readouts with tunable capacitive inputs to match detector pixel capacitance. See needs of National Research Council's Earth Science Decadal Survey

(NRC, 2007): Future Missions include GEO-CAPE, HyspIRI, GACM, future GOES and SOHO programs and planetary science composition measurements.
- Visible-blind SiC Avalanche Photodiodes (APDs) for EUV photon counting are required. The APDs must show a linear mode gain >10E6 at a breakdown reverse voltage between 80 and 100V. The APD's must demonstrate detection capability of better than 6 photons/pixel/s down to 135nm wavelength. See needs of National Research Council's Earth Science Decadal Survey (NRC, 2007): Tropospheric ozone.
- Visible-blind UV and EUV detectors with small (< 10 ¼m) pixels, large format, photon-counting sensitivity and detectivity, low voltage and power requirements, and room-temperature operation suitable for mission concepts such as the EUV Spectrograph on the ESA-NASA Solar Orbiter.
- Large area (3 m^2) photon counting near-UV detectors with 3 mm pixels and able to count at 10 MHz. Array with high active area fraction (>85%), 0.5 megapixels and readout less than 1 mW/channel. Future instruments are focal planes for JEM-EUSO and OWL ultra-high energy cosmic ray instruments and ground Cherenkov telescope arrays such as CTA, and ring-imaging Cherenkov detectors for cosmic ray instruments such as BESS-ISO. As an example, (JEM-EUSO and OWL), imaging from low-Earth orbit of air fluorescence, UV light generated by giant air showers by ultra-high energy (E >10E19 eV) cosmic rays require the development of high sensitivity and efficiency detection of 300-400 nm UV photons to measure signals at the few photon (single photo-electron) level. A secondary goal minimizes the sensitivity to photons with a wavelength greater than 400 nm. High electronic gain (10E4 to 10E6), low noise, fast time response (<10 ns), minimal dead time (<5% dead time at 10 ns response time), high segmentation with low dead area (<20% nominal, <5% goal), and the ability to tailor pixel size to match that dictated by the imaging optics. Optical designs under consideration dictate a pixel size ranging from approximately 2 x 2 mm^2 to 10 x 10 mm^2. Focal plane mass must be minimized (2g/cm^2 goal). Individual pixel readout is required. The entire focal plane detector can be formed from smaller, individual sub-arrays.
- Neutral density filter for hard x-rays (> 1 keV) to provide attenuation by a factor of 10 to 1000 or more. The filter must provide broad attenuation across a broad energy range (from 1 keV to ~100 keV or more) with a flat attenuation profile of better than 20%.
- Solar X-ray detectors with small independent pixels (< 250 ¼m) and fast read-out (>10,000 count/s/pixel) over an energy range from < 5 keV to 300 keV.
- Proposals that address the development of supporting technologies that would help enable X-ray Surveyor mission that requires the development of X-ray microcalorimeter arrays with much larger field of view, ~10^5-10^6 pixels, of pitch ~ 25-100 µm, and ways to read out the signals. For example, modular superconducting magnetic shielding is sought that can be extended to enclose a full scale focal plane array. All joints between segments of the shielding enclosure must also be superconducting.
- For missions such as ATHENA X-IFU and X-ray Surveyor, improved long-wavelength blocking filters are needed for large-area, x-ray microcalorimeters. Filters with supporting grids are sought that, in addition to increasing filter strength, also enhance EMI shielding (1 - 10 GHz) and thermal uniformity for decontamination heating. X-ray transmission of greater than 80% at 600 eV per filter is sought, with infrared transmissions less than 0.01% and ultraviolet transmission of less than 5% per filter. Means of producing filter diameters as large as 10 cm should be considered.

S1.06 Particles and Field Sensors and Instrument Enabling Technologies (SBIR)
Lead Center: GSFC
Participating Center(s): JPL, MSFC
Related Subtopic Pointer(s): H2.01

While the size distribution of matter in space that ranges from large-scale (planets – moons – asteroids – dust) objects is quite well characterized down to micron-sized dust particles, below that there is a significant, largely unobserved gap down to single ions/electrons/ENAs. To cover the observational gap between 10^{-6}m and 10^{-10}m in particle size that includes nano-dust and molecules in space, new technology investment is needed. Advanced sensors for the detection of elementary particles (atoms, molecules and their ions) and electric and magnetic fields in space and associated instrument technologies are often critical for enabling transformational science from the study of the sun's outer corona, to the solar wind, to the trapped radiation in Earth's and other planetary magnetic fields, and to the atmospheric composition of the planets and their moons. Improvements in particles and fields sensors and associated instrument technologies enable further scientific advancement for upcoming NASA missions such as CubeSats, Explorers, STP, LWS, and planetary exploration missions. Technology developments that result in a reduction in size, mass, power, and cost will enable these missions to proceed. Of interest are advanced magnetometers, electric field booms, ion/atom/molecule detectors, dust particle detectors, and associated support electronics and materials. Specific areas of interest include:

- High Voltage Optocoupler / Optoisolator or isolation transformers:
    - Science Traceability: Explorer missions, Decadal survey missions IMAP, MEDICI, GDC, DYNAMICS, DRIVE Initiative, DISCOVERY, New Frontiers, and CubeSat, SmallSat missions, Sub-orbitals.
    - Need Horizon: 1 to 3 years, 3 to 5 years.
    - Low energy particle instruments often require significant high voltage in the range 5KV to 20KV. Floating the electronics is an attractive for low noise. A high reliability radiation hardened device for transferring power, signal and commands across a high voltage is a very useful component. Typical specifications 3.3V and 5V up to 1A, speed up to 1MHz, -55° C to +85° C, and 300 krads.
    - Importance: High – Critical need for next generation particle instruments.
- Curved microchannel plates (MCPs):
    - Science Traceability: Explorer missions, Decadal survey missions IMAP, MEDICI, GDC, DYNAMICS, DRIVE Initiative, DISCOVERY, New Frontiers, and CubeSat, SmallSat missions, Sub-orbitals.
    - Need Horizon: 1 to 3 years.
    - It is highly desirable for MCP channel angles to match MCP curvature. This will make MCP gain and imaging quality independent of incident particle angle. This property will be very useful for particle imaging instruments using MCPs.
    - Importance: Very High for future flagship and Cubesat and SmallSat missions.
- Micro machined particle collimators:
    - Explorer missions, Decadal survey missions IMAP, MEDICI, GDC, DYNAMICS, DRIVE Initiative, DISCOVERY, New Frontiers, and CubeSat, SmallSat missions, Sub-orbitals.
    - Need Horizon: 1 to 3 years, 3 to 5 years.
    - State of art: Light weight vibration reliable, particle collimators from thin metal or other material with FOV to be made in the range of 2dex2 deg to 20x20 deg with physics transparency >=70.
    - Importance: High: Critical need for next generation particle instruments.

S1.07 In Situ Instruments/Technologies for Planetary Science (SBIR)
Lead Center: JPL
Participating Center(s): ARC, GRC, GSFC, MSFC
Related Subtopic Pointer(s): H2.01

This subtopic solicits development of advanced instrument technologies and components suitable for deployment on in-situ planetary missions. These technologies must be capable of withstanding operation in space and planetary environments, including the expected pressures, radiation levels, launch and impact stresses, and range of survival and operational temperatures. Technologies that reduce mass, power, volume, and data rates for instruments and instrument components without loss of scientific capability are of particular importance. In addition, technologies that can increase instrument resolution and sensitivity or achieve new & innovative scientific measurements are solicited.

For example missions, see http://www.nasa.gov/missions. For details of the specific requirements see the National Research Council's, Vision and Voyages for Planetary Science in the Decade 2013-2022 (http://solarsystem.nasa.gov/2013decadal/). Technologies that support NASA's New Frontiers and Discovery missions to various planetary bodies are of top priority.

In-situ technologies are being sought to achieve much higher resolution and sensitivity with significant improvements over existing capabilities. In-situ technologies amenable to CubeSats and SmallSats are also being solicited. Atmospheric probe sensors and technologies that can provide significant improvements over previous missions are also sought. Specifically, this subtopic solicits instrument development that provides significant advances in the following areas, broken out by planetary body:

- *Mars* - Sub-systems relevant to current in-situ instrument needs (e.g., lasers and other light sources from UV to microwave, X-ray and ion sources, detectors, mixers, mass analyzers, etc.) or electronics technologies (e.g., FPGA and ASIC implementations, advanced array readouts, miniature high voltage power supplies). Technologies that support high precision in-situ measurements of elemental, mineralogical, and organic composition of planetary materials are sought. Conceptually simple, low risk technologies for in-situ sample extraction and/or manipulation including fluid and gas storage, pumping, and chemical labeling to support analytical instrumentation. Seismometers, mass analyzers, technologies for heat flow probes, and atmospheric trace gas detectors. Improved robustness and g-force survivability for instrument components, especially for geophysical network sensors, seismometers, and advanced detectors (iCCDs, PMT arrays, etc.). Instruments geared towards rock/sample interrogation prior to sample return are desired.
- *Venus* - Sensors, mechanisms, and environmental chamber technologies for operation in Venus's high temperature, high-pressure environment with its unique atmospheric composition. Approaches that can enable precision measurements of surface mineralogy and elemental composition and precision measurements of trace species, noble gases and isotopes in the atmosphere are particularly desired.
- *Small Bodies* - Technologies that can enable sampling from asteroids and from depth in a comet nucleus, improved in-situ analysis of comets. Imagers and spectrometers that provide high performance in low light environments. Dust environment measurements & particle analysis, small body resource identification, and/or quantification of potential small body resources (e.g., oxygen, water and other volatiles, hydrated minerals, carbon compounds, fuels, metals, etc.). Advancements geared towards instruments that enable elemental or mineralogy analysis (such as high-sensitivity X-ray and UV-fluorescence spectrometers, UV/fluorescence systems, scanning electron microscopy with chemical analysis capability, mass spectrometry, gas chromatography and tunable diode laser sensors, calorimetry, imaging spectroscopy, and LIBS) are sought.
- *Saturn, Uranus and Neptune* - Components, sample acquisition, and instrument systems that can enhance mission science return and withstand the low-temperatures/high-pressures of the atmospheric probes during entry.
- *The Moon* - Note that there is one subtopic, "Lunar Resources (H2.01)" in the HEOMD list. The emphasis of that subtopic is on in-situ resource utilization (ISRU). All proposers are encouraged to submit any proposal related to ISRU to the HEOMD subtopic. However, proposals with pure science objectives and without ISRU application may be submitted to this SMD subtopic. One example is a seismometer.

Proposers are strongly encouraged to relate their proposed development to:

- NASA's future planetary exploration goals.
- Existing flight instrument capability, to provide a comparison metric for assessing proposed improvements.

Proposed instrument architectures should be as simple, reliable, and low risk as possible while enabling compelling science. Novel instrument concepts are encouraged particularly if they enable a new class of scientific discovery.

Technology developments relevant to multiple environments and platforms are also desired.

Proposers should show an understanding of relevant space science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.

S1.08 In-situ Sensors and Sensor Systems for Earth Science (SBIR)
Lead Center: LaRC
Participating Center(s): ARC, GSFC, JPL

NASA seeks measurement capabilities that support current satellite and model validation as well as targeted airborne science program field campaign activities as discussed in the ROSES solicitation. Data from such sensors not only validates models, but informs process studies, and is used to improve models. Topics include air quality, aerosol absorption and optical properties (e.g., brown carbon), and cloud probes suitable for discriminating and characterizing ice and liquid particles in super-cooled and mixed-phase clouds.

In-situ sensor systems can comprise stand-alone instrument and data packages; instrument systems configured for integration on NASA's Airborne Science aircraft fleet or commercial providers, UAS, or balloons, ground networks; or end-to-end solutions providing needed data products from mated sensor and airborne/surface/subsurface platforms. An important goal is to create sustainable measurement capabilities to support NASA's Earth science objectives, with infusion of new technologies and systems into current/future NASA research programs. Instrument prototypes as a deliverable in Phase II proposals and/or field demonstrations are encouraged.

Complete instrument systems are desired, including features such as remote/unattended operation and data acquisition, and minimum size, weight, and power consumption. Desired sensors or mated platform/sensors include:

- Spectrally resolved absorption and extinction of atmospheric aerosols (size 0.1 to 10 micron).
- Aerosol scattering as a function of scattering angle (phase function).
- Aerosol refractive index.
- Aerosols and cloud particle number and size distribution covering the diameter size range of 0.01 micron to 200 micron with 10% accuracy. Probes targeting cloud particles in the lower end of this size range (0.01-5 micron) are particularly encouraged.
- Cloud probes able to differentiate and quantify non-sphericity and phase of particles.
- Liquid and ice water content in clouds with calibrated accuracy and precision.
- Spectrally resolved cloud extinction.
- Static air temperature to better than 0.1° C accuracy.
- Liquid and ice water path, precipitable water path.
- Ice nucleating particle (INP) concentration suitable for airborne deployment.
- Innovative, high-value sensors directly targeting a stated NASA need may also be considered.

S1.09 Cryogenic Systems for Sensors and Detectors (SBIR)
Lead Center: GSFC
Participating Center(s): ARC, JPL, MSFC
Related Subtopic Pointer(s): T13.01

Cryogenic cooling systems often serve as enabling technologies for detectors and sensors flown on scientific instruments as well as advanced telescopes and observatories. As such, technological improvements to cryogenic systems further advance the mission goals of NASA through enabling performance (and ultimately science gathering) capabilities of flight detectors and sensors. There are four potential investment areas that NASA is seeking to expand state of the art capabilities for possible use on future programs such as the Europa Jupiter System Science missions (http://www.nasa.gov/multimedia/podcasting/jpl-europa20090218.html), and flagship missions under consideration for the 2020 Astrophysics Decadal Survey (http://cor.gsfc.nasa.gov/docs/PCOS_facility_missions_report_final.pdf). The topic areas are:

Cryocooler Systems and Components:

- *Miniaturized/Efficient Cryocooler Systems* - Cryocooler systems are sought for application on SmallSat and small low power instrument space platforms. Present state-of-the-art capabilities provide 0.4 W of cooling at 77 K with approximately 5 W input power, while rejecting heat at 300 K, and having a system mass of 400 grams. Desired performance specifications for cryocoolers include a cooling capability on the order of 0.2 W at a temperature of approximately 30 K. For application on missions to outer planets, cryocoolers are needed with a cooling power of 0.3 W at approximately 35 K, with a heat rejection temperature as low as 150 K. Desired masses and input powers in both cases are < 400 grams and < 5W respectively. Component level improvements are also desirable.
- *Low Temperature/High Efficiency Cryocoolers* - High efficiency, multi-stage coolers with a low temperature stage capable of reaching 4 to 10 K will be needed for future astrophysics missions. Current state-of-the-art coolers include a device providing 0.04 W at 4.5 K and another providing 0.09 W at 6 K. Cryocoolers are sought that provide higher cooling power, for example >0.3 W at 10 K and ~ 200 mW at 4 K, with high efficiency. Devices that produce extremely low vibration, particularly at frequencies below a few hundred Hz are of special interest. Component level improvements are also desirable.
- *Cryogenic/Rad-Hard Accelerometers* - Accelerometers that can operate at 150 K, withstand a 0.01 Tesla magnetic field and are radiation hard to mega-rad level doses are needed for cryocooler control and monitoring in missions to outer planets.

Sub-Kelvin Cooling Systems:

- *Magnetic Cooling Systems* - Sub-Kelvin cooling systems include Adiabatic Demagnetization Refrigerators (ADRs) and Active Magnetic Regenerative Refrigerators (AMRRs). The ADR in the Soft X-ray Spectrometer instrument on the Hitomi mission represents the state of the art in sub-Kelvin cooling systems for space application. Future missions requiring sub-Kelvin coolers will need devices that provide lower operating temperature (<50 mK), higher (preferably 100%) duty cycle, higher heat rejection temperature (preferably > 10K), higher overall system efficiency, and lower mass. Improvements at the component level are needed to achieve these goals. Specific components sought include:
    - Compact, lightweight, low current superconducting magnets capable of producing a field of at least 4 Tesla while operating at a temperature of at least 10 K, and preferably above 15 K. Desirable properties include:
        - A high engineering current density, preferably > 300 Amp/mm^2.
        - A field/current ratio of >0.33 Tesla/Amp, and preferably >0.66 Tesla/Amp.
        - Low hysteresis heating.

- Lightweight Active/Passive magnetic shielding (for use with 4 Tesla magnets) with low hysteresis and eddy current losses, and low remanence.
- Heat switches with on/off conductance ratio > 3 10^4 and actuation time of <10 s. Materials are also sought for gas gap heat switch shells: these are tubes with extremely low thermal conductance below 1 K; they must be impermeable to helium gas, have high strength, including stability against buckling, and have an inner diameter > 20 mm.
- High cooling power density magnetocaloric materials, especially single crystals with volume > 20 cm^3.
- Superconducting leads (10K - 90K) capable of 10 A operation with 1 mW conduction.
- 10 mK- 300 mK high resolution thermometry.
- Proposals considered viable for Phase I award will seek to validate hypotheses through proof of concept testing at relevant temperatures.

S1.10 Atomic Interferometry (SBIR)
Lead Center: GSFC
Participating Center(s): JPL

Recent developments of laser control and manipulation of atoms have led to new types of precision inertial force and gravity sensors based on atom interferometry. Atom interferometers exploit the quantum mechanical wave nature of atomic particles and quantum gases for sensitive interferometric measurements. Ground-based laboratory experiments and instruments have already demonstrated beyond the state of the art performances of accelerometer, gyroscope, and gravity measurements. The microgravity environment in space provides opportunities for further drastic improvements in sensitivity and precision. Such inertial sensors will have great potential to provide new capabilities for NASA Earth and planetary gravity measurements, for spacecraft inertial navigation and guidance, and for gravitational wave detection and test of properties of gravity in space.

Currently the most mature development of atom interferometers as measurement instruments are those based on light pulsed atom interferometers with freefall cold atoms. There remain a number of technical challenges to infuse this technology in space applications. Some of the identified key challenges are (but not limited to):

- Compact high flux ultra-cold atom sources for free space atom interferometers (Example: >1x106 total useful free-space atoms, <1 nK, Rb, K, Cs, Yb, Sr, and Hg. Performance and species can be defined by offerors). Other related innovative methods and components for cold atom sources are of great interest, such as a highly compact and regulatable atomic vapor cell.
- Ultra-high vacuum technologies that allow completely sealed, non-magnetic enclosures with high quality optical access and the base pressure maintained <$1x10^{-9}$ torr. Consideration should be given to the inclusion of cold atom sources of interest.
- Beyond the state-of-the-art photonic components at wavelengths for atomic species of interest, particularly at NIR and visible: efficient acousto-optic modulators (low RF power d ~ 200 mW, low thermal distortion, ~80% or greater diffraction efficiency); efficient electro-optic modulators (low bias drift, residual AM, and return loss, fiber-coupled preferred), miniature optical isolators (~30 dB isolation or greater, ~ -2 dB loss or less), robust high-speed high-extinction shutters (switching time < 1 ms, extinction > 60 dB are highly desired).
- Flight qualifiable lasers or laser systems of narrow linewidth, high tunability, and/or higher power for clock and cooling transitions of atomic species of interest. Cooling and trapping lasers: 10 kHz linewidth and ~ 1 W or greater total optical power. Compact clock lasers: $5x10^{-15}$ Hz/τ1/2 near 1 s (wavelengths for Yb+, Yb, Sr clock transitions are of special interest).

- Analysis and simulation tool of a cold atom system in trapped and freefall states relevant to atom interferometer and clock measurements in space.

All proposed system performances can be defined by offerors with sufficient justification. Subsystem technology development proposals should clearly state the relevance, define requirements, relevant atomic species and working laser wavelengths, and indicate its path to a space-borne instrument.

S1.11 In Situ Instruments/Technologies and Sample Processing for Ocean Worlds Life Detection (SBIR)
Lead Center: JPL
Participating Center(s): ARC, GRC, GSFC, MSFC
Related Subtopic Pointer(s): S4.02, S4.04, S4.05

This subtopic solicits development of in-situ instrument technologies and components to advance the maturity of science instruments focused on the detection of evidence of life, especially extant of life, in the Ocean Worlds (e.g., Europa, Enceladus, Titan, Ganymede, Callisto, Ceres, etc.). These technologies must be capable of withstanding operation in space and planetary environments, including the expected pressures, radiation levels, launch and impact stresses, and range of survival and operational temperatures. Technologies that reduce mass, power, volume, and data rates for instruments and instrument components without loss of scientific capability are of particular importance. In addition, technologies that can increase instrument resolution and sensitivity or achieve new & innovative scientific measurements are solicited.

In addition, this subtopic solicits development of innovative sample processing technologies (methodologies and hardware) for the purposes of improving the resolution and sensitivity of life detection measurements and supporting habitability assessment of environmental samples from Ocean Worlds (e.g., Europa, Enceladus, Titan, etc.). Samples are expected to contain water, minerals, salts, etc. that may complicate measurements or interfere with interpretations. Thus, samples are expected to require separation of components as a preparatory step to analysis. Analytes of interest (e.g., organic molecules including biomolecules, cells, and inorganic solutes and particulates) in samples may also be too dilute and could escape detection unless concentration technologies are applied as a preparatory step. These technologies must be capable of operation under space and planetary conditions, including the extreme pressures, temperatures, radiation levels, stress from launch and impact. Technologies should be of low mass, power, volume; capable of radiation-hardening and sterilization; and require low data rates. Technologies that minimize biological and analytical contamination of the sample stream in order to meet planetary protection requirements and can maintain sample integrity for mission-science investigations and support integration of contamination and/or analyte monitoring are solicited.

For synergistic NASA technology solicitation, see ROSES 2016/C.20 Concepts for Ocean worlds Life Detection Technology (COLDTECH) call:

- https://nspires.nasaprs.com/external/solicitations/summary.do?method=init&solId=%7B5C43865B-0C93-6ECA-BCD2-A3783CB1AAC8%7D&path=init.

Specifically, this subtopic solicits instrument technologies and components that provide significant advances in the following areas, broken out by planetary body:

- *Europa, Enceladus, Titan and other Ocean Worlds in general* - Technologies and components relevant to life detection instruments (e.g., microfluidic analyzer, MEMS chromatography/mass spectrometers, laser-ablation mass spectrometer, fluorescence microscopic imager, Raman spectrometer, tunable laser system, liquid chromatography/mass spectrometer, X-ray fluorescence, digital holographic microscope-fluoresce microscope, Antibody microarray biosensor, nanocantilever biodetector etc.) Technologies for high radiation environments, e.g., radiation mitigation strategies, radiation tolerant detectors, and readout electronic components, which enable orbiting instruments to be both radiation-hard and undergo the planetary protection requirements of sterilization (or equivalent).

- *Technologies and components relevant to sample processing of water and ice samples from plumes, surface ice, subsurface ice, or sub-ice waters* - Examples of such technologies include, but are not limited to: sonic processing; subcritical and critical solvent extraction; solid-phase extraction; cell isolation, concentration, and lysing; filtering, separation by osmosis and dialysis; chemical hydrolysis and derivatization; novel substrates or adaptives to enhance sensitivity or selectivity of target analytes; total organic carbon, pressure, temperature, pH, eH, dissolved ion monitoring and regulation components; miniaturized components such as microfluidic valves and pumps; and other fluid and solid handling systems following separation and concentration processing components).
- *Europa* - Life detection approaches optimized for evaluating and analyzing the composition of ice matrices with unknown pH and salt content. Instruments capable of detecting and identifying organic molecules (in particular biomolecules), salts and/or minerals important to understanding the present conditions of Europa's ocean are sought (such as high-resolution gas chromatograph or laser desorption mass spectrometers, dust detectors, organic analysis instruments with chiral discrimination, etc.). These developments should be geared towards analyzing and handling very small sample sizes (mg to mg) and/or low column densities/abundances. Also of interest are imagers and spectrometers that provide high performance in low-light environments (visible and NIR imaging spectrometers, thermal imagers, etc.), as well as instruments capable of providing improving our understanding Europa's habitability by characterizing the ice, ocean, and deeper interior and monitoring ongoing geological activity such as plumes, ice fractures, and fluid motion (e.g., seismometers, magnetometers). Improvements to instruments capable of gravity (or other) measurements that might constrain properties such as ocean and ice shell thickness will also be considered.
- *Sample-processing approaches optimized for particulate, inorganic chemicals, and organic molecules of possible biological origin in aerosols and surface materials* - Mechanical and electrical components and subsystems that work in cryogenic (95 K) and hydrocarbon-rich environments; sample extraction from liquid methane/ethane and/or hydrogen cyanide, sampling from organic 'dunes' at 95 K and robust sample preparation and handling mechanisms that feed into spectral and mass analyzers, as well as X-ray detection devices are solicited.
- *Enceladus* - Life detection approaches optimized for analyzing plume particles, as well as for determining the chemical state of Enceladus' icy surface materials (particularly near plume sites). Instruments capable of detecting and identifying organic molecules (in particular biomolecules), salts and/or minerals important to understand the present conditions of the Enceladus ocean are sought (such as high resolution gas chromatograph or laser desorption mass spectrometers, dust detectors, organic analysis instruments with chiral discrimination, etc.). These developments should be geared towards analyzing and handling very small sample sizes (mg to mg) and/or low column densities/abundances. Also of interest are imagers and spectrometers that provide high performance in low-light environments (visible and NIR imaging spectrometers, thermal imagers, etc.), as well as instruments capable of monitoring the bulk chemical composition and physical characteristics of the plume (density, velocity, variation with time, etc.). Improvements to instruments capable of gravity (or other) measurements that might constrain properties such as ocean and ice shell thickness will also be considered.
- *Titan* - Life detection approaches optimized for searching for biosignatures and biologically relevant compounds in Titan's lakes, including the presence of diagnostic trace organic species, and also for analyzing Titan's complex aerosols and surface materials. Mechanical and electrical components and subsystems that work in cryogenic (95 K) environments; sample extraction from liquid methane/ethane, sampling from organic 'dunes' at 95 K and robust sample preparation and handling mechanisms that feed into mass analyzers are sought. Balloon instruments, such as IR spectrometers, imagers, meteorological instruments, radar sounders, solid, liquid, air sampling mechanisms for mass analyzers, and aerosol detectors are also solicited.

Low mass and power sensors, mechanisms and concepts for converting terrestrial instruments such as turbidimeters and echo sounders for lake measurements, weather stations, surface (lake and solid) properties packages, etc. to cryogenic environments (95 K).

Other Ocean Worlds targets may include Ganymede, Callisto, Ceres, etc. Proposers are strongly encouraged to relate their proposed development to: NASA's future Ocean Worlds exploration goals. Existing flight instrument capability, to provide a comparison metric for assessing proposed improvements.

Proposed instrument architectures should be as simple, reliable, and low risk as possible while enabling compelling science. Novel instrument concepts are encouraged particularly if they enable a new class of scientific discovery. Technology developments relevant to multiple environments and platforms are also desired.

Proposers should show an understanding of relevant space science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.

S4.06 Sample Collection for Life Detection in Outer Solar System Ocean World Plumes (SBIR)
Lead Center: JPL
Participating Center(s): ARC, GSFC
Related Subtopic Pointer(s): S4.02

This subtopic solicits development of technologies for sample collection from plumes in the Ocean Worlds (e.g., Europa, Enceladus, Titan, Ganymede, Callisto, Ceres, etc.). This sample collection system would be used as the front-end system in conjunction with in-situ instruments developed under subtopic S1.11. This fly-through sampling subtopic is distinct from S4.02, which solicits sample collection technologies from surface platforms. These technologies must be capable of withstanding operation in space and planetary environments, including the expected pressures, radiation levels, launch and impact stresses, and range of survival and operational temperatures. Technologies that allow collection during high speed (>1 km/sec) velocity passes through a plume are of interest as are technologies that can maximize total sample mass collected while passing through tenuous plumes. Technologies that reduce mass, power, volume, and data rates without loss of scientific capability are of particular importance.

For synergistic NASA technology solicitation, see ROSES 2016/C.20 Concepts for Ocean worlds Life Detection Technology (COLDTECH) call:

- https://nspires.nasaprs.com/external/solicitations/summary.do?method=init&solId=%7B5C43865B-0C93-6ECA-BCD2-A3783CB1AAC8%7D&path=init.

For the NASA Roadmap for Ocean World Exploration see:

- http://www.lpi.usra.edu/opag/ROW.

The icy moons of the outer Solar System are of astrobiological interest. The most dramatic target for sampling from a plume is for Enceladus. Enceladus is a small icy moon of Saturn, with a radius of only 252km. Cassini data have revealed about a dozen or so jets of fine icy particles emerging from the south polar region of Enceladus. The jets have also been shown to contain organic compounds, and the south-polar region is warmed by heat flow coming from below.

As a target for future missions, Enceladus rates high because fresh samples of interest are jetting into space ready for collection. Indeed, Enceladus has been added to the current call for New Frontiers missions with a focus on habitability and life detection. Particles from Enceladus also form the E-ring around Saturn. The particles in the E-ring are known to contain organics and are thus also an important target for sample collection and analysis. Recent data have indicated a possible plume at Europa that may also be carrying ocean water from that world into space. In addition to plumes, there are other energetic processes that can spray material from the surface of these low-gravity worlds into space where they could also be collected in-flight and analyzed.

Collecting samples for a variety of science purposes is required. These include samples that allow for determination of the chemical and physical properties of the source ocean, samples for detailed characterization of the organics present in the gas and particle phases, and samples for analysis for biomarkers indicative of life. Thus, these Ocean Worlds of the outer Solar System offer the opportunity for a conceptually new approach to life detection focusing on in-flight sample collection of material freshly injected into space. Technologies of particular interest include sample collection systems and subsystems capable of:

- Capture, containment, and/or transfer of gas, liquid, ice, and/or mineral phases from plumes to sample processing and/or instrument interfaces.
- Technologies for characterization of collected sample parameters including mass, volume, total dissolved solids in liquid samples, and insoluble solids.
- Sample collection and sample capture for in-situ imaging.
- Systems capable of high-velocity sample collection with minimal sample alteration to allow for habitability and life detection analyses.
- Microfluidic sample collection systems that enable sample concentration and other manipulations.
- Plume material collection technologies that minimize risk of terrestrial contamination, including organic chemical and microbial contaminates.

Proposers are strongly encouraged to relate their proposed development to NASA's future Ocean Worlds exploration goals. Proposed instrument architectures should be as simple, reliable, and low risk as possible while enabling compelling science. Novel instrument concepts are encouraged particularly if they enable a new class of scientific discovery. Technology developments relevant to multiple environments and platforms are also desired.

Proposers should show an understanding of relevant space science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.

T8.02 Photonic Integrated Circuits (STTR)
Lead Center: GSFC
Participating Center(s): GRC, JSC

Integrated photonics generally is the integration of multiple lithographically defined photonic and electronic components and devices (e.g., lasers, detectors, waveguides/passive structures, modulators, electronic control and optical interconnects) on a single platform with nanometer-scale feature sizes. The development of photonic integrated circuits permits size, weight, power and cost reductions for spacecraft microprocessors, communication buses, processor buses, advanced data processing, free space communications and integrated optic science instrument optical systems, subsystems and components. This is particularly critical for small spacecraft platforms. This topic solicits methods, technology and systems for development and incorporation of active and passive circuit elements for integrated photonic circuits for:

- Integrated photonic sensors (physical, chemical and/or biological) circuits: NASA applications examples include (but are not limited to): Lab-on-a-chip systems for landers, Astronaut health monitoring, Front-end and back-end for remote sensing instruments including trace gas lidars Large telescope spectrometers for exoplanets using photonic lanterns and narrow band filters. On chip generation and detection of light of appropriate wavelength may not be practical, requiring compact hybrid packaging for providing broadband optical input-output and also, as means to provide coupling of light between the sensor-chip waveguides and samples, unique optical components (e.g., Plasmonic waveguides, microfluidic channel) may be beneficial. Examples: Terahertz spectrometer, Optical spectrometer, gyroscope, magnetometer, urine/breath/blood analysis.

- Integrated Photonic Circuits for Analog RF applications: NASA applications include new methods due to Size, Weight and Power improvements, passive and active microwave signal processing, radio astronomy and Terahertz spectroscopy. As an example, integrated photonic circuits having very low insertion loss (e.g., ~1dB) and high spur free dynamic range for analog and RF signal processing and transmission which incorporate, for example, monolithic high-Q waveguide microresonators or Fabry-Perot filters with multi-GHz RF pass bands. These components should be suitable for designing chip-scale tunable opto-electronic RF oscillator and high precision optical clock modules. Examples: Ka, W, V band radar/receivers.
- Integrated photonic circuits for very high-speed computing and free space communications: Advanced computing engines that approach Teraflop per second computing power for spacecraft in a fully integrated combined photonic and electronic package. Free space communications downlink modems at the > 1 Terabit per second level for Near-Earth (Low-Earth Orbit to ground) and > 100 Mbls for > 1 AU distances. Examples: Transmitters, receivers, microprocessors.

Focus Area 10: Advanced Telescope Technologies

Lead MD: SMD

The NASA Science Mission Directorate seeks technology for cost-effective high-performance advanced space telescopes for astrophysics and Earth science. Astrophysics applications require large aperture light-weight highly reflecting mirrors, deployable large structures and innovative metrology, control of unwanted radiation for high-contrast optics, precision formation flying for synthetic aperture telescopes, and cryogenic optics to enable far infrared telescopes. A few of the new astrophysics telescopes and their subsystems will require operation at cryogenic temperatures as cold a 4 K. This topic will consider technologies necessary to enable future telescopes and observatories collecting electromagnetic bands, ranging from UV to millimeter waves, and also include gravity waves. The subtopics will consider all technologies associated with the collection and combination of observable signals. Earth science requires modest apertures in the 2 to 4-meter size category that are cost effective. New technologies in innovative mirror materials, such as silicon, silicon carbide and nanolaminates, innovative structures, including nanotechnology, and wavefront sensing and control are needed to build telescopes for Earth science.

S2.01 Proximity Glare Suppression for Astronomical Direct Detection (SBIR)
Lead Center: JPL
Participating Center(s): ARC, GSFC
Related Subtopic Pointer(s): S1.04

This subtopic addresses the unique problem of imaging and spectroscopic characterization of faint astrophysical objects that are located within the obscuring glare of much brighter stellar sources. Examples include planetary systems beyond our own, the detailed inner structure of galaxies with very bright nuclei, binary star formation, and stellar evolution. Contrast ratios of one million to ten billion over an angular spatial scale of 0.05-1.5 arcsec are typical of these objects. Achieving a very low background requires control of both scattered and diffracted light. The failure to control either amplitude or phase fluctuations in the optical train severely reduces the effectiveness of starlight cancellation schemes.

This innovative research focuses on advances in coronagraphic instruments, starlight cancellation instruments, and potential occulting technologies that operate at visible and near infrared wavelengths. The ultimate application of these instruments is to operate in space as part of a future observatory mission. Measurement techniques include imaging, photometry, spectroscopy, and polarimetry. There is interest in component development and innovative instrument design, as well as in the fabrication of subsystem devices to include, but not limited to, the following areas:

Starlight Suppression Technologies:

- Image plane hybrid metal/dielectric, and polarization apodization masks in linear and circular patterns.
- Transmissive holographic masks for diffraction control and PSF apodization.
- Sharp-edged, low-scatter pupil plane masks.
- Low-scatter, low-reflectivity, sharp, flexible edges for control of scatter in starshades.
- Systems to measure spatial optical density, phase inhomogeneity, scattering, spectral dispersion, thermal variations, and to otherwise estimate the accuracy of high-dynamic range apodizing masks.
- Pupil remapping technologies to achieve beam apodization.
- Techniques to characterize highly aspheric optics.
- Methods to distinguish the coherent and incoherent scatter in a broad band speckle field.
- Coherent fiber bundles consisting of up to 10,000 fibers with lenslets on both input and output side, such that both spatial and temporal coherence is maintained across the fiber bundle for possible wavefront/amplitude control through the fiber bundle.

Wavefront Measurement and Control Technologies:

- Small stroke, high precision, deformable mirrors and associated driving electronics scalable to 10,000 or more actuators (both to further the state-of-the-art towards flight-like hardware and to explore novel concepts). Multiple deformable mirror technologies in various phases of development and processes are encouraged to ultimately improve the state-of-the-art in deformable mirror technology. Process improvements are needed to improve repeatability, yield, and performance precision of current devices.
- Instruments to perform broad-band sensing of wavefronts and distinguish amplitude and phase in the wavefront.
- Integrated mirror/actuator programmable deformable mirror.
- Multiplexers with ultra-low power dissipation for electrical connection to deformable mirrors.
- Low-order wavefront sensors for measuring wavefront instabilities to enable real-time control and post-processing of aberrations.
- Thermally and mechanically insensitive optical benches and systems.
- Optical Coating and Measurement Technologies:
    - Instruments capable of measuring polarization cross-talk and birefringence to parts per million.
    - Highly reflecting, uniform, broadband coatings for large (> 1 m diameter) optics.
    - Polarization-insensitive coatings for large optics.
    - Methods to measure the spectral reflectivity and polarization uniformity across large optics.
    - Methods to apply carbon nanotube coatings on the surfaces of the coronagraphs for broadband suppression from visible to NIR.

Other:

- Methods to fabricate diffractive patterns on large optics to generate astrometric reference frames.
- Artificial star and planet point sources, with 1e10 dynamic range and uniform illumination of an f/25 optical system, working in the visible and near infrared.

- Deformable, calibrated, collimating source to simulate the telescope front end of a coronagraphic system undergoing thermal deformations.
- Technologies for high contrast integral field spectroscopy, in particular for microlens arrays with or without accompanying mask arrays, working in the visible and NIR (0.4 - 1.8 microns), with lenslet separations in the 0.1 -0.4 mm range, in formats of ~140x140 lenslets.

S2.02 Precision Deployable Optical Structures and Metrology (SBIR)
Lead Center: JPL
Participating Center(s): GSFC, LaRC
Related Subtopic Pointer(s): H9.01, Z8.02

Planned future NASA Missions in astrophysics, such as the Wide-Field Infrared Survey Telescope (WFIRST) and the New Worlds Technology Development Program (coronagraph, external occulter and interferometer technologies) will push the state of the art in current optomechanical technologies. Mission concepts for New Worlds science would require 10 - 30 m class, cost-effective telescope observatories that are diffraction limited at wavelengths from the visible to the far IR, and operate at temperatures from 4 - 300 K. In addition, ground based telescopes such as the Cerro Chajnantor Atacama Telescope (CCAT) requires similar technology development.

The desired areal density is 1 - 10 kg/m^2 with a packaging efficiency of 3-10 deployed/stowed diameter. Static and dynamic wavefront error tolerances to thermal and dynamic perturbations may be achieved through passive means (e.g., via a high stiffness system, passive thermal control, jitter isolation or damping) or through active opto-mechanical control. Large deployable multi-layer structures in support of sunshades for passive thermal control and 20m to 50m class planet finding external occulters are also relevant technologies. Potential architecture implementations must package into an existing launch volume, deploy and be self-aligning to the micron level. The target space environment is expected to be the Earth-Sun L2.

This subtopic solicits proposals to develop enabling, cost effective component and subsystem technology for deploying large aperture telescopes with low cost. Research areas of interest include:

- Precision deployable structures and metrology for optical telescopes (e.g., innovative active or passive deployable primary or secondary support structures).
- Architectures, packaging and deployment designs for large sunshields and external occulters.
- In particular, important subsystem considerations may include:
- Innovative concepts for packaging fully integrated subsystems (e.g., power distribution, sensing, and control components).
- Mechanical, inflatable, or other precision deployable technologies.
- Thermally-stable materials (CTE < 1ppm) for deployable structures.
- Innovative systems, which minimize complexity, mass, power and cost.
- Innovative testing and verification methodologies.

The goal for this effort is to mature technologies that can be used to fabricate 16 m class or greater, lightweight, ambient or cryogenic flight-qualified observatory systems. Proposals to fabricate demonstration components and subsystems with direct scalability to flight systems through validated models will be given preference. The target launch volume and expected disturbances, along with the estimate of system performance, should be included in the discussion. Proposals with system solutions for large sunshields and external occulters will also be accepted. A successful proposal shows a path toward a Phase II delivery of demonstration hardware scalable to 5-meter diameter for ground test characterization.

Before embarking on the design and fabrication of complex space-based deployable telescopes, additional risk reduction in operating an actively controlled telescope in orbit is desired. To be cost effective, deployable apertures that conform to a cubesat (up to 3-U) or ESPA format are desired. Consequently, deployment hinge and latching concepts, buildable for these missions and scalable to larger systems are desired. Such a system should allow <25-micron deployment repeatability and sub-micron stability for both thermal and mechanical on-orbit disturbances. A successful proposal would deliver a full-scale cubesat or ESPA ring compatible deployable aperture with mock optical elements.

Proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop the relevant subsystem technologies and to transition into future NASA program(s).

S2.03 Advanced Optical Systems and Fabrication/Testing/Control Technologies for EUV/Optical and IR Telescope (SBIR)
Lead Center: MSFC
Participating Center(s): GRC, GSFC, JPL, LaRC
Related Subtopic Pointer(s): H9.01

Proposals must show an understanding of one or more relevant science needs, and present a feasible plan to develop the proposed technology for infusion into a NASA program: sub-orbital rocket or balloon; competed SMEX or MIDEX; or, Decadal class mission.

An ideal Phase I deliverable would be a precision optical system of at least 0.25 meters; or a relevant sub-component of a system; or a prototype demonstration of a fabrication, test or control technology leading to a successful Phase II delivery; or a reviewed preliminary design and manufacturing plan which demonstrates feasibility. While detailed analysis will be conducted in Phase II, the preliminary design should address how optical, mechanical (static and dynamic) and thermal designs and performance analysis will be done to show compliance with all requirements. Past experience or technology demonstrations which support the design and manufacturing plans will be given appropriate weight in the evaluation.

An ideal Phase II project would further advance the technology to produce a flight-qualifiable optical system greater than 0.5 meters or relevant sub-component (with a TRL in the 4 to 5 range); or a working fabrication, test or control system. Phase I and Phase II mirror system or component deliverables would be accompanied by all necessary documentation, including the optical performance assessment and all data on processing and properties of its substrate materials. A successful mission oriented Phase II would have a credible plan to deliver for the allocated budget a fully assembled and tested telescope assembly which can be integrated into the potential mission; and, demonstrate an understanding of how the engineering specifications of their system meets the performance requirements and operational constraints of the mission (including mechanical and thermal stability analysis).

Successful proposals will demonstrate an ability to manufacture, test and control ultra-low-cost optical systems that can meet science performance requirements and mission requirements (including processing and infrastructure issues). Material behavior, process control, active and/or passive optical performance, and mounting/deploying issues should be resolved and demonstrated.

Technical Challenges
To accomplish NASAs high-priority science requires low-cost, ultra-stable, large-aperture, normal incidence mirrors with low mass-to-collecting area ratios. After performance, the most important metric for an advanced optical system is affordability or areal cost (cost per square meter of collecting aperture). Current normal incidence space mirrors

cost \$4 million to \$6 million per square meter of optical surface area. This research effort seeks a cost reduction for precision optical components by 5 to 50 times, to between \$100K/m^2 to \$1M/m^2.

Specific metrics are defined for each wavelength application region:

Aperture Diameter for all wavelengths:

- Monolithic: 1 to 8 meters.
- Segmented: > 12 meters.

For UV/Optical:

- Areal Cost < \$500K/m^2.
- Wavefront Figure < 5 nm RMS.
- Wavefront Stability < 10 pm/10 min.
- First Mode Frequency 250 to 500 Hz.
- Actuator Resolution < 1 nm RMS.

For Far-IR:

- Areal Cost for Far-IR < \$100K/m^2.
- Cryo-deformation for Far-IR < 100 nm RMS.

For EUV:

- Slope < 0.1 micro-radian.

Also needed is ability to fully characterize surface errors and predict optical performance.

1. Optical Components and Systems for potential UV/Optical Missions

Large UV/Optical (LUVOIR) and Habitable Exoplanet (HabEx) Missions
Potential UV/Optical missions require 4 to 16 meter monolithic or segmented primary mirrors with < 5 nm RMS surface figures. Active or passive alignment and control is required to achieve system level diffraction limited performance at wavelengths less than 500 nm (< 40 nm RMS wavefront error, WFE). Additionally, potential Exoplanet mission, using an internal coronagraph, requires total telescope wavefront stability on order of 10 pico-meters RMS per 10 minutes. This stability specification places severe constraints on the dynamic mechanical and thermal performance of 4 meter and larger telescope. To meet this requirement requires active thermal control systems, ultra-stable mirror support structures, and vibration compensation.

Mirror areal density depends upon available launch vehicle capacities to Sun-Earth L2 (i.e., 15 kg/m^2 for a 5 m fairing EELV vs. 150 kg/m^2 for a 10 m fairing SLS). Regarding areal cost, a good goal is to keep the total cost of the primary mirror at or below \$100M. Thus, an 8-m class mirror (with 50 m^2 of collecting area) should have an areal cost of less than \$2M/m^2. And, a 16-m class mirror (with 200 m^2 of collecting area) should have an areal cost of less than \$0.5M/m^2.

Key technologies to enable such a mirror include new and improved:

- Mirror substrate materials and/or architectural designs.
- Processes to rapidly fabricate and test UVO quality mirrors.
- Mirror support structures that are ultra-stable at the desired scale.
- Mirror support structures with low-mass that can survive launch at the desired scale.
- Mechanisms and sensors to align segmented mirrors to < 1 nm RMS precisions.
- Thermal control (< 1 mK) to reduce wavefront stability to < 10 pm RMS per 10 min.
- Dynamic isolation (> 140 dB) to reduce wavefront stability to < 10 pm RMS per 10 min.

Also needed is ability to fully characterize surface errors and predict optical performance via integrated opto-mechanical modeling.

Potential solutions for substrate material/architecture include, but are not limited to: ultra-uniform low CTE glasses, silicon carbide, nanolaminates or carbon-fiber reinforced polymer. Potential solutions for mirror support structure material/architecture include, but are not limited to: additive manufacturing, nature inspired architectures, nano-particle composites, carbon fiber, graphite composite, ceramic or SiC materials, etc. Potential solutions for new fabrication processes include, but are not limited to: additive manufacture, direct precision machining, rapid optical fabrication, roller embossing at optical tolerances, slumping or replication technologies to manufacture 1 to 2-meter (or larger) precision quality components. Potential solutions for achieving the 10 pico-meter wavefront stability include, but are not limited to: metrology, passive, and active control for optical alignment and mirror phasing; active vibration isolation; metrology, passive, and active thermal control;

Ultra-Stable Balloon Telescopes and Telescope Structures

Multiple potential balloon and space missions to perform Astrophysics, Exoplanet and Planetary science investigations require a complete optical telescope system with 0.5 meter or larger of collecting aperture. 1-m class balloon-borne telescopes have flown successfully, however, the cost for design and construction of such telescopes can exceed $6M, and the weight of these telescopes limits the scientific payload and duration of the balloon mission. A 4X reduction in cost and mass would enable missions which today are not feasible. Space-based gravitational wave observatories (eLISA) need a 0.5-meter class ultra-stable telescope with an optical path length stability of a picometer over periods of roughly one hour at temperatures near 230K in the presence of large applied thermal gradients. The telescope will be operated in simultaneous transmit and receive mode, so an unobstructed design is required to achieve extremely low backscatter light performance.

Balloon Planetary Telescope

Astronomy from a stratospheric balloon platform offers numerous advantages for planetary science. At typical balloon cruise altitudes (100,000 to 130,000 ft.), 99%+ of the atmospheric is below the balloon and the attenuation due to the remaining atmosphere is small, especially in the near ultraviolet band and in the infrared bands near 2.7 and 4.25 μm. The lack of atmosphere nearly eliminates scintillation and allows the resolution potential of relatively large optics to be realized, and the small amount of atmosphere reduces scattered light and allows observations of brighter objects even during daylight hours.

For additional discussion of the advantages of observations from stratosphere platforms, refer to "Planetary Balloon-Based Science Platform Evaluation and Program Implementation - Final Report," Dankanich et. al. (NASA/TM-2016-218870, available from https://ntrs.nasa.gov/).

To perform Planetary Science requires a 1-meter class telescope 500 nm diffraction limited performance or Primary Mirror System that can maintain < 10 nm rms surface figure error for elevation angles ranging from 0 to 60 degrees over a temperature range from 220K to 280K.

Phase I will produce a preliminary design and report including initial design requirements such as wave-front error budget, mass allocation budget, structural stiffness requirements, etc. trade studies performed and analysis that compares the design to the expected performance over the specified operating range. Development challenges shall be identified during Phase I including trade studies and challenges to be addressed during Phase II with subsystem proof of concept demonstration hardware. If Phase II can only produce a sub-scale component, then it should also produce a detailed final design, including final requirements (wave-front error budget, mass allocation, etc.) and performance assessment over the specified operating range.

Additional information about Scientific Balloons can be found at https://www.csbf.nasa.gov/docs.html.

Telescope Specifications:

- Diameter > 1 meter
- System Focal Length 14 meter (nominal)
- Diffraction Limit < 500 nm
- Mass < 300 kg
- Shock 10G without damage
- Elevation 0 to 60 degrees
- Temperature 220 to 280 K

Primary Mirror Assembly Specifications:

- Diameter > 1 meter
- Radius of Curvature 3 meters (nominal)
- Surface Figure Error < 10 nm rms
- Mass < 150 kg
- Shock 10G without damage
- Elevation 0 to 60 degrees
- Temperature 220 to 280 K

2.0 Optical Components and Systems for potential Infrared/Far-IR missions

Large Aperture Far-IR Surveyor Mission
Potential Infrared and Far-IR missions require 8 m to 24-meter class monolithic or segmented primary mirrors with ~ 1 µm RMS surface figure error which operates at < 10 K. There are three primary challenges for such a mirror system:

- Areal Cost of < $100K per m^2.
- Areal Mass of < 15 kg per m^2 substrate (< 30 kg per m^2 assembly).
- Cryogenic Figure Distortion < 100 nm RMS from 300K to <10K.

Infrared Interferometry Balloon Mission Telescope
A balloon-borne interferometry mission requires 0.5-meter class telescopes with siderostat steering flat mirror. There are several technologies which can be used for production of mirrors for balloon projects (aluminum, carbon fiber, glass, etc.), but they are high mass and high cost.

3.0 NIR LIDAR Beam Expander Telescope
Potential airborne coherent LIDAR missions need compact 15-cm diameter 20X magnification beam expander telescopes. Potential space based coherent LIDAR missions need at least 50-cm 65X magnification beam expander

telescopes. Candidate coherent LIDAR systems (operating with a pulsed 2-micrometer laser) have a narrow, almost diffraction limited field of view, close to 0.8 lambda/D half angle. Aberrations, especially spherical aberration, and surface roughness in the optical telescope can kill the signal. Additionally, the telescope beam expander must maintain the laser beam's circular polarization. The incumbent telescope technology is a Dahl-Kirkham beam expander. Technology advance is needed to make the beam expander more compact while retaining optical performance.

4.0 Fabrication, Test and Control of Advanced Optical Systems
Finally, this sub-topic also encourages proposals to develop technology which makes a significant advance the ability to fabricate, test or control an optical system.

S2.04 X-Ray Mirror Systems Technology, Coating Technology for X-Ray-UV-OIR, and Free-Form Optics (SBIR)
Lead Center: GSFC
Participating Center(s): JPL, MSFC
Related Subtopic Pointer(s): S1.04

This subtopic focuses on three areas of technology development:

- X-Ray manufacturing, coating, testing, and assembling complete mirror systems in addition to maturing the current technology.
- Coating technology including Carbon Nanotubes (CNT) for wide range of wavelengths from X-Ray to IR: X-Ray, EUV (extreme ultraviolet), LUV (Lyman ultraviolet), VUV (vacuum ultraviolet), Visible, and IR (infrared) telescopes.
- Free-form Optics design, fabrication, and metrology for CubeSat, SmallSat and various coronagraphic instruments.

A typical Phase I proposal for X-Ray technology would address the relevant optical sub-component of a system with necessary coating and stray light suppression for X-Ray missions or prototype demonstration of a fabricated system and its testing. Similarly, a Coating technology proposal would address fabrication and testing of optical surfaces for a wide range of wavelengths from X-Ray, EUV, LUV, VUV, Visible and IR. The Free-form Optics proposals tackle the challenges involved in design, fabrication, and metrology of non-spherical surfaces for small-size missions such as CubeSat, NanoSat, and coronagraphic instruments.

In a nutshell, a successful proposal demonstrates a low-cost ability to address NASA science mission needs and technical challenges specified under each category with feasible plan to develop the technology for infusion into NASA Decadal class missions and sub-orbital rockets and/or balloon for IR-class telescopes.

The National Academy Astro2010 Decadal Report identifies studies of optical components and ability to manufacture, coat, and perform metrology needed to enable future X-Ray observatory missions such as Next Generation of X-Ray Observatories (NGXO). The Astrophysics Decadal specifically calls for optical coating technology investment for future UV, Optical, Exoplanet, and IR missions while Heliophysics 2009 Roadmap identifies the coating technology for space missions to enhance rejection of undesirable spectral lines, improve space/solar-flux durability of EUV optical coatings, and coating deposition to increase the maximum spatial resolution.

Future optical systems for NASAs low-cost missions, CubeSat and other small-scale payloads, are moving away from traditional spherical optics to non-spherical surfaces with anticipated benefits of freeform optics such as fast wide-field and distortion-free cameras.

X-Ray Optical Component, Systems, and Technologies
NASA large X-Ray observatory requires low-cost, ultra-stable, light-weight mirrors with high-reflectance optical coatings and effective stray light suppression. The current state-of-art of mirror fabrication technology for X-Ray missions is very expensive and time consuming. Additionally, a number of improvements such as 10 arc-second angular resolutions and 1 to 5 m^2 collecting area are needed for this technology. Likewise, the stray-light suppression system is bulky and ineffective for wide-field of view telescopes.

In this area, we are looking to address the multiple technologies including: improvements to manufacturing (machining, rapid optical fabrication, slumping or replication technologies), improved metrology, performance prediction and testing techniques, active control of mirror shapes, new structures for holding and actively aligning of mirrors in a telescope assembly to enable X-Ray observatories while lowering the cost per square meter of collecting aperture and effective design of stray-light suppression in preparation for the Decadal Survey of 2020. Currently, X-Ray space mirrors cost $4 million to $6 million per square meter of optical surface area. This research effort seeks a cost reduction for precision optical components by 5 to 50 times, to less than $1M to $100 K/$m^2$.

Coating Technologies for X-Ray, EUV, LUV, UV, Visible, and IR Telescopes
The optical coating technology is a mission-enabling feature that enhances the optical performance and science return of a mission. Lowering the areal cost of coating determines if a proposed mission could be funded in the current cost environment. The most common forms of coating used on precision optics are anti-reflective (AR) coating and high reflective coating. The current coating technology of optical components needs to achieve TRL-6 by approximately 2018 to support the 2020 Astrophysics Decadal process. A number of optical coating metrics specific to each wavelength are desired such as:

The Optical Coating Metrics
The telescope optical coating needs to meet low temperature operation requirement. Its desirable to achieve 35 K in future.

X-Ray Metrics:
- Multilayer high-reflectance coatings for hard X-Ray mirrors similar to NuSTAR.
- Multilayer depth gradient coatings for 5 to 80 KeV with high broadband reflectivity.
- Zero-net-stress coating for iridium or other high-reflectance elements on thin substrates (< 0.5 mm).

EUV Metrics:
- Reflectivity > 90% from 6 nm to 90 nm and the ability to be applied onto a < 2-meter mirror substrate.

LUVOIR Metrics:
- Broadband reflectivity > 70% from 90 nm to 120 nm (LUV); > 90% from 120 nm to 2500 nm (VUV/Visible/IR); Reflectivity non-uniformity < 1% from 90 nm to 2500 nm. Induced polarization aberration < 1% from 400 nm to 2500 nm and depositable onto 1 to 8 m substrates.

Non-Stationary Metric:
- Non- uniform optical coating to be used in both reflection and transmission that vary with location and optical surface. Variation pertains to ratio of reflectivity to transmissivity, optical field amplitude, phase, and polarization change. The optical surface area ranges from 1/2 to 6 cm.

Scattered Light Suppression Using Carbon Nanotube (CNT) Coating
A number of future NASA missions require suppression of scattered light. For instance, the precision optical cube utilized in a beam-splitter application forms a knife-edge that is positioned within the optical system to split a single beam into two halves. The scattered light from the knife-edge could be suppressed by CNT coating. Similarly, the scattered light for gravitational-wave application and lasercom system where the simultaneous transmit/receive operation is required, could be achieved by highly absorbing coating such as CNT. Ideally, the application of CNT coating needs to achieve:

- Broadband (visible plus Near IR), reflectivity of 0.1% or less.
- Resist bleaching of significant albedo changes over a mission life of at least 10 years.
- Withstand launch conditions such vibe, acoustics, etc.
- Tolerate both high continuous wave (CW) and pulsed power and power densities without damage. ~10 W for CE and ~ 0.1 GW/cm^2 density, and 1 kW/nanosecond pulses.
- Adhere to the multi-layer dielectric or protected metal coating including Ion Beam Sputtering (IBS) coating.

Freeform Optics Design, Fabrication, and Metrology
Future NASA missions with alternative low-cost science and small-size payload are constrained by the traditional spherical form of optics. These missions could benefit greatly by the freeform optics as they provide non-spherical optics with better aerodynamic characteristics for spacecraft with lightweight components to meet the mission requirements. Currently, the design and utilization of conformal and freeform shapes are costly due to fabrication and metrology of these parts. Even though various techniques are being investigated to create complex optical surfaces, small-size missions highly desire efficient small packages with lower cost that increase the field of view and expand operational temperature range of unobscured systems. For the coronagraphic applications, freeform optical components allow coronagraphic nulling without shearing and increase the useful science field of view. In this category, freeform optical prescription for surfaces of 0.5 cm to 6 cm diameters with tolerances of 1 to 2 nm rms are needed. In this respect, the freeform refers to either 2nd order conic prescription with higher order surface polished onto it or without underlying conic prescription with no steps in the surface. The optics with underlying conic prescription would need to be in F/# range of F/2 to F/20. In addition to the freeform fabrication, the metrology of freeform optical components is difficult and challenging due to the large departure from planar or spherical shapes accommodated by conventional interferometric testing. New methods such as multibeam low-coherence optical probe and slope sensitive optical probe are highly desirable.

Ultra-Stable X-Ray Grazing-Incident Telescopes for Sub-Orbital Balloons and Rocket-Borne Missions
Technology maturation to build complete low-cost, lightweight X-ray telescopes with grazing-incident optics that can be flown on potential long duration high-altitude balloon-borne or rocket-borne missions. The focus here is to reduce the areal cost of telescope by 2x such that the larger collecting area can be produced for the same cost or half the cost.

Focus Area 11: Spacecraft and Platform Subsystems
Lead MD: SMD
Participating MD(s): STMD

The Science Mission Directorate will carry out the scientific exploration of our Earth, the planets, moons, comets, and asteroids of our solar system and the universe beyond. SMD's future direction will be moving away from exploratory missions (orbiters and flybys) into more detailed/specific exploration missions that are at or near the surface (landers, rovers, and sample returns) or at more optimal observation points in space. These future destinations will require new vantage points, or would need to integrate or distribute capabilities across multiple assets. Future destinations will also be more challenging to get to, have more extreme environmental conditions and challenges once the spacecraft gets there, and may be a challenge to get a spacecraft or data back from. A major objective of the NASA science spacecraft and platform subsystems development efforts are to enable science measurement capabilities using smaller and lower cost spacecraft to meet multiple mission requirements thus making the best use of our limited resources. To accomplish this objective, NASA is seeking innovations to significantly improve spacecraft and platform subsystem capabilities while reducing the mass and cost that would in turn enable increased scientific return for future NASA missions. A spacecraft bus is made up of many subsystems like: propulsion; thermal control; power and power distribution; attitude control; telemetry command and control; transmitters/antenna; computers/on-board processing/software; and structural elements. High performance space computing technologies are also included in this focus area. Science platforms of interest could include unmanned aerial vehicles, sounding rockets, or balloons that carry scientific instruments/payloads, to planetary ascent vehicles or Earth return vehicles that bring samples back to Earth for analysis. This topic area addresses the future needs in many of these sub-system areas, as well as their application to specific spacecraft and platform needs. For planetary missions, planetary protection requirements vary by planetary destination, and additional backward contamination requirements apply to hardware with the potential to return to Earth (e.g., as part of a sample return mission). Technologies intended for use at/around Mars, Europa (Jupiter), and Enceladus (Saturn) must be developed so as to ensure compliance with relevant planetary protection requirements. Constraints could include surface cleaning with alcohol or water, and/or sterilization treatments such as dry heat (approved specification in NPR 8020.12; exposure of hours at 115° C or higher, non-functioning); penetrating radiation (requirements not yet established); or vapor-phase hydrogen peroxide (specification pending). The following references discuss some of NASA's science mission and technology needs:

- The Astrophysics Roadmap - https://science.nasa.gov/science-committee/subcommittees/nac-astrophysics-subcommittee/astrophysics-roadmap.
- Astrophysics Decadal Survey "New Worlds, New Horizons: in Astronomy and Astrophysics" - http://www.nap.edu/catalog.php?record_id=12951.
- The Earth Science Decadal Survey - http://books.nap.edu/catalog.php?record_id=11820.
- The Heliophysics roadmap "The Solar and Space Physics of a New Era: Recommended Roadmap for Science and Technology 20092030" - http://hpde.gsfc.nasa.gov/2009_Roadmap.pdf.
- The 2011 Planetary Science Decadal Survey was released March 2011. This decadal survey is considering technology needs - https://solarsystem.nasa.gov/2013decadal/.

S3.05 Terrestrial Balloons and Planetary Aerial Vehicles (SBIR)
Lead Center: GSFC
Participating Center(s): JPL

Satellite Communications
Improved and innovative downlink bitrates using satellite relay communications from balloon payloads are needed. Long duration balloon flights currently utilize satellite communication systems to relay science and operations data from the balloon to ground based control centers. The current maximum downlink bit rate is 150 kilobits per second operating continuously during the balloon flight. Future requirements are for bit rates of 1 megabit per second or more. Improvements in bit rate performance, reduction in size and mass of existing systems, or reductions in cost of high bit rate systems are needed. TDRSS and Iridium satellite communications are currently used for balloon payload applications. A commercial S-band TDRSS transceiver and mechanically steered 18 dBi gain antenna provide 150 kbps continuous downlink. TDRSS K-band transceivers are available but are currently cost prohibitive. Open Port Iridium service is also currently being used.

Balloon Sensors and Instrumentation
Improved and innovative devices to make measurements of the balloon and the ambient flight environment are needed. Devices or methods to accurately and continuously measure ambient air, helium gas, balloon film

temperatures, ambient wind velocity and film strain are desired. These measurements are needed to accurately model the balloon performance during a typical flight at altitudes of approximately 120,000 feet. The measurements must compensate for the effects of direct solar radiation through shielding or calculation. Minimal mass and volume are highly desired. For film measurements, a non-invasive and non-contact approach is highly desired for the thin polyethylene film, with film thickness ranging from 0.8 to 1.5 mil, used as the balloon envelope. Devices for these measurements must be compatible with existing NASA systems and operations.

Planetary Aerial Vehicles

Innovations in materials, structures, and systems concepts have enabled aerial vehicles to play an expanding role in NASA's future Solar System Exploration Program. Aerial vehicles are expected to carry scientific payloads at Venus that will perform in-situ investigations of its atmosphere, surface and interior. Venus features extreme environments that significantly impact the design of aerial vehicles. Proposals are sought in the following areas:

- *Aerial Vehicle Platforms for Venus* - NASA is interested in conducting long term monitoring of the Venus atmosphere and planetary surface using aerial vehicles at altitudes around 50 to 60 km. Concepts for Lighter-than-Air (e.g., balloons, airships) and Heavier-than-Air (e.g., fixed wing, rotary wing) vehicles are encouraged. The aerial platforms should be capable of operation through daylight and/or night time observations on Venus. The proposal should describe how the vehicle concept would be deployed into the atmosphere and operated for its mission. Concepts for any of the following capabilities of aerial vehicle are encouraged:
    - Technology demonstration with science payload less than 10 kg.
    - Pathfinder mission with science payload less than 50 kg.
    - Flagship mission with science payload up to 100 kg.

It is expected that a Phase I effort will consist of a system-level design and a proof-of-concept experiment on one or more key components.

S3.08 Command, Data Handling, and Electronics (SBIR)
Lead Center: GSFC
Participating Center(s): JPL, LaRC
Related Subtopic Pointer(s): S5.06, Z8.03

NASA's space based observatories, fly-by spacecraft, orbiters, landers, and robotic and sample return missions, require robust command and control capabilities. Advances in technologies relevant to command and data handling and instrument electronics are sought to support NASA's goals and several missions and projects under development.

The 2018 subtopic goals are to develop platforms for the implementation of miniaturized highly integrated avionics and instrument electronics that:

- Are consistent with the performance requirements for NASA science missions.
- Minimize required mass/volume/power as well as development cost/schedule resources.
- Can operate reliably in the expected thermal and radiation environments.
- Successful proposal concepts should significantly advance the state-of-the-art. Proposals should clearly:
    - State what the product is.
    - Identify the needs it addresses.
    - Identify the improvements over the current state of the art.
    - Outline the feasibility of the technical and programmatic approach.
    - Present how it could be infused into a NASA program.

Furthermore, proposals developing hardware should indicate an understanding of the intended operating environment, including temperature and radiation. It should be noted that environmental requirements can vary significantly from mission to mission. For example, some low earth orbit missions have a total ionizing dose (TID) radiation requirement of less than 10 krad(Si), while some planetary missions can have requirements well in excess of 1 Mrad(Si). For descriptions of radiation effects in electronics, the proposer may visit (http://radhome.gsfc.nasa.gov/radhome/overview.htm).

If a Phase II proposal is awarded, the combined Phase I and Phase II developments should produce a prototype that can be characterized by NASA.

The technology priorities sought are listed below:

- *I/O Expansion Chip for next generation spaceflight processor devices, including the High-Performance Spaceflight Computing (HPSC) Chiplet* - This ASIC interfaces to a radiation hardened space processor, via a XAUI port and acts as an I/O expansion and protocol converter. Desired interfaces include TIA/EIA-422, SpaceWire, SpaceFiber, MIL-STD-1553, SPI, CameraLink, PCI-e, and Time Triggered Ethernet (TTE)/Time-Triggered Gigabit Ethernet (TTGbE). The offeror should survey the market and develop a list of I/O interconnects that will accelerate adoption of next generation processors into the broader space, and potentially terrestrial, markets, then design the device and implement it in a form suitable for use in spacecraft, and cyber-physical/robotics or autonomous systems in both terrestrial and natural space radiation environments. The I/O Expansion Chip hardware design and associated software will facilitate interfacing the processor to the I/O Expansion Chip in a manner that is transparent to the rest of the processor and will make the Expansion Chip seem an integral part of the processor architecture.
- *Serial RapidIO (SRIO) Hub/Switch* - This module, preferably implemented as an ASIC, provides switching and routing of SRIO Version 4 Harsh Device Class links. The SRIO Hub will provide the necessary routing of SRIO links onboard spacecraft, and other platforms to enable use of SRIO as the system interconnect. The full SRIO Version 4 speed need not be supported. The Offeror should determine what levels of radiation tolerance vs baud rate are achievable, perform a survey of anticipated spacecraft interconnect needs, and propose an implementation that is compatible with spacecraft systems envisioned for the near-mid future.
- *Smart, multi-output high efficiency POL (point of load) converter* - This module, preferably implemented utilizing one or more controller ASICs, will source a minimum of 3 settable output voltages when provided with standard spacecraft power bus input. Output voltages should be independently settable to any voltage between 5 and .5 V with efficiency of at least 95%. Regulation, noise filtering and other operational specifications should be commensurate with industry standards for space-based systems. The module should provide standard spacecraft power supply features, including over voltage protection, fault tolerance, load monitoring, and should allow control and status monitoring by a remote power system controller. There is also interest in a capability to provide data over powerline communication to the converter for control and monitoring functions. The offeror should determine radiation tolerance levels achievable utilizing commercially available processes and indicate, in the proposal, the radiation tolerance capability to be achieved.
- *System-In-Package Integrated Assemblies* – Technologies are sought enabling highly integrated System-In-Package (SIP) assemblies integrating multiple die from different processes and foundries, enabling implementation of miniaturized, highly-reliable embedded processing, sensor readout, or motor/actuator control modules. The offeror should propose both the SIP technology to be developed, as well as a proof of concept application (relevant to spaceflight subsystems or instruments) that demonstrates the technology. The offeror should address key technical issues in the SIP implementation including thermal management, reliability, and signal integrity.

- *COTS Micropower/Ultra-Low Power Computing* - Technologies enabling the use of COTS micropower/ultra-low power computing devices in highly reliable spacecraft avionics systems.

Please see Z8.03 for a related topic of potential interest.

S4.03 Spacecraft Technology for Sample Return Missions (SBIR)
Lead Center: JPL
Participating Center(s): GRC, GSFC, JPL, MSFC
Related Subtopic Pointer(s): Z10.02

NASA plans to perform sample return missions from a variety of scientifically important targets including Mars, small bodies such as asteroids and comets, and outer planet moons. These types of targets present a variety of spacecraft technology challenges.

Some targets, such as Mars and some moons, have relatively large gravity wells and will require ascent propulsion. Includes propellants that are transported along with the mission or propellants that can be generated using local resources.

Other targets are small bodies with very complex geography and very little gravity, which present difficult navigational and maneuvering challenges.

In addition, the spacecraft will be subject to extreme environmental conditions including low temperatures (-270° C), dust, and ice particles.

Technology innovations should either enhance vehicle capabilities (e.g., increase performance, decrease risk, and improve environmental operational margins) or ease sample return mission implementation (e.g., reduce size, mass, power, cost, increase reliability, or increase autonomy).

S4.04 Extreme Environments Technology (SBIR)
Lead Center: JPL
Participating Center(s): ARC, GRC, GSFC, LaRC, MSFC
Related Subtopic Pointer(s): S1.11, S4.02, Z5.02, Z8.03

NASA is interested in expanding its ability to explore the deep atmosphere and surface of giant planets, asteroids, and comets through the use of long-lived (days or weeks) balloons and landers. Survivability in extreme high-temperatures and high-pressures is also required for deep atmospheric probes to planets. Proposals are sought for technologies that are suitable for remote sensing applications at cryogenic temperatures, and in-situ atmospheric and surface explorations in the high-temperature high-pressure environment at the Venusian surface (485° C, 93 atmospheres), or in low-temperature environments such as Titan (-180° C), Europa (-220° C), Ganymede (-200° C), Mars, the Moon, asteroids, comets and other small bodies. Also, Europa-Jupiter missions may have a mission life of 10 years and the radiation environment is estimated at 2.9 Mega-rad total ionizing dose (TID) behind 0.1-inch-thick aluminum. Proposals are sought for technologies that enable NASA's long duration missions to extreme wide-temperature and cosmic radiation environments. High reliability, ease of maintenance, low volume, low mass, and low out-gassing characteristics are highly desirable. Special interest lies in development of following technologies that are suitable for the environments discussed above:

- Wide temperature range precision mechanisms i.e., beam steering, scanner, linear and tilting multi-axis mechanisms.

- Radiation-tolerant/radiation hardened low-power low-noise mixed-signal mechanism control electronics for precision actuators and sensors.
- Wide temperature range feedback sensors with sub-arc-second/nanometer precision.
- Long life, long stroke, low power, and high torque/force actuators with sub-arc-second/nanometer precision.
- Long life Bearings/tribological surfaces/lubricants.
- High temperature energy storage systems.
- High-temperature actuators and gear boxes for robotic arms and other mechanisms.
- Low-power and wide-operating-temperature radiation-tolerant /radiation hardened RF electronics.
- Radiation-tolerant/radiation-hardened, low-power/ultra-low-power, wide-operating-temperature, low-noise, mixed-signal electronics for space-borne system such as guidance and navigation avionics and instruments.
- Radiation-tolerant/radiation-hardened power electronics.
- Radiation-tolerant/ radiation-hardened electronic packaging (including, shielding, passives, connectors, wiring harness and materials used in advanced electronics assembly).

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract.

Please see subtopic Z8.03 for related topics of potential interest.

S4.05 Contamination Control and Planetary Protection (SBIR)
Lead Center: JPL
Participating Center(s): GSFC
Related Subtopic Pointer(s): S1.11, S4.02, Z5.02

A need to develop technologies to implement Contamination Control and Planetary Protection requirements has emerged in recent years with increased interest in investigating bodies with the potential for life detection such as Europa, Enceladus, Mars, etc. and the potential for sample return from such bodies. Planetary Protection is concerned with both forward and backward contamination. Forward contamination is the transfer of viable organisms from Earth to another body. Backward contamination is the transfer of material posing a biological threat back to Earth's biosphere. NASA is seeking innovative technologies or applications of technologies to facilitate meeting portions of forward and backward contamination Planetary Protection requirements as well as analytical technologies that can ensure hardware and instrumentation can meet organic contamination requirements in an effort to preserve sample science integrity.

For contamination control efforts, analytical technologies and techniques for quantifying submicron particle and organic contamination for validating surface cleaning methods are needed. In particular, capabilities for measuring Total Organic Carbon (TOC) at <<40 ppb or <<20 ng/cm^2 on a surface and detection of particles <0.2 microns in size are being sought. In addition, techniques for detection of one or more of the following molecules and detection level are needed:

- DNA (1 fmole).
- Dipicolinic acid (1 pg).
- N-acetylglucosamine (1 pg).
- Glycine and alanine (1 pg).
- Palmitic acid (1 pg).
- Sqalene (1 pg).
- Pristane (1pg).

- Chlorobenzene (<1 pg).
- Dichloromethane (<1 pg).
- Naphthalene (1 pg).

For many missions, Planetary Protection requirements are often implemented in part by processing hardware or potentially entire spacecraft with one or more sterilization processes. These processes are often incompatible with particular materials or components on the spacecraft and extensive effort is made to try to mitigate these issues. Innovative new or improved sterilization/re-sterilization processes are being sought for application to spacecraft hardware to increase effectiveness of reducing bio-load on spacecraft or increase process compatibility with hardware (e.g., toxicity to hardware, temperature, duration, etc.). Accepted processes currently include heat processing, gamma/electron beam irradiation, cold plasma, and vapor hydrogen peroxide. Options to improve materials and parts (e.g., sensors, seals, in particular, batteries, valves, and optical coatings) to be compatible with currently accepted processes, in particular heat tolerance, are needed. NASA is seeking novel technologies for preventing recontamination of sterilized components or spacecraft as a whole (e.g., biobarriers). In addition, active in-situ recontamination/decontamination approaches (e.g., in-situ heating of sample containers to drive off volatiles prior to sample collection) and in-situ sterilization approaches (e.g., UV or plasma) for surfaces are desired.

Missions planning sample return from bodies such as Mars, Europa, and Enceladus are faced with developing technologies for sample return functions to assure containment of material from these bodies. Thus far, concepts have been developed specifically for Mars sample return but no end-to-end concepts have been developed that do not have technical challenges remaining in one or more areas. Options for sample canisters with seal(s) (e.g., brazing, explosive welding, soft) with sealing performed either on surface or in orbit and capability to verify seal(s), potentially by leak detection are needed. In addition, capability is needed for opening seals while maintaining sample integrity upon Earth return. These technologies need to be compatible with processes the materials may encounter over the lifecycle of the mission (e.g., high temperature heating). Containment assurance also requires technologies to break-the-chain of contact with the sampled body. Any native contamination on the returned sample container and/or Earth return vehicle must be either be fully contained, sterilized, or removed prior to return to Earth, therefore, technologies or concepts to mitigate this contamination are desired. Lightweight shielding technologies are also needed for meteoroid protection for the Earth entry vehicle and sample canister with capability to detect damage or breach to meet a 10-6 probability of loss of containment.

Focus Area 12: Entry, Descent, and Landing Systems

Lead MD: STMD
Participating MD(s): HEOMD, SMD, STTR

The SBIR focus area of Entry, Descent and Landing (EDL) includes the suite of technologies for atmospheric entry as well as descent and landing on both atmospheric and non-atmospheric bodies. EDL mission segments are used in both robotic planetary science missions and human exploration missions beyond Low Earth Orbit, and some technologies have application to commercial space capabilities.

Robust, efficient, and predictable EDL systems fulfill the critical function of delivering payloads to planetary surfaces through challenging environments, within mass and cost constraints. Future NASA missions will require new technologies to break through historical constraints on delivered mass, or to go to entirely new planets and moons. Even where heritage systems exist, no two planetary missions are exactly “build-to-print,” so there are frequently issues of environmental uncertainty, risk posture, and resource constraints that can be dramatically improved with investments in EDL technologies. New capabilities and improved knowledge are both important facets of this focus area.

Because this topic covers a wide area of interests, subtopics are chosen to enhance and or fill gaps in the existing technology development programs. Future subtopics will support one or more of four broad capability areas, which represent NASA's goals with respect to planetary Entry, Descent and Landing:

- High Mass to Mars Surface.
- Precision Landing and Hazard Avoidance.
- Planetary Probes and Earth Return Vehicles.
- EDL Data Return and Model Improvement.

A cross-cutting set of disciplines and technologies will help mature these four capability areas, to enable more efficient, reliable exploration missions. These more specific topics and subtopics may include, but are not limited to:

- Thermal Protection System materials, modeling, and instrumentation.
- Deployable and inflatable decelerators (hypersonic and supersonic).
- Guidance, Navigation, and Control sensors and algorithms.
- Aerodynamics and Aerothermodynamics advances, including modeling and testing.
- Precision Landing and Hazard Avoidance sensors.
- Multifunctional materials and structures.

This year the Entry, Descent and Landing focus area is seeking innovative technology for:

- Deployable Decelerator Technologies.
- EDL Sensors, including those embedded in thermal protection systems and those used for proximity operations and landing.
- Hot Structure Technology for Atmospheric Entry Vehicles.
- Lander Systems Technology.

The specific needs and metrics of each of these specific technology developments are described in the subtopic descriptions.

H5.02 Hot Structure Technology for Atmospheric Entry Vehicles (SBIR)
Lead Center: LaRC
Participating Center(s): AFRC, JSC, MSFC

This subtopic encompasses the development of reusable, hot structure technology for primary structure that is exposed to extreme heating environments on atmospheric entry vehicles. A hot structure system is a multifunctional structure that can reduce or eliminate the need for a separate thermal protection system (TPS). The potential advantages of using a hot structure system in place of a TPS with underlying cool structure are: reduced mass, increased mission capability such as reusability, improved aerodynamics, improved structural efficiency, and increased ability to inspect the structure. Hot structure is an enabling technology for reusability between missions or mission phases, such as aerocapture followed by entry, and has been used in prior NASA programs (HyperX and X-37) on control surfaces and leading edges, and Department of Defense programs.

This subtopic seeks to develop innovative low-cost, damage tolerant, reusable and lightweight hot structure technology applicable to atmospheric entry vehicles, exposed to extreme temperatures between 1000° C to 2200° C. The material systems of interest for use in developing the hot structure technology include: advanced carbon-carbons (C-C), ceramic matrix composites (CMC), or advanced high temperature metals. Potential applications of the hot structure technology include: primary load-carrying aeroshell structure, control surfaces, and propulsion system components (such as hot gas valves and passively-cooled nozzle extensions). Proposals should address one or more of the following:

- Employing advanced materials in novel structural system concepts for thermal management associated with atmospheric entry and/or hypersonic flight.
- Utilizing preceramic polymers for producing advanced material systems with tailored chemical, mechanical, and physical properties. Of particular interest are polymers yielding ceramics in the SiOC, SiNBC, SiNC or SiC families in the form of ceramic foams, fibers, coatings, and fiber-reinforced CMC, for use in a hot structure concept.
- Material/structural architectures and multifunctional systems providing significant improvements of interlaminar mechanical properties while maintaining in-plane and thermal properties compared to state-of-the-art C-C or CMC. Examples include: incorporating through the thickness stitching or 3D woven preforms.
- Improvements in manufacturing process and/or material design to achieve repeatable and uniform material properties, scalable to actual vehicle components; specifically, data obtained from flat-panel test coupons should represent the properties of future flight vehicles.
- High temperature oxidation resistant coating integrated with a hot structure concept to extend performance for multiple cycles up to 2200^{o} C.

For proposals to this subtopic, research, testing, and analysis should be conducted to demonstrate technical feasibility during Phase I and show a path towards Phase II hardware demonstration. Phase I feasibility studies should also address cost and risk associated with the hot structures technology. At completion of Phase I, project deliverables should include: coupon specimens of components adequate for thermal/mechanical and/or arc-jet testing and a final report that is acceptable for publication as a NASA Technical Memorandum. Emphasis should be on the delivery of a manufacturing demonstration unit for NASA testing at the completion of the Phase II contract. In addition, Phase II studies should address vehicle integration. Opportunities and plans should also be identified and summarized for potential commercialization.

Z7.01 Entry Descent & Landing Sensors for Environment Characterization, Vehicle Performance, and Guidance, Navigation and Control (SBIR)
Lead Center: ARC
Participating Center(s): JPL, JSC, LaRC
Related Subtopic Pointer(s): S1.01, S3.04, H9.03

NASA manned and robotic missions to the surface of planetary or airless bodies require Entry, Descent, and Landing (EDL). For many of these missions, EDL represents one of the riskiest phases of the mission. Despite the criticality of the EDL phase, NASA has historically gathered limited engineering data from such missions, and use of the data for real-time Guidance, Navigation and Control (GN&C) during EDL for precise landing (aside from Earth) has also been limited. Recent notable exceptions are the Orion EFT-1 flight test, MSL MEDLI sensor suite, and the planned sensor capabilities for Mars 2020 (MEDLI2 and map-relative navigation). NASA requires EDL sensors to:

- Understand the in-situ entry environment.
- Characterize the performance of entry vehicles.
- Make autonomous and real-time onboard GN&C decisions to ensure a precise landing.

This subtopic describes three related technology areas where innovative sensor technologies would enable or enhance future NASA EDL missions. Candidate solutions are sought that can be made compatible with the environmental conditions of deep spaceflight, the rigors of landing on planetary bodies both with and without atmospheres. Proposers may submit to topic areas 1, 2 or 3 below:

- High accuracy, light weight, low power fiber optic sensing system for EDL instrumentation systems.
- Miniaturized spectrometers for vacuum ultraviolet & mid-wave infrared radiation in-situ measurements during atmospheric entry.
- Novel sensing technologies for EDL GN&C and small body proximity operations.

High Accuracy, Light Weight, Low Power Fiber Optic Sensing System for EDL Instrumentation Systems
Current NASA state-of-the-art EDL sensing systems are very expensive to design and incorporate on planetary missions. Commercial fiber optic systems offer an alternative that could result in a lower overall cost and weight, while actually increasing the number of measurements. Fiber optic systems are also immune to Electro-Magnetic Interference (EMI) which reduces design and qualification efforts. This would be highly beneficial to future planetary missions requiring thermal protection system (TPS).

Fiber optic sensing systems can offer benefits over traditional sensing system like MEDLI and MEDLI2, and can be used for both rigid and flexible TPS. To be considered against NASA state-of-the-art TPS sensing systems for future flight missions, fiber optic systems must be competitive in sensing capability (measurement type, accuracy, quantity), and sensor support electronics (SSE) mass, size and power.

The upcoming Mars 2020 mission will fly the Mars Entry, Descent, and Landing Instrumentation II (MEDLI2) sensor suite consisting of a total of 24 thermocouples, 8 pressure transducers, 2 heat flux sensors, and a radiometer embedded in the TPS. This set of instrumentation will directly inform the large performance uncertainties that contribute to the design and validation of a Mars entry system. A better understanding of the entry environment and TPS performance could lead to reduced design margins enabling a greater payload mass fraction and smaller landing ellipses. Fiber optic sensing systems can offer benefits over traditional sensing system like MEDLI and MEDLI2, and can be used for both rigid and flexible TPS. Fiber optic sensing benefits include, but are not limited to; sensor immunity to EMI, the ability to have thousands of measurements per fiber using Fiber Bragg grating (FBG), multiple types of measurements per fiber (i.e., temperature, strain, and pressure), and resistance to metallic corrosion.

To be considered against NASA state-of-the-art TPS sensing systems for future flight missions, fiber optic systems must be competitive in sensing capability (measurement type, accuracy, quantity), and sensor support electronics (SSE) mass, size and power. Therefore, NASA is looking for a fiber optic system that can meet the following requirements:

- Sensing Requirements:
  - TPS Temperature: Measurement Range: -200 to 1250° C (up to 2000° C preferred), Accuracy: +/- 5° C desired.
  - Surface Pressure: Measurement Range: 0-15 psi, Accuracy: +/-1%
- Sensor Support Electronics Requirements (including enclosure):
  - Weight: 12 lbs or less,
  - Size: 240 cubic inches or smaller,
  - Power: 15W or less,
  - Measurement Resolution: 14-bit or Higher,
  - Acquisition Rate per Measurement: 16 Hz or Higher.
  - Compatibility with other sensors types (e.g.) Heat Flux, Strain, Radiometer, TPS recession.

Miniaturized Spectrometers for Vacuum Ultraviolet & Mid-Wave Infrared Radiation In-Situ Measurements During Atmospheric Entry

The current state-of-the-art for flight radiation measurements includes radiometers and spectrometers. Radiometers can measure heating integrated over a wide wavelength range (e.g., MEDLI2 Radiometer), or over a narrow-wavelength bands (COMARS+ ICOTOM at 2900 nm and 4500 nm). Spectrometers gather spectrally resolved signal and have been developed for Orion EM-2 (combined Ocean Optics STS units with range of 190-1100 nm). A spectrometer provides the gold standard for improving predictive models and improving future entry vehicle designs.

For NASA missions through CO_2 atmospheres (Venus and Mars), a majority of the radiative heating occurs in the midwave infrared range (MWIR: 1500 nm - 6000 nm) [Brandis, AIAA 2015-3111]. Similarly, for entries to Earth, the radiation is dominated by the Vacuum Ultraviolet range (VUV: 100 - 190 nm) [Cruden, AIAA 2009-4240]. Both of these ranges are outside of those detectable by available miniaturized spectrometers. While laboratory scale spectrometers and detectors are available to measure these spectral ranges, there are no versions of these spectrometers which would be suitable for integration into a flight vehicle due to lack of miniaturization. This SBIR calls for miniaturization of VUV and MWIR spectrometers to extend the current state of the art for flight diagnostics.

Advancements in either VUV or MWIR measurements are sought, preferably for sensors with:

- Self-contained with a maximum dimension of ~10 cm or less.
- No active liquid cooling.
- Simple interfaces compatible with spacecraft electronics, such as RS232, RS422, or Spacewire.
- Survival to military spec temperature ranges [-55 to 125C].
- Power usage of order 5W or less.

Novel Sensing Technologies for EDL GN&C and Small Body Proximity Operations

NASA seeks innovative sensor technologies to enhance success for EDL operations on missions to other planetary bodies (including Earth's Moon, Mars, Venus, Titan, and Europa). Sensor technologies are also desired to enhance proximity operations (including sampling and landing) on small bodies such as asteroids and comets. NASA is also looking for high-fidelity real-time simulation and stimulation of passive and active optical sensors for computer vision at update rates greater than 2 Hz to be used for signal injection in terrestrial spacecraft system test beds. These solutions are to be focused on improving system-level performance Verification and Validation during spacecraft assembly and test.

Sensing technologies are desired that determine any number of the following:

- Terrain relative translational state (altimetry/3-axis velocimetry).
- Spacecraft absolute state in planetary/small-body frame (either attitude, translation, or both).
- Terrain characterization (e.g., 3D point cloud) for hazard detection, absolute and/or relative state estimation, landing/sampling site selection, and/or body shape characterization.
- Wind-relative vehicle state and environment during atmospheric entry (e.g., velocity, density, surface pressure, temperature).

Successful candidate sensor technologies can address this call by:

- Extending the dynamic range over which such measurements are collected (e.g., providing a single surface topology sensor that works over a large altitude range such as 1m to >10km, and high attitude rates such as greater than 45° /sec).
- Improving the state-of-the-art in measurement accuracy/precision/resolution for the above sensor needs.

- Substantially reducing the amount of external processing needed by the host vehicle to calculate the measurements.
- Significantly reducing the impact of incorporating such sensors on the spacecraft in terms of Size, Weight, and Power (SWaP), spacecraft accommodation complexity, and/or cost.
- Providing sensors that are robust to environmental dust/sand/illumination effects.
- Mitigation technologies for dust/particle contamination of optical surfaces such as sensor optics, with possible extensibility to solar panels and thermal surfaces for Lunar, asteroid, and comet missions.
- Sensing for wind-relative vehicle velocity, local atmospheric density, and vehicle aerodynamics (e.g., surface pressures and temperatures).

Z7.03 Deployable Aerodynamic Decelerator Technology (SBIR)
Lead Center: LaRC
Participating Center(s): ARC, GRC, JSC, MSFC

Background: NASA is developing deployable aerodynamic decelerators to enhance, and enable, robotic and human missions to destinations such as Mars, Venus, and Titan, as well as returning payloads to Earth from Low Earth Orbit (LEO). The biggest challenge facing Entry, Descent and Landing systems is the delivery of human class missions to the surface of Mars. One benefit of deployable decelerators is that a relatively large atmospheric entry vehicle can be packed into, and deployed from, a comparatively small space transit vehicle. Eliminating these entry vehicle size constraints imposed by the launch system enables delivery of very large (20 metric tons or more) of usable payload required to support Mars human exploration. For reference, it is estimated that safely landing 20 metric tons may need a deployable diameter as large as 20 meters. The technology also allows for the return of payloads from LEO and recovery of launch assets that will reduce the cost of space access. This subtopic area solicits innovative technology solutions applicable to deployable entry vehicles. Specific technology development areas include:

- Advancements in woven and non-woven textile technologies that can be used in the design and production of mass efficient flexible thermal protection systems (TPS) such as durable, high-temperature fibrous insulators capable of efficiently suppressing both radiation and convective heat transfer at temperatures above 1200° C. TPS concepts must be flexible to allow compact stowage. They can be passive approaches that do not rely on decomposition to manage heat loads, or active systems, such as phase change approaches, that enhance thermal management capability. Reusable concepts and/or materials, capable of surviving multiple atmospheric entries, are of particular interest. Focus of Phase I development can be subscale manufacturing demonstrations that lead to Phase II manufacturing scale up that is relevant to Mars human exploration.
- Concepts that augment the drag of rigid or deployable hypersonic aerodynamic decelerators subsequent to the hypersonic entry phase. Envisioned secondary decelerator systems would be activated after the entry heat pulse during the earliest stages of the supersonic regime. Devices can be either deployable or rigid design concepts, but must be suitable for, and scalable to, a Mars human exploration architecture. Inflatable structural designs and deployment methods for a secondary decelerator that augment drag over the primary decelerator by a factor or 2 to 4 are to be considered. Phase I proof of concept and preliminary design requirements that will lead to a demonstration under a Phase II effort are of interest.
- Inflatable structural concepts with non-axisymmetric geometries, or features, that provide lift for flight control during atmospheric entry. Envisioned concepts can be deployed or adjusted to provide active flight control to improve landing accuracy. Concepts that provide lift-to-drag ratios of 0.1 to 0.2 during hypersonic flight conditions appear to be sufficient for human exploration of Mars. Lift-to-drag ratios of 0.8 or more may provide benefit, or may be enabling, for other destinations with atmospheres. Innovations can include morphing concepts, drag modulators, or center of gravity offset approaches. Thermal management and response time should be addressed. Phase I proof of concept and preliminary design requirements that will lead to a demonstration under a Phase II effort are of interest.

T9.01 Lander Systems Technology (STTR)
Lead Center: MSFC
Participating Center(s): GRC, JSC, LaRC
Related Subtopic Pointer(s): Z10.02

Lander Components and Affordable/Sustainable Development
Lander systems require many components that will need to advance beyond their current capability to meet the needs of lander missions. A lander is essentially a system of components and each must be developed to enable mission success. Several components for lander systems have been identified as weak points or long lead development and/or qualification concerns that necessitate advancement. These include the following:

- Additive manufacturing for LOX/Methane and other propulsion components. Additional development in the area of additive manufacturing for propulsion components will continue to open up the trade space for lander systems.
- Testbed and hardware-in-the-loop testing systems that allow rapid hardware development and permit parallel design and test efforts.
- Less expensive methods for qualifying Commercial Off the Shelf (COTS) components as well as flight developed components.
- Developments to improve mission design and simulation tools. With advancing Technology Readiness Level (TRL) components, better mission design and simulation tools will be needed to capture and model the changing lander systems in order to leverage improvements.
- Avionics and flight software development is needed for proper lander systems control, navigation, propulsion operation.
- Lander systems scalability studies to facilitate larger payloads.
- Deep Space Engine capability; particularly in Monomethylhydrazine (MMH) and Mixed Oxides of Nitrogen (MON-25) development which allow lower propellant temperatures.

LOX/Methane Propulsion Technology (see also Z10.02)
LOX/Methane propulsion remains attractive to lander systems and will require further advancements to leverage its full potential. LOX/Methane Propulsion Technology is focused on propulsion systems and engine components development that increase durability, reliability, and capability, while reducing the mass of the component or the overall system. These technologies include the following:

- Integrated propulsions systems that reduce duplication of systems to support main engines and Reaction Control Systems (RCS).
- 25lbf to 100 lbf thrust Reaction Control Systems (RCS) to enable higher payloads and manned missions.
- Engine components designed for 1000 lbf to 4000 lbf thrust LOX/Methane systems.
- Low leakage valves that minimize propellant loss over long duration missions. With missions to Mars taking years, low leakage valves are essential to conserve propellant that will be needed for ascent and maneuvers.
- Reliable, low actuator load valves designed to operate and be compatible with cryogenic propellants (such as Methane). Low actuator loads keep power and mass requirements to a minimum which is of particular importance for long duration lander missions.
- LOX/Methane Engine components compatible with In-Situ Resource Utilization capabilities that reduce launch mass.
- Design and test demonstration of Integrated Main Propulsion System (MPS) Reaction Control with LOX/Methane.
- Large scale nozzle and nozzle extension technology (> 40” dia) using novel processing techniques that reduce fabrication costs and schedule.

- High temperature (>2600° F) nozzle material development to support in-space, ultra-light weight applications in a methane environment. This includes but is not limited to Carbon-Carbon (C-C) and refractory metal nozzles that are regeneratively or radiatively-cooled.

In-Situ Resource Utilization (ISRU) Compatible Propulsion
ISRU compatible propulsions systems will be essential to make long-term manned missions possible with landers. ISRU compatible propulsion technologies include the following:

- Liquefaction system design and testing.
- Liquefaction subsystem development that demonstrates the performance required for a Mars ISRU plant.
- Integrated liquefaction and propulsion system concepts.
- Tanking and Cryogenic Fluid Management (CFM) capabilities for ISRU applications.
- Insulation systems for ISRU propulsion.

Lander Systems of Interest
Additional lander systems are needed to develop capabilities and open trade spaces for further concepts. Other lander systems of interest include the following:

- Reduced toxicity hypergolic thrusters and components.
- Multi-engine architecture with distributed avionics.
- Long duration wetted seals for MON-25 propulsion.
- Engine cooling technologies.
- Variable Conductance Heat Pipes (active and/or passive).
- Alternate Reaction Control System (RCS) pressurization capability.
- Valve drivers for high speed valves.
- Guidance, Navigation, and Control senor studies and development.
- Propellant vapor pressure studies.
- Tank slosh management.
- Flight computers and flight software development.

Focus Area 13: Information Technologies for Science Data
Lead MD: SMD

NASA Missions and Programs create a wealth of science data and information that are essential to understanding our earth, our solar system and the universe. Advancements in information technology will allow many people within and beyond the Agency to more effectively analyze and apply these data and information to create knowledge. For example, modeling and simulation are being used more pervasively throughout NASA, for both engineering and science pursuits, than ever before. These tools allow high fidelity simulations of systems in environments that are difficult or impossible to create on Earth, allow removal of humans from experiments in dangerous situations, provide visualizations of datasets that are extremely large and complicated, and aid in the design of systems and missions. In many of these situations, assimilation of real data into a highly-sophisticated physics model is needed. Information technology is also being used to allow better access to science data, more effective and robust tools for analyzing and manipulating data, and better methods for collaboration between scientists or other interested parties. The desired end result is to see that NASA data and science information are used to generate the maximum possible impact to the nation: to advance scientific knowledge and technological capabilities, to inspire and motivate the nation's students and teachers, and to engage and educate the public.

S5.01 Technologies for Large-Scale Numerical Simulation (SBIR)
Lead Center: ARC
Participating Center(s): GSFC

NASA scientists and engineers are increasingly turning to large-scale numerical simulation on supercomputers to advance understanding of complex Earth and astrophysical systems, and to conduct high-fidelity aerospace engineering analyses. The goal of this subtopic is to increase the mission impact of NASA's investments in supercomputing systems and associated operations and services. Specific objectives are to:

- Decrease the barriers to entry for prospective supercomputing users.
- Minimize the supercomputer user's total time-to-solution (e.g., time to discover, understand, predict, or design).
- Increase the achievable scale and complexity of computational analysis, data ingest, and data communications.
- Reduce the cost of providing a given level of supercomputing performance for NASA applications.
- Enhance the efficiency and effectiveness of NASA's supercomputing operations and services.

Expected outcomes are to improve the productivity of NASA's supercomputing users, broaden NASA's supercomputing user base, accelerate advancement of NASA science and engineering, and benefit the supercomputing community through dissemination of operational best practices.

The approach of this subtopic is to seek novel software and hardware technologies that provide notable benefits to NASA's supercomputing users and facilities, and to infuse these technologies into NASA supercomputing operations. Successful technology development efforts under this subtopic would be considered for follow-on funding by, and infusion into, NASA's high-end computing (HEC) projects - the High-End Computing Capability project at Ames and the Scientific Computing project at Goddard. To assure maximum relevance to NASA, funded SBIR contracts under this subtopic should engage in direct interactions with one or both HEC projects, and with key HEC users where appropriate. Research should be conducted to demonstrate technical feasibility and NASA relevance during Phase I and show a path toward a Phase II prototype demonstration.

Offerors should demonstrate awareness of the state-of-the-art of their proposed technology, and should leverage existing commercial capabilities and research efforts where appropriate. Open source software and open standards are strongly preferred. Note that the NASA supercomputing environment is characterized by:

- HEC systems operating behind a firewall to meet strict IT security requirements.
- Communication-intensive applications.
- Massive computations requiring high concurrency.
- Complex computational workflows and immense datasets.
- The need to support hundreds of complex application codes - many of which are frequently updated by the user/developer.

Projects need not benefit all NASA HEC users or application codes, but demonstrating applicability to an important NASA discipline, or even a key NASA application code, could provide significant value. For instance, a GPU accelerated (or multi-core) planetary accretion code such as LIPAD (Lagrangian Integrator for Planetary Accretion and Dynamics) could be one possible project.

The three main technology areas of S5.01 are aligned with three objectives of NSCI, the National Strategic Computing Initiative, announced by the White House in July 2015. The overarching goal of NSCI is to coordinate and accelerate U.S. activities in HEC, including hardware, software, and workforce development, so that the U.S. remains the world leader in HEC technology and application. NSCI charges every agency that is a significant user of HEC to make a significant contribution to this goal. This SBIR subtopic is an important part of NASA's contribution to NSCI. See https://www.nitrd.gov/nsci/index.aspx for more information about NSCI. The three main elements of S5.01 are:

- Many NASA science applications demand much faster supercomputers. This area seeks technologies to accelerate the development of an efficient and practical exascale computing system (1018 operations per second). Innovative file systems that leverage node memory and a new exascale operating system geared toward NASA applications are two possible technologies for this element. At the same time, this area calls for technology to support co-design (i.e., concurrent design) of NASA applications and exascale supercomputers, enabling application scaling to billion-fold parallelism while dramatically increasing memory access efficiency. This supports NSCI Objective 1 (Accelerating delivery of a capable exascale computing system that integrates hardware and software capability to deliver approximately 100 times the performance of current 10 petaflop systems across a range of applications representing government needs.).
- Data analytics is becoming a bigger part of the supercomputing workload, as computed and measured data expand dramatically, and the need grows to rapidly utilize and understand that data. This area calls for technologies that support convergence of computing systems optimized for modeling & simulation and those optimized for data analytics (e.g., data assimilation, data compression, image analysis, machine learning, visualization, and data mining). In-situ data analytics that can run in-memory side-by-side with the model run is another possible technology for this element. This supports NSCI Objective 2 (Increasing coherence between the technology base used for modeling and simulation and that used for data analytic computing.).
- Presently it is difficult to integrate cyberinfrastructure elements (supercomputing system, data stores, distributed teams, instruments, mobile devices, etc.) into an efficient and productive science environment. This area seeks technologies to make elements of the supercomputing ecosystem much more accessible and composable, while maintaining security. This supports NSCI Objective 4 (Increasing the capacity and capability of an enduring national HPC ecosystem by employing a holistic approach that addresses relevant factors such as networking technology, workflow, downward scaling, foundational algorithms & software, accessibility, and workforce development.).

S5.02 Earth Science Applied Research and Decision Support (SBIR)
Lead Center: GSFC
Participating Center(s): JPL, MSFC

The NASA Earth (http://science.nasa.gov/earth-science/) and Applied Science (http://appliedsciences.nasa.gov/) programs seeks innovative and unique approaches to increase the utilization and extend the benefit of Earth Science research data to better meet societal needs. The main focus of this subtopic is improving the pipeline from NASA Earth Science data and products to a range of end user communities to support decision making. To that end, one area of interest is new or improved decision support tools for a variety of applications areas (http://appliedsciences.nasa.gov/sites/default/files/ar2014/index.html#/applications-areas), including but not limited to, disaster response, agricultural and food security, water resource management, ecological forecasting, land surface modeling, air quality and health.

Under this subtopic, NASA also invites proposals from companies that provide innovative data science tools to extract new insights from applicable NASA Earth science dataset that can support emerging commercial activities. State-of-the-art geospatial data analytics such as automated image classification, feature extraction, or change detection deployed at scale can reveal new insights and drive increased utilization of publicly available NASA Earth science data. NASA Earth science data may be fused with non-NASA remote sensing data or even non-remote sensing data to provide context or other added value and unlock new information products. Areas of commercial focus (not all inclusive) include agricultural, financial services, transportation, logistics, oil, gas, resource extraction, land management, water resource management, and leisure industries.

This subtopic aims to connect and demonstrate the integration of NASA Earth science data and models into societal benefit areas and commercial applications. This solicitation encourages project teams to consider products from recently-launched NASA Missions, as well as simulated products from upcoming, planned missions (e.g., SMAP, GPM, Landsat, GRACE, GRACE-FO, IceSat-2, SWOT), and field campaigns or other observatories (e.g., Airborne Snow Observatory (http://aso.jpl.nasa.gov/), SnowEx (https://snow.nasa.gov/snowex)). Projects may consider connecting with NASA-sponsored activities including, but not limited to SPoRT (http://weather.msfc.nasa.gov/sport/) and NASA Earth Exchange- NEX (https://nex.nasa.gov/nex/). The NASA Applied Science Program sponsors several Capacity Building Programs, including SERVIR (http://www.nasa.gov/mission_pages/servir/), DEVELOP (https://develop.larc.nasa.gov/) and ARSET (https://arset.gsfc.nasa.gov/); proposed projects may find it valuable to leverage resources and relationships with these capacity building activities. Proposed projects should also note that NASA hosts a broad range of modeling systems and related that have been highly valuable to operational and end user communities, including MERRA-2 (https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/), climate project information from GISS GCMs (http://www.giss.nasa.gov/projects/gcm/) and Land Data Assimilation Systems (LDAS (http://ldas.gsfc.nasa.gov/gldas/).

Currently, creating decision support tools (DST) that effectively utilize remote sensing data requires significant efforts by experts in multiple domains. NASA Earth Science data, while accessible, is massive in breadth and scope – a true “Big Data” problem. However, the formatting of the data is not easily accessed or readily usable beyond remote sensing experts and the research community, suggesting that application by commercial users is even more challenging. While the data has commercial use, it is underutilized due to accessibility and translation issues. This creates a barrier to the widespread use of Earth observations by state and local governments, businesses, and the public. This subtopic aims to democratize the creation of Earth science driven decision support tools and to unleash a creative explosion of DST development that significantly increases the return on investment for Earth science missions.

Specifically, this subtopic develops core capabilities that can be integrated to build multiple remote sensing driven DSTs customized to the requirements of different users in varied fields. Proven development and commercialization strategies will be used to meet these objectives. The goal of this solicitation is to directly link what is being done at NASA with the end user community to support decision making. The outcomes of this work could include new tools, integration systems, visualization interfaces, among others. Responsive proposals must include a clear identification of a data product(s), modeling tools, or NASA activities that will be used and a clear end user or business application to which the tools, systems, etc. are intended to support for applied research and decision support. Proposals should explain how the proposed capabilities will address an end user need, business opportunity or gap area in decision support capabilities. Proposals should also outline existing capabilities, including software, models, and data that are already implemented at NASA or through related NASA activities and how the proposed activities may leverage, complement, or expand from existing infrastructure. Projects must be mindful of NASA security restrictions in the development of new activities.

Ultimately, this subtopic aims to provide commercial analytics firms and other data-driven companies with improved access to, and translation of, NASA data. The subtopic supports research and technology focused on innovative data science tools and information products that will improve business productivity, reduce the cost of operations, and provide for better informed decision making. Research proposed to this subtopic should demonstrate technical feasibility during Phase I, and in partnership with Commercial customers, show a path toward a Phase II prototype demonstration, with significant communication with commercial stakeholders to increase the potential for non-governmental market penetration.

S5.03 Machine Learning and Deep Learning for Science and Engineering (SBIR)
Lead Center: GSFC
Participating Center(s): ARC, JPL, LaRC

NASA research and engineering has begun exploring the application of Machine Learning and Deep Learning (ML/DL) within Science and Engineering. While there are many problems that can be addressed with ML/DL, the adoption of these techniques and technologies are slow due to the large learning curve associated with the application of this technology and the applicability of commercial and open source tools to specific problems of interest for NASA.

This subtopic area seeks to close those gaps and accelerate the use of ML/DL across NASA Science and Engineering. The emphasis of this subtopic will be on the application of ML/DL to solve challenging Science and Engineering problems and also for new technologies to enable and accelerate the use of ML/DL within NASA.

Proposals MUST be in alignment with existing and/or future NASA programs and address or extend a specific need or question for those programs. It is therefore incumbent upon the proposers to have discussions with NASA scientists and engineers to receive feedback prior to submission and to adequately show the alignment of the proposed innovation to NASA.

Specifically, innovative proposals are being sought to assist NASA Science and Engineering in the following two areas:

- Application of ML/DL to solve challenging and unique problems in order to significantly advance NASA's Science and Engineering.
- New algorithms, methods, or tools to accelerate the use and adoption of ML/DL within NASA.

Research proposed to this subtopic should demonstrate technical feasibility during Phase I, and in partnership with scientists, show a path toward a Phase II prototype demonstration, with significant communication with missions and programs to later plan a potential Phase III infusion. It is highly desirable that the proposed projects lead to solutions that will be infused into NASA programs and projects.

Tools and products developed under this subtopic may be developed for broad public dissemination or used within a narrow scientific community. These tools can be plug-ins or enhancements to existing software, on-line data/computing services, or new stand-alone applications or web services, provided that they promote interoperability and use standard protocols, file formats, and Application Programming Interfaces (APIs).

S5.04 Integrated Science Mission Modeling (SBIR)
Lead Center: JPL
Participating Center(s): GSFC, KSC

The focus for the coming year is on the integration of model-based approaches into NASA's life-cycle processes: Design, Build, Assemble, Integrate and Operate. Specific areas of interest supporting one or more of these life-cycle processes are listed below. Proposers are encouraged to be familiar with the State-of-the-art in these areas. Proposers are also encouraged to address more than one of these areas with an approach that emphasizes integration with others on the list.

Visualization and tool interaction
Techniques and tools for:

- Using MBSE to support trade evaluation and capabilities for visualization and comprehension of results/options. NASA needs the ability to engage the intuition and experience of those without significant tool expertise.
- Enabling SysML profiles to be more easily created, integrated and compared with other profiles. NASA has a wide variety of users and use cases and the ability to better manage profiles (or the equivalent) is important.
- Enabling early phase agility. In the early phases, rapid trade space exploration presents challenges in utilizing typical models or library elements, trade space navigation, rationale capture, and archival/retrieval of options.

Model Management:

- Methods for archiving/storing, retrieving and integrating model fragments. The approach should be easy to use and not require significant new infrastructure investment.
- Approaches for defining and utilizing permission/access control in a collaborative environment.

Training and Engagement

As NASA continues down the Model-based approach to the engineering disciplines it will be imperative to engage and develop the skilled engineers necessary to achieve our desired end state. To that end, NASA seeks approaches for initial engagement with MBSE/SysML that are "lightweight" without onerous costs and complexity. This must include approaches for transitioning to "full featured" tool sets without significant retraining. Proposers encouraged, but not required, to consider utilizing plug-ins to existing tool sets

Tool and Process integration

As MBSE continues to develop at NASA, it is critical to explore and develop tools and techniques for better integration at the boundaries of Systems Engineering both breadth (other disciplines) and depth (detailed information). Integration (breadth) includes integration with other discipline tools and processes (e.g., Finite Element Modeling, Circuit Analysis) as well as business and programmatic processes. Integration (depth) includes integration, or at least interfacing, with lower-level information (e.g., Piece part data, assembly process specifications). It is critical that we understand the nature of these interfaces, and reduce the complexity and difficulty of developing and maintaining these interfaces.

S5.06 Space Weather R2O/O2R Technology Development (SBIR)
Lead Center: GSFC
Related Subtopic Pointer(s): S3.08

NASA's role under the NSWAP is to provide increased understanding of the fundamental physics of the Sun-Earth system through space-based observations and modeling, develop new space-based technologies and missions, and monitor space weather for NASA's space missions. This SBIR subtopic is intended to solicit new enabling technologies as part of NASA's response to this national objective. While this subtopic will consider all concepts demonstrably related to NASA's Research-to-Operations/Operations-to-Research (R2O/O2R) responsibilities outlined in the NSWAP, four broad areas have been identified for priority development:

- NASA supports the Community Coordinated Modeling Center (CCMC), located at GSFC, as a centralized government-run facility that hosts, maintains, and validates heliophysics models, some of which will become suitable for use by the space weather operations and forecasting community. Innovations solicited include modernization of the CCMC core infrastructure, the preparation and validation of existing science models in preparation for transition to operations, and ideas for future models tied to space weather forecasting needs. Proposals directly tied to NASA's NSWAP activities may be given priority. Infrastructure improvement proposals should be coordinated with NASA CCMC requirements and needs, and outline the process for implementation, mitigations to ensure continued community access to CCMC resources throughout the transition process, and flexibilities that allow for future integration of additional modeling tools, archives, or repositories. For example, the CCMC is interested in technologies that enable utilization of high-end computing architectures to optimize system performance for tasks such as "runs on request (RoR).

- The Heliophysics System Observatory (HSO) data archives include a vast array of spacecraft observations suitable for the development of space weather benchmarks, which are the set of characteristics against which space weather events are measured. Baseline benchmarks have been established or are nearing completion. Innovations to further refine these benchmarks are solicited, as are concepts for future creative approaches utilizing new data types or models that could become available. Proposals should address the feasibility and utility of establishing any newly proposed functional benchmarks, preferably in coordination with one or more of the participating NSWAP agencies.
- A particular challenge is to combine the sparse, vastly distributed data sources with realistic models of the near-Earth space environment. Innovations across the broad range of data assimilation techniques are solicited, with the long-term goal of enabling future tools and protocols for the operations community. Proposals should address requirements that:
    - Develop space weather applications or technologies desired by operational organizations that augment existing and future needs.
    - Include the ability to integrate data from assets which typically do not share similar time series, utilize different measurement techniques (e.g., imaging vs in-situ particles and fields), and are distributed throughout the heliosphere.
    - Specify that new forecasting tools which can be straightforwardly validated by the CCMC or other equally robust validation methodology.
    - Examine the potential for integrating additional resources, such as ground based instrumentation e.g., USGS ground conductivity measurements which can be used to calculate geomagnetically induced currents.
- Heliophysics science relies on a wide variety of instrumentation for its research and often makes its data available in near-real-time for space weather forecasting purposes. Concepts are solicited for instrumentation concepts, flight architectures, and reporting systems that may be suitable for data assimilation into space weather monitoring and forecasting systems. This includes the miniaturization of existing systems and/or technologies deployable as an array of CubeSats. In order to be considered for investment, SBIR technologies should demonstrate comparable, or better, precision and accuracy when compared to the current state-of-the art. Further, SBIR instrument designs should avoid duplicating current NASA research spacecraft arrays or detector systems including those currently in formulation (e.g., SDO, Van Allen Probes, MMS, IMAP).

Proposals should demonstrate an understanding of the current state-of-the-art, describe how the proposed innovation is superior, and provide a feasible plan to develop the technology and infuse into a specific NSWAP activity.

Focus Area 14: In-Space and Advanced Manufacturing

Lead MD: HEOMD
Participating MD(s): STMD, STTR

NASA is seeking technological innovations that will accelerate development and adoption of advanced manufacturing technologies supporting a wide range of NASA Missions. NASA has an immediate need for more affordable and more capable materials and processes across its unique missions, systems, and platforms. Cutting-edge manufacturing technologies offer the ability to dramatically increase performance and reduce the cost of NASA's programs. This topic is focused on technologies for both the ground-based advancements and in-space manufacturing capabilities required for sustainable, long-duration space missions to destinations such as Mars. The terrestrial subtopic areas concentration is on research and development of advanced metallic materials and processes and additive manufacturing technologies for their potential to increase the capability and affordability of engines, vehicles, space systems, instruments and science payloads by offering significant improvements over traditional manufacturing methods. Technologies should facilitate innovative physical manufacturing processes combined with the digital twin modeling and simulation approach that integrates modern design and manufacturing. The in-space manufacturing subtopic areas which focus on the ability to manufacture parts in space rather than launch them from Earth represents a fundamental paradigm shift in the orbital supply chain model for human spaceflight. In-space manufacturing capabilities will decrease overall launch mass, while increasing crew safety and mission success by providing on-demand manufacturing capability to address known and unknown operational scenarios. In addition, advances in lighter-weight metals processing (on ground and in-space) will enable the delivery of higher-mass payloads to Mars and beyond. In order to achieve necessary reliabilities, in-situ process assessment and feedback control is urgently needed. Research should be conducted to demonstrate technical feasibility and prototype hardware development during Phase I and show a path toward Phase II hardware and software demonstration and delivering an engineering development unit for NASA testing at the completion of the Phase II that could be turned into a proof-of-concept system for flight demonstration.

H7.01 Development of Higher Strength Feedstocks for In-Space Manufacturing (SBIR)
Lead Center: MSFC
Participating Center(s): LaRC

There is a substantial rift between the properties of 3D printed thermoplastics (that can be produced with the current printers on the International Space Station) and the aerospace metals traditionally used in critical space systems. However, processes compatible with metals are more challenging from the perspective of operations in the space environment, often having volumes, powers, and safety hazards that may be incompatible with ISS requirements. As an alternative to adapting traditional AM of metals process to microgravity, this topic seeks development of higher strength feedstocks compatible with the FDM process that would uniquely enable NASA applications, facilitating sparing and/or palliative repair scenarios (the latter is where FDM would provide a stopgap solution until a more permanent fix could be developed). This work also has clear terrestrial benefits, as it stands to stands to significantly enhance the properties achievable with FDM techniques and expand the use of FDM processes for manufacturing beyond low-criticality applications. Proposers must clearly state how their development work under this opportunity advances the state of the art and enables new applications of AM.

This SBIR subtopic is intended to investigate development of materials and/or post-processing techniques that will:

- Narrow the gap between the properties of materials produced using FDM techniques and metals.
- Result in much higher strength plastics with isotropic properties and improved dimensional tolerances.
- Homogenize material by reducing presence of pores.

The solution may be obtained by a variety of approaches, including but not limited to:

- Novel post-processing or heat treatment techniques. Any techniques developed must be adaptable to the microgravity environment of ISS. Post-processing techniques must also preserve the characteristic dimensions of the part.
- Incorporation of nano or microfibers into filament feedstock.
- Benchtop materials development of high strength feedstock materials that are also extrudable with FDM. Feedstock materials which incorporate in-situ materials (such as those found on a planetary surface) and/or materials which represent polymer trash recyclables are of strong interest.
- Materials testing activities must be undertaken to demonstrate and quantify improvements in mechanical properties, densification, and dimensional accuracy possible with a proposed approach. Complementary

modeling efforts are not required, but will be value added in establishing predictive relationships between processing conditions and material outcomes.

Phase I SBIR is a feasibility demonstration and should provide:

- Development and implementation of new materials in FDM systems that represent a significant improvement over current material options.
- Materials testing and characterization to quantify material improvement over traditional FDM techniques or FDM manufactured material in the as-built condition.
- Proposed design approach for integrating methods developed into current or future ISM payloads for FDM as well as ground based machines and processes.
- Verification that material approaches or exceeds key mechanical performance targets for polymeric feedstocks sought under this opportunity: tensile strength of at least 200 MPa, specific strength of at least 100 kN-m/kg, Poisson's ratio of 0.20-0.45, and fracture toughness of at least 5 MPa/m$^{1/2.}$ Ability to meet these requirements will be demonstrated as part of the materials development activities in Phase I.

H7.02 In-situ Monitoring and Development of In-Process Quality Control for In-Space Manufacturing (ISM) Applications (SBIR)
Lead Center: MSFC
Participating Center(s): KSC, LaRC

The ability to ensure production of parts with repeatable quality is critical for ISM implementation. There are essentially two approaches to ensure consistency in the parts and the manufacturing process: a traditional qualification and certification (which may be difficult for ISM due to constraints on crew time and equipment size limitations) and online quality control (i.e., process monitoring, where in-situ monitoring of process signals provides information about the quality of the part produced by the process).

Qualification and certification processes for ISM require better machine and feedback control than is currently available with off the shelf printers and other small manufacturing systems. While traditional approaches to qualification and certification are also being pursued, a more immediate solution is that of online/off-line quality control techniques that are adaptable to ISM. This SBIR seeks approaches to real-time, in-situ quality assurance of parts manufactured in the space environment and specifically focuses on manufacturing platforms similar to those used on ISS. The solicitation seeks methods that can be demonstrated for FDM or nonmetallic additive processes initially but are also broadly applicable to other candidate manufacturing processes for ISM, including AM of metallics and potentially even CNC machining. The latter technologies will likely be incorporated in to the Fabrication Laboratory in some capacity.

Development of in-situ techniques for quality control applicable for ISM may utilize the following approaches or leverage other techniques not listed here:

- Online layer/trace monitoring would allow for rapid identification of defects as they are generated and well before the part is finished. In turn, this would allow for stoppage of the production run (thus conserving feedstock and lowering processing/recycling energy) or for the correction of defects by introducing layer compensation algorithms. Ideally, evaluation should occur with every layer (enabling corrective actions to be taken right away) but can also be done after a batch of layers. This approach may require:
    - A multi-sensor approach and the ensuing data fusion and signal processing to extricate sensor data signatures that point to anomalies in the current print layer. This might include a combination of vision, structured light profilometry, thermography (IR), temperature, etc. Sensors and measurement methods are needed for:

        - Dimension and geometry.
        - Roughness and general surface finish.
        - Defects, porosity and flaws.
        - Feedstock tolerance.
        - Energy source.
        - Microstructure and mesostructured.
        - Strength of the interlayer bonding.
        - Residual stresses.
    - Collection of extensive data that will help develop feedback systems, predictive processing and modeling capabilities. Defect taxonomies (type, frequency and size quantification) and algorithms will be needed to map the functional correlation between the type and size of defects and the potential impact on material composition and microstructure (thus mechanical and functional properties).
    - Validation of modeling with process measurements to enable robust process control (e.g., vision system identifies a defect/pore and process control system corrects and eliminates defect).
    - Use of statistical process control.
    - Measurement of in-situ materials properties.
    - In-situ, monitoring of operating conditions (e.g., temperature management and others) to reduce and control residual stresses and distortion.
    - On-demand/adaptive post-processing based on actual thermal history of part
- Off-line quality control (nondestructive testing), including traditional finished part inspection and verification. Less desirable because it is *post-mortem*. Must be non-destructive testing. Computer Tomography (CT) and X-Ray analyses have become the norm for aerospace components. Others include visual and instrument-based inspection of dimensional accuracy, surface finish and perhaps some mechanical/physical properties. Likely to be intensive on crew time and limited by size of equipment.

Phase I is a feasibility demonstration and should provide:

- Approach for in-situ quality control and verification of parts manufactured in space with clear adaptability to current and future ISM systems.
- Demonstration of approach:
    - Sensors integrated into a ground based AM system (can be FDM initially), but has high extensibility to other processes that operate in a similar volume.
    - Demonstrate that process signals acquired during build are correlated with and predictive of material outcomes (density, mechanical properties, other metrics) through a combination of material testing and statistical analysis.

Phase II would focus on integration of the system in a NASA ground-based ISM platform as a demonstration and development of closed-loop control systems. Phase III would integrate the technique/NDE system into an ISM platform on ISS and verify its efficacy for V&V applications.

H7.03 Plasma Jet Printing Technology for Printable Electronics in Space (SBIR)
Lead Center: ARC
Participating Center(s): MSFC

This emerging alternative needs further maturation before it can be used in space missions. Common inks and dispersions used in inkjet printing and aerosol systems must be usable in plasma jet printers with proper nebulizers for extended deposition times. Throughput vs. plasma cylinder/nozzle diameter needs to be optimized with possibility of multiple nozzles that can be arranged in a showerhead configuration either to increase throughput or mix various types of feedstock for alloy-type materials.

In Phase I, a print head that can print materials using plasma and tailor oxidation states of materials should be developed. The print head should have an integrated fluid delivery system that can work in microgravity environment and should use low weight power supply. A preliminary prototype printer demonstrating basic features of plasma printing is a preferred deliverable.

In Phase II, the technology should be advanced by showing capability of printing a wide range of materials including organics, inorganics and others. The system also should be advanced by using appropriately sized electrical components, flow controllers etc. for meeting space operation needs and including an enclosure for trapping any airborne materials that would ensure safe use in closed environments such as the International Space Station.

Atmospheric pressure plasma jet systems have cross cutting applications in sterilization and plasma treatment of surfaces as well. Phase II should demonstrate in-situ resource utilization applications of the plasma jet including in-space printable electronics, removal of biological contaminations in science tools, etc. The completed system at the end of the effort should have integrated hardware and software.

Z3.01 Advanced Metallic Materials and Processes Innovation (SBIR)
Lead Center: MSFC
Participating Center(s): JPL, LaRC

This subtopic addresses specific NASA needs in the broad area of metals and metals processes with the focus for this solicitation on solid state welding, additive manufacturing, and processing of specialty materials including bulk metallic glasses and nano-crystalline metallic alloys.

Solid State Joining
Topic areas for solid state welding revolve around joining metallic materials preferably using solid state welding processes such as friction stir, thermal stir, and ultrasonic stir welding. Higher melting point materials of interest include the nickel based super-alloys such as Inconel 718, Inconel 625, titanium alloys such as Ti-6Al-4V, GRCop, and Mondaloy. Lower melting point materials of interest include Aluminum alloys such as 2195 and 2219. The technology needs for solid state welding should be focused on process improvement, structural efficiency, quality, and reliability for propulsion and propulsion-related components and hardware.

For the 2018 solicitation, the solid state joining focus is:

- Advances in process control, temperature monitoring and control, closed loop feedback, and implementing changes to the process parameters such as temperature, power, welding speed, etc.
- Monitoring and controlling processing parameters in real time in order to make quality, defect-free weld joints with desired and optimal grain morphology, mechanical properties and minimal distortion.
- Innovations in in-situ diagnostic and non-destructive testing technologies for solid state welding.
- Decoupling of the stirring, heating, and forging process elements characteristic of thermal or ultrasonic stir welding to achieve greater process control.
- Solid state welding of aluminum alloys plates of thicknesses greater than ½ inch.

Additive Manufacturing
Several NASA programs are embracing metallic Additive Manufacturing (AM) technologies for their potential to increase the affordability of aerospace components by offering significant schedule and cost savings over traditional

manufacturing methods. This technology is rapidly evolving and a deeper understanding of the process is needed to support hardware development and the use of AM hardware. For this subtopic AM topic area needs are concentrated on advancing the state of the art for the development powder bed fusion and/or directed energy deposition processes. For the 2018 solicitation, the AM focus is:

- Surface finish improvements for internal and external AM components targeting a goal of 32 RMS; approaches may include in-situ process modifications to achieve better surface finishes directly from the AM machine, or secondary finishing approaches. The impact on total cycle time and cost from CAD to final part should be assessed as part of the justification for the approach proposed. The goal of work supporting this area is to help build the knowledge needed to support development of AM hardware.
- Development of hardware and/or process modifications to eliminate distortion and thermal residual stresses in as-built AM parts.
- Development of hardware and software tools that enable integrated CAD-to-part digital data capture, comparison, and archival for maintaining a "digital twin" correlation between parts and CAD design, slicing and tool path programming, in-process build information, secondary processing, and inspection data to document a traceable pedigree on parts.

Specialty Metals
In the specialty materials processing area, the focus for this solicitation is on bulk metallic glasses (BMG) and nano-crystalline metallic alloys. Specific areas of interest relate to optimized processing to fabricate these materials while retaining their unique microstructures and properties.

Specialty Metals: Nano-crystalline
Grain-size strengthening is a well-known phenomenon in metallic materials. The challenge for engineering applications has been maintaining ultrafine-grained microstructures in bulk materials. Processes that can demonstrate the production of stable, nano-grain structures without negative performance impacts are of interest. Exploiting these high-strength microstructures will enable new applications within NASA. One such application of interest is thin-walled structures, such as composite overwrapped pressure vessels (COPVs), where traditional material grain sizes approach the thickness of the part (< 25 grains through the wall). This leads to design challenges and concerns for fracture and fatigue properties. Ideally, nano-grained alloys with sufficient strength, ductility, and fracture/fatigue properties can be used to overcome design issues in thin-gage components.

For the 2018 solicitation of specific interest for nano-grained metallic alloys are innovative processing methods that:

- Produce bulk materials with grain sizes in the nanometer range for alloys of interest to NASA application (e.g., structural Al and titanium alloys).
- Ensure that these nano-grained structures are stable during:
    - Relevant thermal exposures experienced in aerospace applications of interest to NASA and meet typical property requirements for those applications, and/or,
    - post-fabrication heat treatment, if necessary to develop suitable properties, and/or,
    - incorporation into end use items via additive manufacturing methods.

Specialty Metals: Bulk Metallic Glass
Of specific interest for BMGs are innovative processing methods for rapid prototyping of net shape bulk metallic glass components. Product forms of interest are uniformly thin walled structures, structures of high dimensional accuracy and precision (from nm to cm scales), and structures with features larger than the critical casting thickness of the BMG alloy but still amorphous. Consideration must be given to the availability of BMG feedstocks or accommodating the

raw materials for in-situ alloy fabrication. Any approach should demonstrate control of contaminant elements (e.g., oxygen and carbon) or show an immunity to their presence.

For the 2018 solicitation of specific interest for bulk metallic glasses are innovative processing methods that:

- Rapid prototyping, while maintaining high dimensional accuracy.
- Uniform thin walled structures, that again, retain high dimensional accuracy.
- BMG structures with features that are larger than the critical casting thickness, but still amorphous.

T12.02 Extensible Modeling of Metallurgical Additive Manufacturing Processes (STTR)
Lead Center: JPL

The subtopic of modeling of additive processes is highly relevant to NASA as NASA is currently on a path to implement additive processes in space flight systems with little or no ability to model the process and thereby predict the results. In order to reliably use this process with a variety of materials for space flight applications, NASA has to have a much deeper understanding of the process. NASA is currently considering these processes for MOXIE, SHERLOC, ion engines and other spacecraft structural and multifunctional applications.

Additive manufacturing of development and flight hardware with metallic alloys is being developed by NASA and its various partners for a variety of spacecraft applications. These components are expected to see extreme environments coupled with a need for high-reliability (e.g., manned spaceflight), which requires a deeper understanding of the manufacturing processes. Modeling of the additive processes to provide accurate dimensional designs, preferred microstructures and defect-free is a significant challenge that would dramatically benefit from a joint academic-industry approach. The objective would be to create process models that are compatible with current alloys systems and additive manufacturing equipment which will provide accurate prediction of outcomes from a variety of additive manufacturing process parameters and materials combinations. The primary alloys of interest to NASA at this time include: Inconel 625 & 718, stainless steels, such as 304 and 316, Al10SiMg, Ti-6Al-4V, and copper alloys (GrCop-84). It is desired that the modeling approach address a focused material system, but be readily adaptable to eventually accommodate all of these materials. Therefore, the model should incorporate modest parameter changes coupled with being easily extensible for future alloys of interest to NASA. NASA is interested in modeling of the Selective Laser Melting (SLM), Electron Beam Melting (EBM) and Laser Engineered Net Shaping (LENS) processes.

Focus Area 15: Lightweight Materials Structures and Assembly / Construction

Lead MD: STMD
Participating MD(s): HEOMD, STTR

As NASA strives to explore deeper into space than ever before, lightweight structures and advanced materials have been identified as a critical need. The Lightweight Materials, Structures, Advanced Assembly and Construction focus area seeks innovative technologies and systems that will reduce mass, improve performance, lower cost, be more resilient and extend the life of structural systems. Reliability will become an enabling consideration for deep space travel where frequent and rapid supply and resupply capabilities are not possible.

Improvement in all of these areas is critical to future missions. Applications include structures and materials for launch, in-space and surface systems, deployable and assembled systems, integrated structural health monitoring (SHM) and technologies to accelerate structural certification. Since this focus area covers a broad area of interests, specific topics and subtopics are chosen to enhance and or fill gaps in the space and exploration technology development programs as well as to complement other mission directorate structures and materials needs.

Specific interests include but are not limited to:

- Improved performance and cost from advances in composite, metallic and ceramic material systems as well as nanomaterial and nanostructures.
- Improved performance and mass reduction in innovative lightweight structural systems, extreme environments structures and multifunctional/multipurpose materials and structures.
- Improved cost, launch mass, system resiliency and extended life time by advancing technologies to enable large structures that can be deployed, assembled/constructed, reconfigured and serviced in-space or on planetary surfaces.
- Improved life and risk mitigation to damage of structural systems by advancing technologies that enhance nondestructive evaluation and structural health monitoring.
- Improved approaches that provide the development of extreme reliability technologies.

The specific needs and metrics for this year's focus technology needs are requested in detail in the topic and subtopic descriptions.

H5.01 Mars Surface Solar Array Structures (SBIR)
Lead Center: LaRC
Participating Center(s): GRC
Related Subtopic Pointer(s): Z1.01

Human missions to the Mars surface will require tens of kilowatts of electrical power for life support, science, in-situ resource utilization (ISRU), and other equipment. Possible power sources include nuclear reactors and solar arrays with batteries or regenerative fuel cells. Solar arrays are a mature, reliable technology used on most spacecraft and increasingly for Earth terrestrial power, and also at small sizes up to ~3 m^2 for several successful Mars landers and rovers. However, human missions will need thousands of square meters of solar cells to generate the required power. Furthermore, the solar arrays must survive inevitable dust storms and possibly months of dormancy before and between crew visits.

This subtopic seeks structural and mechanical innovations for solar arrays with at least 1000 m^2 of total area that autonomously deploy from Mars landers. Design guidelines for these large deployable solar arrays are:

- Solar arrays must self-deploy.
- Total area: 1000 m^2. Extensibility to 1500+ m^2 is desirable.
- Mass goal: < 1.5 kg/m^2 including all mechanical and electrical components. Packaging goal: < 10 m^3 per 1000 m^2 of deployed area.
- Launch loads: 5 g axial, 2 g lateral, 145 dB OASPL.
- Lander may not have azimuth control (i.e., guaranteed landing clocking angle). State all assumptions concerning array orientation and sun pointing.
- Solar arrays deploy in Mars 0.38 gravity and low winds (use 0.5 g for preliminary design). Solar arrays operate in Mars 0.38 gravity and wind gusts (use 1.0 g for preliminary design).
- Must survive peak winds of 50-100 m/s and simultaneous upward winds of 25-50 m/s (dust devils) with maximum air density of 0.023 kg/m^3.
- Deployable on terrain with up to 0.5 m obstacles/depressions, 15 degree slopes, and potentially hidden hazards (e.g., sand-filled holes). Operating height > 0.5 m to avoid wind-blown sand collection.
- Time to deploy: < 8 hrs.
- Deployed strength: Ideally > 1 g to allow unconstrained Earth deployment qualification.

- Integrated dust abatement or removal methods. Dust accumulation is the #1 design risk issue for sustained solar power production on Mars.
- Tolerant of daily thermal cycling from -100° C to 25° C over a lifetime of 10-15 years.
- Describe the concept of operations (ConOps) including all packaging, deployment, and operating assumptions.

This subtopic seeks innovations in the following areas for Mars solar array structures:

- Novel packaging, deployment, retraction, terrain-following ground supports, or in-situ assembly or manufacturing concepts.
- Lightweight, compact components including booms, ribs, substrates, and mechanisms.
- Load-limiting devices to avoid damage during extreme winds.
- Optimized use of advanced ultra-lightweight materials (but not materials development).
- Validated modeling, analysis, and simulation techniques.
- High-fidelity, functioning laboratory models and test methods.

Proposals should emphasize structural and mechanical innovations, not photovoltaics, electrical, or energy storage innovations, although a complete solar array systems analysis is encouraged. If solar concentrators or solar tracking are proposed, strong arguments must be developed to justify why this approach is better from technical, cost, and risk points of view over fixed planar solar arrays. Of special interest are design innovations that improve NASA's proposed solar array concepts using multiple Compact Telescoping Arrays (CTAs) as depicted on Charts 16-19 of Reference 2. Load alleviation methods to avoid damage during extreme winds are also of high interest.

In Phase I, contractors should prove the feasibility of proposed innovations using suitable analyses and tests. In Phase II, significant hardware or software capabilities that can be tested at NASA should be developed to advance their Technology Readiness Level (TRL). TRLs at the end of Phase II of 3-4 or higher are desired.

References:

1. Joseph Appelbaum and Geoff Landis, "Photovoltaic Array for Martian Surface Power," 43rd Congress of the International Astronautical Federation, NASA TM-105827, August 28, 1992, https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19920024655.pdf.

2. Richard Pappa and Tom Kerslake, "Mars Surface Solar Arrays," FISO telecon seminar with recorded audio, June 7, 2017, http://spirit.as.utexas.edu/~fiso/telecon/Pappa-Kerslake_6-7-17/.

3. Lee Mason, "Mars Surface Power" panel, AIAA Propulsion and Energy Forum with recorded video, July 12, 2017, https://livestream.com/AIAAvideo/PropEnergy2017/videos/159709334.

Z4.01 MISSE Experiments (SBIR)
Lead Center: LaRC
Participating Center(s): MSFC
Related Subtopic Pointer(s): H8.01

Space technology experiments are solicited to fly on a new space environmental effects platform on the outside of the International Space Station (ISS). The new platform is called the MISSE-FF (Materials International Space Station Experiment - Flight Facility). The MISSE-FF provides experiment accommodations for both active experiments (requires power and communications) and passive experiments. The technology can be materials or non-materials (devices). The physical size of the experiments can vary depending on the technology being demonstrated (2 inches by 2 inches up to 7 inches by 14 inches). Of special interest are space technologies already developed under the NASA SBIR program, particularly technologies that would mature in TRL due to successful demonstration in the space environment. The proposal should justify the need for spaceflight exposure and justify that the ISS environment is adequate to gather the data they need. The commercial partner Alpha Space Test and Research Alliance, LLC (Alpha Space) plans to service the MISSE-FF every 6 months. The MISSE-FF data will be made available to the global community of researchers through the NASA MAPTIS (Materials and Processes Technical Information System) database. Phase I deliverables could be data from ground testing the candidate technology and passive samples for flight on the MISSE-FF. Phase II deliverables could include an active technology experiment, packaged and ready for flight on the MISSE-FF. The experiments would fly free of charge with standard services on the NASA surface area allocation of the MISSE-FF. Any optional services desired from Alpha Space should be included in the proposal budget.

Z4.02 In-Space Sub-Modular Assembly (SBIR)
Lead Center: LaRC
Participating Center(s): GSFC, JSC, MSFC

NASA envisions that persistent (very long duration) assets in space will require modular assembly architectures and interfaces to facilitate routine expansion, upgrade and refurbishment at the module and submodule level. This subtopic seeks novel approaches to two classes of module interface systems.

First, autonomous (and highly automated) approaches and hardware concepts that support the interconnection of modules in the 100 – 5,000 kg range using some form of space robotics. (Note: The robotic manipulation systems are not the subject of this solicitation.) The objective of this first subtopic area is to minimize the parasitic mass from the joints and modularity features that are required for inter-module assembly. The lightweight connections between modules must include both electrical (power and data) and structural connections. Joining strategies that support fluid connections are of interest but not necessary to be responsive to this subtopic area. The structural connection should occur at a minimum of 3 discrete locations fixing the rigid body motion of the 2 modules in all 6 degrees of freedom while isolating (minimizing) forces resulting from thermal induced strain between the modules consistent with a LEO orbit. The three (or more) connections do not have to occur simultaneously.

The second assembly need is the development of a lightweight modular, palletizing system to support transport, emplacement and exchange of sub-modules in the 1-100 kg range. The palletizing system must support power and structural connections between the pallet and supporting backbone structure (fluid connections are a plus). Important considerations for the system are structurally efficient approaches that minimize parasitic mass, volume and power necessary to operate the palletizing system while minimizing forces resulting from temperature induced strain consistent with a LEO orbit.

Z11.01 NDE Sensors (SBIR)
Lead Center: LaRC
Participating Center(s): ARC, JSC
Related Subtopic Pointer(s): T13.01

Technologies sought under this SBIR program can be defined as advanced sensors, sensor systems, sensor techniques or software that enhance or expand NASAs current senor capability. It desirable but not necessary to target structural components of space flight hardware. Examples of space flight hardware will include light weight structural materials including composites and thin metals. Technologies sought include modular, smart, advanced Nondestructive Evaluation (NDE) sensor systems and associated capture and analysis software. It is advantageous for techniques to include the development on quantum, meta- and nano sensor technologies for deployment. Technologies enabling the ability to perform inspections on large complex structures will be encouraged. Technologies should provide reliable assessments of the location and extent of damage. Methods are desired to perform inspections in areas with difficult access in pressurized habitable compartments and external environments for flight hardware. Many applications require the ability to see through assembled conductive and/or thermal insulating materials without contacting the surface. Techniques that can dynamically and accurately determine position and orientation of the NDE sensor are needed to automatically register NDE results to precise locations on the structure. Advanced processing and displays are needed to reduce the complexity of operations for astronaut crews who need to make important assessments quickly. NDE inspection sensors are needed for potential use on free-flying inspection platforms. Integration of wireless systems with NDE may be of significant utility. It is strongly encouraged to provide explanation of how proposed techniques and sensors will be applied to a complex structure. Examples of structural components include but are not limited to multi-wall pressure vessels, batteries, tile, thermal blankets, micrometeoroid shielding, International Space Station (ISS) Radiators or aerospace structural components.

Phase I Deliverables - Lab prototype, feasibility study or software package including applicable data or observation of a measurable phenomenon on which the prototype will be built. Inclusion of a proposed approach to develop a given methodology to Technology Readiness Level (TRL) of 2-4. All Phase Is will include minimum of short description for Phase II prototype. It will be highly favorable to include description of how the Phase II prototype or methodology will be applied to structures.

Phase II Deliverables - Working prototype or software of proposed product, along with full report of development and test results. Prototype or software of proposed product should be of Technology Readiness Level (TRL 5-6). Proposal should include plan of how to apply prototype or software on applicable structure or material system. Opportunities and plans should also be identified and summarized for potential commercialization.

For proposers with an interest in airframes, please see Subtopic A1.01 - Structural Efficiency - Tailored Airframes and Structures.

T12.01 Thin-Ply Composite Technology and Applications (STTR)
Lead Center: LaRC

The use of thin-ply composites is one area of composites technology that has not yet been fully explored or exploited. Thin-ply composites are those with cured ply thicknesses below 0.0025 in. and commercially available prepregs are now available with ply thicknesses as thin as 0.00075 in. By comparison, a standard-ply-thickness composite would have a cured ply thickness of approximately 0.0055 in. or greater. Thin-ply composites hold the potential for reducing structural mass and increasing performance due to their unique structural characteristics, which include (when compared to standard-ply-thickness composites):

- Improved damage tolerance.
- Resistance to microcracking (including cryogenic-effects).
- Improved aging and fatigue resistance.
- Reduced minimum-gage thickness.
- Thinner sections capable of sustaining large deformations without damage.
- Increased scalability.

These characteristics can make thin-ply composites attractive for a number of applications in both aeronautics and space. For example, preliminary analyses show that the notched strength of a hybrid of thin and standard ply layers can increase the notched tensile strength of composite laminates by 30%. Thus, selective incorporation of thin plies into composite aircraft structures may significantly reduce their mass. There are numerous possibilities for space applications. The resistance to microcracking and fatigue makes thin-ply composites an excellent candidate for a deep-space habitation structure where hermeticity is critical. Since the designs of these types of pressurized structures are typically constrained by minimum gage considerations, the ability to reduce that minimum gage thickness also offers the potential for significant mass reductions. For other space applications, the reduction in thickness enables: thin-walled, deployable structural concepts only a few plies thick that can be folded/rolled under high strains for launch (and thus have high packaging efficiencies) and deployed in orbit; and greater freedom in designing lightweight structures for satellite buses, landers, rovers, solar arrays, and antennas. For these reasons, NASA is interested in exploring the use of thin-ply composites for aeronautics applications requiring very high structural efficiency, for pressurized structures (such as habitation systems and tanks), for lightweight deep-space exploration systems, and for low-mass high stiffness deployable space structures (such as rollable booms or foldable panels, hinges or reflectors). There are many needs in development, qualification and deployment of composite structures incorporating thin-ply materials – either alone or as a hybrid system with standard ply composite materials.

The particular capabilities requested for in a Phase I proposal in this subtopic are:

- New processing methods for making repeatable, consistent, high quality thin-ply carbon-fiber prepreg materials, (i.e., greater than 55% fiber density with low degree of fiber twisting, misalignment and damage, low thickness non-uniformity and minimal gaps in the material across the width). Prepreg product forms of interest have areal weights below 60 g/m^2 for unidirectional tape with tape widths between 6 and 100 mm wide, and below 130 g/m^2 for woven/braided prepreg materials. Matrices of interest include both toughened epoxy resins for aeronautics applications, and resins qualified for use in space.
- Initial process development in using thin-ply prepregs for component fabrication using automated tape layup or other robotic technologies.
- Contributing to the development of the design and qualification database though testing and interrogation of the structural response and damage initiation/progression at multiple scales including evaluation of environmental durability and ageing.
- Analysis and design tool validation and calibration to ensure that the technology to appropriately design, identify any application-specific shortcomings with suggested improvements, and certify thin-ply composite components is matured sufficiently to be used for NASA applications.
- Micromechanics models for spread-tow woven/braided laminates, including viscoelastic response.
- Development of testing methods adapted for thin-ply high-strain composite materials and structures, with particular interest to dedicated large deformation bending and creep tests.
- Engineering viscoelastic behavior of thin-ply laminates for controlled deployment of space structures.

The intention of a Phase II follow-on effort would be to develop or to further mature the necessary design/analysis codes, and to validate the approach though design, build, and test of an article representative of the component/application of interest to NASA.

Focus Area 16: Ground & Launch Processing

Lead MD: HEOMD

Ground processing technology development prepares the agency to test, process and launch the next generation of rockets and spacecraft in support of NASA's exploration objectives by developing the necessary ground systems, infrastructure and operational approaches.

This topic seeks innovative concepts and solutions for both addressing long-term ground processing and test complex operational challenges and driving down the cost of government and commercial access to space. Technology infusion and optimization of existing and future operational programs, while concurrently maintaining continued operations, are paramount for cost effectiveness, safety assurance, and supportability.

A key aspect of NASA's approach to long term sustainability and affordability is to make test, processing and launch infrastructure available to commercial and other government entities, thereby distributing the fixed cost burden among multiple users and reducing the cost of access to space for the United States.

Unlike previous work focusing on a single kind of launch vehicle such as the Saturn V rocket or the Space Shuttle, NASA is preparing common infrastructure to support several different kinds of spacecraft and rockets that are in development. Products and systems devised at a NASA center could be used at other launch sites on earth and eventually on other planets or moons.

Specific emphasis includes development of ground test and launch environment technology components and system level ground test systems for advanced propulsion and autonomous propellant management.

H10.01 Advanced Propulsion Systems Ground Test Technology (SBIR)
Lead Center: SSC
Participating Center(s): KSC

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 non-chemical propulsion, boost stage and in-space propulsion and so forth. It involves a combination of component-level and engine-level testing to demonstrate that propulsion devices were designed to meet the specified requirements for a specified operational envelope and over robust margins and shown to be sufficiently reliable, prior to its first flight.

This topic area seeks to develop advanced ground test and launch environment technology components and system level ground test systems that enhance Chemical and Advanced Propulsion technology development and certification. The goal is to advanced propulsion ground test technologies to enhance environment simulation, minimize test program time, cost and risk and meet existing environmental and safety regulations. It is focused on near-term products that augment and enhance proven, state-of-the-art propulsion test facilities. This subtopic is especially interested in ground test and launch environment technologies with potential to substantially reduce the costs and improve safety/reliability of NASA's test and launch operations.

In particular, technology needs include producing large quantities of hot hydrogen, and developing robust materials, advanced instruments and monitoring systems capable of operating in extreme temperature and harsh environments. Harsh environments include high vibration and ablative.

This subtopic seeks innovative technologies in the following areas:

- Efficient generation of high temperature (>2500° R), high flowrate (<60 lb/sec) hydrogen.
- Devices for measurement of pressure, temperature, strain and radiation in a high temperature and/or harsh environment.
- Development of innovative rocket test facility components (e.g., valves, flowmeters, actuators, tanks, etc.) for ultra-high pressure (>8000 psi), high flow rate (>100 lbm/sec) and cryogenic environments.
- Robust and reliable component designs which are oxygen compatible and can operate efficiently in high vibro-acoustic, environments.

- Advanced materials to resist high-temperature (<4400° F), hydrogen embrittlement and harsh environments.
- Tools using computational methods to accurately model and predict system performance are required that integrate simple interfaces with detailed design and/or analysis software. 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, 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. This capability is 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; fluid-structure interactions in internal flows.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path towards Phase II hardware/software demonstration with delivery of a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

H10.02 Autonomous Control Technologies (ACT) for Ground Operations (SBIR)
Lead Center: KSC
Participating Center(s): ARC, LaRC, SSC

Autonomous Control Technologies (ACT) are needed to reduce operations and maintenance costs of ground and payload operations and to increase the availability of systems to support mission operations. These technologies perform functions such as anomaly and fault detection, fault isolation, diagnostics and prognostics and enable variable levels of autonomous control and recovery of system operations, where recovery may include reconfiguration or repair. Autonomous Control Technologies are enabled by intelligent systems health management component technologies, methodologies, and approaches; command and control architectures; computing architectures; software for decision-making and control; and intelligent devices.

ACT will be applied to operations such as autonomous propellant management, which includes the transfer, storage, measuring, and sampling of cryogenic, or other propellant for use in launch systems without requiring human interaction. Propellant management includes pre-planned nominal capabilities such as vehicle fill and drain as well as contingency and off-nominal capabilities such as emergency safing, venting and system reconfiguration. ACT capabilities will enable the autonomous monitoring and control of the integrated system resulting from the loading system and all other associated systems involved in the loading process. The system autonomy software itself includes both prerequisite control logic (PCL) and reaction control logic (RCL) programming, and may utilize some form of machine learning, neural network, or other form of artificial intelligence to adapt to degraded system components or other form of off-nominal conditions. In addition to cryogenic and other propellants, propellant management systems may utilize additional commodities to prepare a vehicle for launch, such as high-pressure gases for purges, pressurization, or conditioning, and may include power and data interfaces with the vehicle to configure vehicle valves or other internal systems and utilize on-board instrumentation to gain visibility into the vehicle during loading.

ACT must also support tasks such as setup, testing and checkout, troubleshooting, maintenance, upgrades and repair. These additional tasks drive the need for autonomous element to element interface connection and separation, multi-element inspection, and recovery of high value cryogenic propellants and gases to avoid system losses.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II demonstration, and delivering a demonstration package for NASA testing in operational or analog test environments at the completion of the Phase II contract.

Phase I Deliverables - Research, identify and evaluate candidate technologies or concepts for systems and components fault detection, isolation and recovery, fault prediction and diagnosis, and decision-making algorithms for control to enable autonomy of ground systems. Demonstrate the technical feasibility, and show a path towards a demonstration. Concept methodology should include the path for adaptation of the technology, infusion strategies (including risk trades), and business model. It should identify improvements over the current state of the art for both operations and systems development and the feasibility of the approach in a multi-customer environment. Bench or lab-level demonstrations are desirable. Deliverables must include a report documenting findings.

Phase II Deliverables - Emphasis should be placed on developing, prototyping and demonstrating the technology under simulated operational conditions using analog earth-based systems including dynamic events such as commodity loading, disconnect or engine testing. Deliverables shall include a report outlining the path showing how the technology could be matured and applied to mission-worthy systems, functional and performance test results and other associated documentation. Deliverable of a functional prototype (software and hardware) is expected at the completion of the Phase II contract. The technology concept at the end of Phase II should be at a TRL of 6 or higher.

Focus Area 17: Thermal Management Systems

Lead MD: STMD
Participating MD(s): SMD

From the smallest satellite to the most complicated human rated spacecraft, thermal is seen as an enabling function to a vehicle. Temperatures must be maintained within design limits, whether those be cryogenic systems for science instruments, or comfortable shirt sleeve operations temperatures for crew missions. As missions evolve and waste energy rejection becomes more of a demand, NASA seeks components for both active and passive thermal systems. Such components complete the thermal cycle which includes waste energy acquisition, transport, rejection/storage, and insulation. The ultimate goal for any thermal control hardware is to minimize mass, volume, and power while maintaining the aforementioned temperature limits on a spacecraft.

Z2.01 Thermal Management (SBIR)

Lead Center: JSC
Participating Center(s): GRC, GSFC, JPL, MSFC

NASA seeks new technologies that will facilitate low mass and highly reliable thermal control systems for exploration vehicles. Broad topics of interest include development of: high efficiency lightweight radiators, advanced heat exchangers and coldplates, condensate separators with inlet air/water volume ratios greater than 99:1 and outlet separation efficiency of greater than 95%, phase change materials with optimized thermal capacity to structural mass ratios, high heat flux acquisition and transport devices, variable heat rejection technologies, closed-loop space suit thermal systems, high efficiency miniature pumped fluid systems, and improved thermal math modeling tools. Of particular interest in this solicitation are thermal control technologies that serve an integrated vehicle level function at a net mass benefit, those that enable human missions to Mars, and those enabling more than 24 hours of operation on the surface of Venus.

Integrated Spacecraft Solutions

The development of the systems required for spacecraft operations generally focus on providing a single primary function. Here, novel thermal control hardware that provides additional vehicle level functionality at a net mass benefit is sought. A concept of interest is body mounted radiators that provide effective micrometeoroid protection for deep space vehicles. Such a radiator must continuously provide its thermal control function while tolerating the micrometeoroid environment of cis-lunar space. The integrated radiator/micrometeoroid shield should have a radiator fin-efficiency better than 0.95. The shielding approach taken should provide a similar level of module and radiator flow tube protection as is currently in use on the International Space Station (ISS). The shielding configuration for ISS modules is 2 mm thick Al Alloy 6061 T6 stood off from the pressure vessel. The radiator tube shielding is a 1.2 mm thick aluminum bumper above a 4.75 mm gap, followed by a second 0.3 mm aluminum bumper over the flow tube. Another concept of interest includes flexible radiator solutions that could be integrated with existing inflatable structures. Flexible radiator solutions should meet a fin efficiency of at least 0.85 and provide radiative optical properties consistent with the current state of the art.

Enabling Thermal Control Technologies Missions to Mars

Operating large vehicles on the Martian surface presents unique challenges on a number of vehicle systems. During the entry, descent, and landing phase of the mission spacecraft surfaces are expected to experience incident heat loads up to 3.5 W/cm^2 for up to 5 minutes over the course of entry. These heat fluxes result in radiative equilibrium temperatures between 500 K and 900K. As a result, vehicle components must either be isolated from these loads or tolerate the loads by design. Large pumped fluid loop radiators, as the currently exist, were not designed to tolerate these types of external loads. Here NASA seeks new highly efficient radiator designs that are capable of surviving the described entry environment. Radiator designs should target mass to area ratios better than 5.4 kg/m^2. In addition to external loads experienced through the entry phase, the vehicle must also be capable of managing its own heat load. Concepts that incorporate both external environment tolerance and vehicle thermal management are desired.

Thermal Systems for Surface Missions to Venus

Proposals are sought for enabling thermal technology systems for the in-situ planetary exploration of deep atmosphere and surface environments. A driving scenario is exploration of the surface of Venus through the use of long-lived (> day) landers. Venus features a dense, CO_2 atmosphere completely covered by clouds with sulfuric acid aerosols, a surface temperature of 760K, and a surface pressure of 90 atmospheres. Thermal technologies are needed that permit more than 24 hours of operation of internal components within a 1 m diameter pressure vessel while minimizing resources consumed by the thermal system. A total systems approach must be considered that may include, but are not limited to, novel insulation, energy storage, heat pumping, and expendable coolant systems. The thermal system should be capable of providing heat management for 150 W of average internal dissipation. The entire assembly initial temperature can be assumed to be 273K and the maximum allowable temperature of internal equipment is 343K. Proposals must include a detailed description of the assumptions, thermal model, and bases of estimate for mass and power consumption of the technologies being put forward. Phase I results should include analytical proof-of-concept and provide a feasibility and development assessment of novel thermal control technologies. Phase II results should include development and testing of a prototype system or key piece of enabling technology identified in the Phase I effort.

Focus Area 18: Air Vehicle Technology

Lead MD: ARMD

Participating MD(s): STTR

This focus area includes tools and technologies that contribute to meeting metrics derived from a definitive set of Technical Challenges responsive to the goals of the National Aeronautics Research and Development (R&D) Policy and Plan, the National Aeronautics R&D Test and Evaluation (T&E) Infrastructure Plan (2011), and the NASA Aeronautics Strategic Implementation Plan (2017). In 2012 ARMD introduced more focused solicitations by rotating some of the subtopics every other year. The reduction in the scope of some of our solicitations does not imply a change in interest in a given year. For example, in 2014 we solicited proposals for quiet performance with an emphasis on propulsion noise reduction technology, then in 2015 we focused our quiet performance subtopic on airframe noise reduction. In 2016, we returned to quiet performance – propulsion noise reduction technology.

A1.01 Structural Efficiency - Aeroelasticity and Aeroservoelastic Control (SBIR)
Lead Center: LaRC
Participating Center(s): AFRC

The technical discipline of aeroelasticity is a critical ingredient necessary in the design process of a flight vehicle for maintaining optimal performance while ensuring freedom from aeroelastic and aeroservoelastic instabilities. This discipline requires a thorough understanding of the complex interactions between a flexible structure and the steady and unsteady aerodynamic forces acting on the structure, with interactive control systems for flight vehicle performance and stability. This fundamental aeronautics work is focused on active/adaptive aerostructural control for lightweight flexible structures, specifically related to load distribution, flutter prediction and suppression, gust load prediction and alleviation, and aeroservoelasticity for Ultra-Efficient and Supersonic Commercial Vehicles.

The program's work on aeroservoelasticity includes conduct of broad-based research and technology development to obtain a fundamental understanding of aeroelastic and unsteady-aerodynamic phenomena experienced by aerospace vehicles in subsonic, transonic, supersonic, and hypersonic speed regimes.

The program content includes theoretical aeroelasticity, experimental aeroelasticity, and advanced aeroservoelastic concepts. Of interest are:

- Aeroelastic, aeroservoelastic, and unsteady aerodynamic analyses at the appropriate level of fidelity for the problem at hand.
- Aeroelastic, aeroservoelastic, and unsteady aerodynamic experiments to validate methodologies and to gain valuable insights available only through testing.
- Development of computational-fluid-dynamic (CFD), computational-aeroelastic, and computational-aeroservoelastic analysis tools that advance the state of the art in aeroservoelasticity through novel and creative application of aeroelastic knowledge.

Specific subjects to be considered include:

- Development of aerostructural control design methodologies that include CFD steady and unsteady aerodynamics, flexible structures, and active control systems.
- Development of efficient methods to generate mathematical models of wind-tunnel models and flight vehicles for performing aeroservoelastic studies.
- Development of CFD-based methods (reduced-order models) for aeroservoelasticity models and simulation that can be used to predict gust loads, ride quality issues, flight dynamics stability, and aerostructural control issues.
- Development of novel aeroservoelasticity sensing and control approaches, including active/adaptive control concepts and architectures that employ smart materials embedded in the structure and aerodynamic sensing and control schemes for suppressing aeroelastic instabilities and improving performance.
- Development of techniques that support simulations, ground testing, wind-tunnel tests, and flight experiments for aerostructural control of aeroservoelastic phenomena.

Links to program/project websites:
- ARMD's Advanced Air Vehicles Program (AAVP) - https://www.nasa.gov/aeroresearch/programs/aavp.
- ARMD's Flight Demonstrations and Capabilities (FDC) project under the Integrated Aviation Systems Program (IASP) - https://www.nasa.gov/aeroresearch/programs/iasp/fdc.
- X-56 Flight Project - https://www.nasa.gov/centers/armstrong/research/X-56/index.html.

A1.02 Quiet Performance - Propulsion Noise Reduction Technology (SBIR)
Lead Center: GRC
Participating Center(s): LaRC

Aircraft noise reduction in general, and propulsion noise in particular, are areas of active research under the Advanced Air Transport Technology (AATT) Project and Commercial Supersonic Technology (CST) Project. In support of these projects environmental goals, innovations are sought in the following areas:

Noise Reduction:

- Advanced liners including broadband liners (i.e., liners capable of appreciable sound absorption over at least two octaves), low-frequency liners (i.e., liners with optimum absorption frequencies half of the current ones but without increasing liner depth), low-drag liner concepts that provide the same or better acoustic performance compared to those in use today, and high-temperature liners for reducing engine core noise.
- Low-noise propulsor concepts that are significantly quieter than the current generation turbofans and open rotors.
- Concepts for active control of broadband noise sources including fan, open rotor, jet, compressor, combustor, and turbine.
- Adaptive flow and noise control technologies for reducing propulsion noise including smart structures for inlets and nozzles.
- Concepts to mitigate the effects of distorted inflow on propulsor noise.

Noise Prediction:

- High-fidelity fan, compressor and turbine broadband noise prediction models, 3D fan and turbine acoustic transmission models for tone and broadband noise.
- Low-order, efficient and robust 3D noise models for engine noise sources (i.e., fan, jet, and core).
- Accurate models for prediction of installed noise for jet surface interaction, fan inlet distortion, and open rotors.

Noise Diagnostics:

- Tools/Technologies for quantitative characterization of fan in-duct broadband noise in terms of its spatial and temporal content.
- Techniques for measuring realistic propulsion noise sources in low-signal-to-noise ratio wind tunnel environments.
- Characterization of fundamental jet noise sources and structures.
- Innovative measurement of radiated acoustic fields from aeroacoustic sources.

A1.03 Low Emissions/Clean Power - Combustion Technology/Emissions Measurement Techniques (SBIR)
Lead Center: GRC
Participating Center(s): LaRC
Related Subtopic Pointer(s): T13.01

Achieving low emissions and finding new pathways to cleaner power are critical for the development of future air vehicles. Vehicles for subsonic and supersonic flight regimes will be required to operate on a variety of certified aircraft fuels and emit extremely low amounts of gaseous and particulate emissions to satisfy increasingly stringent emissions regulations. Future vehicles will be more fuel-efficient which will result in smaller engine cores operating at higher pressures. Future combustors will also likely employ lean burn concepts which are more susceptible to combustion instabilities. Fundamental combustion research coupled with associated physics based model development of combustion processes will provide the foundation for technology development critical for these vehicles.

Combustion involves multi-phase, multi-component fuel, turbulent, unsteady, 3D, reacting flows where much of the physics of the processes are not completely understood. CFD codes used for combustion do not currently have the predictive capability that is typically found for non-reacting flows. Low emissions combustion concepts require very rapid mixing of the fuel and air with a minimum pressure loss to achieve complete combustion in the smallest volume. Areas of specific interest where research is solicited include:

- Development of laser-based diagnostics for quantitative spatially and temporally resolved measurements of fuel/air ratio in reacting flows at elevated pressure.
- Development of ultra-sensitive instruments for determining the size-dependent mass of combustion generated particle emissions.
- Low emissions combustor concepts for small high pressure engine cores.
- Development of miniature high-frequency fuel modulation valve for combustion instability control able to withstand the surrounding high-temperature air environment.

Infusion/Commercial Potential - These developments will impact future aircraft engine combustor designs (lower emission, control instabilities) and may have commercial applications in other gas-turbine based industries (such as power generation and industrial burners). The modeling and results can be and will be employed in current and future hydrocarbon rocket engine designs (improving combustion efficiency, ignition, stability, etc.).

A1.04 Supersonic Technology - Reduce Take-off and Landing Noise (SBIR)
Lead Center: GRC

This solicitation is aimed at further exploring technologies that reduce landing and take-off noise while maintaining range and sonic boom within acceptable levels. This may include innovations in propulsion design, propulsion-airframe integration, vehicle operations, and high-lift airframe elements. A concept vehicle with low-boom configurations such as those identified in the above references is desired; however, other operational concepts, for example those not involving overland supersonic flight may be considered if there is an overlap in technology benefits.

The following list summarizes the topics for which proposals are sought in this solicitation. Details for each topic area are provided in the following section:

- Topic 2.1 - Innovative High Lift Concepts for Highly Swept Supersonic Wings.
- Topic 2.2 - Alternative Variable Propulsion Architectures.
- Topic 2.3 - Efficient Optimization of Supersonic Nozzles to Minimize Jet Noise.

Topic 2.1 - Innovative High Lift Concepts for Highly Swept Supersonic Wings.

Objective
This topic seeks innovative high lift concept proposals that would enable takeoff and landing noise levels that meet certification requirements (consistent with those of the subsonic fleet), have minimal to no impact on supersonic performance, and are compatible with low-boom vehicle designs. Each concept should include a preliminary

assessment of its performance at takeoff/landing speeds, its component noise, and an assessment of its impact on likely laminar flow requirements.

Approach

The high-lift system is an integral part of the take-off, landing, stall recovery, and low-altitude maneuvering segments of a supersonic aircraft's mission. Low-aspect ratio, thin, highly swept wings typical of supersonic aircraft generally do not perform well at low speed and present challenges to designing a high lift system. For modern supersonic aircraft, high lift systems not only need to enable good takeoff and landing performance, but also need to be quiet and stow so as to not interfere with natural laminar flow leading-edge design approaches that may be under consideration. Any high-lift system should also delay or reduce undesirable pitch characteristics.

Modern supersonic aircraft may have to meet the same low-noise requirements near an airport that subsonic aircraft do. Therefore, high-lift systems must have good performance to get the aircraft as high as possible over the "cutback" measurement point, and be low-noise for the approach-to-landing measurement point. An estimate of component noise will be required for all proposed high lift concepts and the basis of that estimate provided. As an example, continuous mold-line flaps have been investigated for subsonic aircraft and may be also be applicable on supersonic aircraft. Therefore, the subsonic studies would serve as a basis for the estimate of the component noise in a supersonic application. If there are no relevant studies for a particular concept, a proposal for such a study should be included.

Wing leading-edge laminar flow design technology may include a sufficiently small wing leading-edge radius (to manage supersonic attachment-line flow transition associated with leading-edge boundary-layer contamination/stability) as well as certain leading-edge treatments (to manage insect/debris contamination and cross-flow transition). Technology enabling wing leading-edge radius variations ranging from a large radius for use at low-speed conditions to a small radius for use at supersonic conditions may be considered. The leading-edge high-lift system shall minimize any steps/gaps/sealing issues when stowed for the supersonic cruise configuration. The trailing-edge high-lift system is not a concern for the laminar flow wing design, but still needs to address steps/gaps/sealing issues to minimize drag for supersonic cruise efficiency requirements. Although a subtle distinction, the laminar-flow requirement only applies to the supersonic cruise conditions; for low-speed conditions, a turbulent high-lift wing configuration may be more robust and preferable to meet these challenging high-lift requirements.

Ideas considered in previous supersonic research efforts (which had L/D requirements, but not low-noise or laminar-friendly requirements) included simply-hinged leading- and trailing-edge flaps. Questions remain regarding the adequacy of the performance of these concepts, given the more stringent criteria stated above.

Under a prior NRA contract, a baseline commercial passenger concept was developed for the Commercial Supersonic Technology Project. This representative mid-term configuration can be used to evaluate the proposed high lift concepts.

The proposed approach should involve multiple stages of activity if more than one concept is being investigated. During initial studies open trade spaces are encouraged. Through quarterly technical interchanges with the NASA team, it is anticipated that a down-select or prioritization of the most viable concepts will occur and will be more fully developed through CFD or experimental studies.

Outcome:

This effort will result in:

- A suite of high-lift concepts, evaluated for low-speed performance (L/D), component noise, and "laminar-friendliness." The most promising of these concepts will subsequently be used for experimental or high-fidelity computational proof-of-concept investigations on a relevant supersonic transport wing geometry.

- Complete documentation of findings and relevant comparisons.
- Recommendations for follow-on studies.

References:

1. H. R. Welge, J. Bonet, T. Magee, D. Chen, S. Hollowell, A. Kutzman, A. Mortlock, J. Stengle, C. Nelson, E. Adamson, S. Baughcum, R. Britt, G. Miller, and J. Tai, "N+2 supersonic concept development and systems integration", CR-2010-216842, NASA, 2010. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100030607.pdf

Topic 2.2: Alternative Variable Propulsion Architectures

Objective

The objective of this subtopic is to explore one or more alternative variable propulsion concepts capable of a two-fold variability in effective bypass ratio with minimal compromise of supersonic cruise performance. The work will consider three-dimensional inlet and nozzle geometries and perform analysis of key propulsion efficiency trades, flight envelope operability, and propulsion noise at the Landing Take-Off phases of flight.

Background

To satisfy the increasing stringency of commercial Landing/Take-Off (LTO) noise, efficient supersonic cruise propulsion systems would ideally operate at high mass flow for take-off (low jet velocity) and safely transition to high specific thrust (high jet velocity) for supersonic operation. In recent decades, variable cycle technologies have afforded a measure of success in this pursuit, with some compromise in propulsion system weight and complexity [1]. Most recently, tip-fan versions of a variable cycle engine have been explored as a way to invoke higher fan mass flows at take-off with higher installed specific thrust for cruise3. Additional alternative concepts have also been expressed (e.g., mixer-ejector nozzles, supplemental mechanical/electric fans, or other concepts) to reconcile the dichotomy of high flow acoustic take-off with efficient supersonic cruise. Historically, however, all such variable propulsion systems have suffered size, weight, and realizability issues adversely affecting vehicle integration and cruise range performance. Furthermore, development of a propulsion system with such unique operating characteristics has challenged the economics of limited production supersonic vehicles.

While a number of such variable propulsion concepts have been contemplated for commercial supersonics to date, many have yet to be explored with modern analysis tools/methods or at a sufficiently credible level of detail or with an eye toward reducing uncertainty. Lack of realistic geometry including inlet, nozzle, and vehicle integration have oversimplified or obviated issues with such concepts as flow valves and moving surfaces that transition throughout the flight envelope. In addition to new concepts, use of modern design methods may allow reconsideration of some alternative propulsion architectures but with greater design realism in overcoming prior associated technical roadblocks. Vehicle integration for low sonic boom and supersonic drag has also been a major issue impacting the utility of high flow propulsion concepts as these considerations value minimizing nacelle cross-sectional area or fineness ratio. Correspondingly, engine/accessories packaging, inlet and nozzle interfaces, and integration with endemic features of supersonic vehicles must be considered (e.g., highly swept thin wings, propulsion in-board or aft-fuselage mounting and boundary-layer diversion).

Approaches

A set of metrics, including mass flow variability, cruise efficiency, range, and airport noise should be developed to evaluate alternative variable propulsion architectures. Promising alternative variable propulsion architectures should be evaluated using low-fidelity system analysis on a representative supersonic aircraft mission. Low-boom aircraft concepts, such as those referenced in published system studies4-10 may be used as a point of departure. Furthermore, propulsion approaches that modify existing or more "conventional" propulsion architectures are of key interest for achieving large changes in effective bypass ratio or specific thrust in an economical approach.

In their search for innovative concepts, proposers are encouraged to seek partnerships with non-traditional industries, large and small engine manufacturers, and universities with capabilities to explore credible levels of detail and reduced uncertainty.

Outcome
A final report (non-proprietary and proprietary (if required) versions) is expected at the conclusion of this effort showing at least one conceptual propulsion configuration with a two-fold variability in effective bypass ratio, capable of powering a representative Mach 1.4-1.8 commercial supersonic transport sized for range of at least 4000 nautical miles and 8 - 90 passengers. The following items should be included in the final report:

- One to a few alternative variable propulsion concepts, investigated to a credible design level and accompanied by supporting trade studies of key design parameters.
- Engine cross-section(s) including outer dimensions and component weights (at a minimum).
- Three-dimensional geometry representations of inlet, nozzle and key components, with appropriate characterization for use in propulsion system model(s).
- Propulsion system model(s) (preferably in NPSS) and assumptions, with recommendations for further development of key technologies or components.
- Installed propulsion performance throughout a representative flight operating envelope.
- Low-fidelity acoustic analysis of the selected concept(s), reflective of the LTO trajectory for the representative vehicle.

References:

1. Berton, Jeffery J, et al "A Comparative Propulsion System Analysis for the High-Speed Civil Transport". NASA/TM—2005-213414. Glenn Research Center, Cleveland, Ohio. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20050123580.pdf.
2. Pratt & Whitney West Palm Beach, Florida & General Electric Aircraft Engines Cincinnati, Ohio. "Critical Propulsion Components Volume 1: Summary, Introduction, and Propulsion Systems Studies". NASA/CR—2005-213584/VOL1. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20050185247.pdf.
3. Dennis L. Huff, Brenda S. Henderson, Jeff J. Berton, and Jonathan A. Seidel. "Perceived Noise Analysis for Offset Jets Applied to Commercial Supersonic Aircraft", 54th AIAA Aerospace Sciences Meeting, AIAA SciTech Forum, (AIAA 2016-1635).
4. John Morgenstern, et al, "Final Report for the Advanced Concept Studies for Supersonic Commercial Transports Entering Service in the 2030 to 2035 Period, N+3 Supersonic Program", NASA/CR—2010-216796, NASA, 2010. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100036507.pdf.
5. H. R. Welge, et.al., "N+2 Supersonic Concept Development and Systems Integration", CR-2010-216842, NASA, 2010. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100030607.pdf.
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the 2018-2020 Period Phase II", NASA/CR—2015-218719, NASA, 2015.
https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20150015837.pdf.
10. Todd E. Magee, et al, "System-Level Experimental Validations for Supersonic Commercial Transport Aircraft Entering Service in the 2018-2020 Time Period", NASA/CR–2015-218983, NASA, 2015.
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Topic 2.3: Efficient Optimization of Supersonic Nozzles to Minimize Jet Noise

Objective
The objective of this subtopic is to apply optimization methodology to problems in aeroacoustics, specifically to minimize jet noise of future commercial supersonic nozzle designs and installations.

Background
Currently, predicting the noise of a non-axisymmetric jet requires either time-accurate computation using Large Eddy Simulation, which is very expensive but potentially very accurate, or Reynolds-Averaged Navier-Stokes (RANS) CFD and acoustic source modeling, which is cheaper but has failed to provide absolute accuracies needed for design. The latter methods have demonstrated the capability to predict trends in noise from variations in nozzle geometry, however, and this capability may be harnessed to do optimization of nozzle geometries to minimize the jet noise. In the time-average methods, the flow solution can be obtained from a RANS-based CFD code, the noise produced from the flow can be computed using an established NASA code, and the transformation of the sound spectra to that of an overhead flight and its EPNL metric is given in FAA documentation.

Approach
The vision is that RANS-based methods which predict the noise of an engine nozzle for a given flow condition can be applied in optimization to reduce noise by varying the nozzle shape and/or installation. A successful effort would utilize NASA jet noise prediction knowledge and tools, determine viable optimization strategies and methods that are appropriate for these tools, and demonstrate the system by applying it to a nozzle design problem of interest to NASA.

Using a suitable optimization methodology, the proposer would develop a coupled Computational Fluid Dynamics-Computational Aero-acoustics (CFD-CAA) optimization system to find the minimum EPNL metric for a given set of geometric design parameters that describe the nozzle shape. It is expected the process would be suitable for designing three-dimensional, multi-stream, and unconventional nozzle concepts. Given the dependence on high-fidelity RANS computations for jet noise prediction, an efficient optimization process that utilizes gradient information (e.g. a continuous or discrete adjoint approach) is desired. Ideally, the CFD-CAA system will be developed to leverage and/or easily interface with adjoint-capable CFD codes like NASA's Fully Unstructured Navier-Stokes 3D (FUN3D)3 framework, or similar. Analytical derivatives for the calculations transforming the predicted noise spectra to the EPNL metric have been described in Reference 5.

Ultimately, the optimization strategy developed in this task will need to be implemented in an existing design and optimization framework. This framework is not the objective of the task. The success of the method chosen will depend upon ability to manipulate the given prediction codes with an emphasis on computational time, preferably being done on an engineering workstation-class computer, but could include the use of NASA supercomputer resources. The development effort is envisioned to consist of three phases. Phase I would include a survey of optimization methods that might be applied to the current prediction methods and a down-select of approaches to be pursued. Phase II would include development of the optimization method chosen and a simple demonstration of feasibility. Phase III would include demonstration of the system applied to a nozzle relevant to NASA.

Outcome
This effort will result in:

- A documented exploration of the application of optimization methods to future commercial supersonic nozzles and installations.
- At least one method being demonstrated with enough documentation to be implemented within a NASA design framework.
- An optimized design based on a NASA-originated nozzle suitable for validation in scale-model testing.
- Any codes derived from or integrated with government-furnished codes would be included as deliverables.

References:

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A1.05 Computational Tools and Methods (SBIR)
Lead Center: LaRC
Participating Center(s): ARC, GRC

The CFD Vision 2030 Study (https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140003093.pdf) highlighted the many shortcomings in the existing technologies used for conducting high-fidelity simulations, and made specific recommendations for investments necessary to overcome these challenges. Areas of research that help to significantly reduce CFD workflow are the subject of this solicitation. It was recognized that the generation of meshes suitable for high-accuracy CFD simulations constitutes a principal bottleneck in the simulation workflow process as it requires significant human intervention. As more capable high performance computing (HPC) hardware enables higher resolution simulations, fast, reliable mesh generation and adaptivity will become more problematic. The other area of research pertains to extracting knowledge of physical relevance from computed and experimental data from wind tunnels and flight.

To enable accurate CFD solutions for complex configurations, proposals are solicited for generating unstructured and mixed-element meshes for accurate flow solutions. The new capability will be demonstrated for configurations of interest to NASA aeronautics (http://www.aeronautics.nasa.gov/programs.htm) in terms of accuracy, speed and robustness. Of particular interest is the NASA juncture flow model (AIAA Paper 2016-1557) for which grids suitable for unsteady flow simulations (e.g., large eddy simulation (LES) and wall-modeled LES) needs to be generated. Another potential test case is the aircraft landing gear requiring hybrid RANS/LES solutions. The metrics for success are the quality and speed of grid generation. The proposers must present a convincing case that the proposed approach has the potential for dramatic decrease in CFD workflow time while generating quality grids that would produce physically relevant results. Proposers should also specify how the grid quality will be determined.

The second area of research for which proposals are solicited pertain to merging of high-fidelity CFD simulations with other aerodynamic data**.** With wind tunnel and flight testing still expected to play a key role in the aerospace system design process, methods to merge and assimilate CFD simulation data with other experimental/computational data sources to create an integrated database, including some measure of confidence level and/or uncertainty of all (or individual) portions of the database, are required. Currently, the merging of large amounts of experimental and variable fidelity computational data is mostly carried out through experience and intuition using fairly unsophisticated tools. Well-founded mathematically and statistically-based approaches are required for merging such data, for eliminating outlier numerical solutions as well as experimental points, and for generally quantifying the level of uncertainties throughout the data base.

Phase I research is expected to develop the technology and demonstrate it on relatively simpler configurations, while Phase II will increase the technology readiness level and include demonstration for more complex flow configurations.

A1.06 Vertical Lift Technology and Urban Air Mobility (SBIR)
Lead Center: GRC
Participating Center(s): AFRC, LaRC

Urban air mobility (UAM) is a concept for immediate and flexible air transportation within a metropolitan area consisting of passenger-carrying operations. UAM passengers can select a trip origin, destination and timing without being aggregated with many other air travelers. An emerging UAM market will require a high density of vertical takeoff and landing (VTOL) operations for on-demand, affordable, quiet, and fast transportation in a scalable and conveniently-accessible "vertiport" network. It is envisioned that UAM will provide increased mobility within a given metropolitan area by flying faster, and using shorter (< 100 miles) and more direct routing as compared to ground vehicles. UAM vehicles are assumed to require various degrees of autonomous operations to reach their full potential as the concepts are implemented and the market develops.

A series of workshops with NASA, FAA, academia, and industry were held over the past few years to discuss the potential benefits and challenges of UAM. The outcomes of these workshops, including technology roadmaps, are available at http://www.nianet.org/ODM/roadmap.htm. Growth of UAM is dependent on affordable, low-noise VTOL configurations, which may be enabled by electric aircraft propulsion technologies, and the ability of these vehicles to operate within densely populated urban areas in most weather conditions including low altitude operations in rain, ice, wind, and turbulence.

The Vertical Lift Technology and Urban Air Mobility subtopic is primarily interested in innovative technologies focused on passenger-carrying UAM vehicles that include:

- Development and demonstration of technologies for vertical lift Urban Air Mobility (UAM) vehicle airframes and propulsion systems, including validated modeling and analysis tools and prototype demonstrations, that show benefits in terms of operating cost, noise, safety, weight, efficiency, emissions, fuel consumption, and/or reliability based on the vehicle mission, operating environment, and system status. Examples include:
    - Reconfigurable power and energy management system technologies.
    - Distributed electric propulsion and airframe technologies and associated design tools.
    - Technologies to enable operations in most weather conditions including rain, ice, wind, and turbulence.

- Computationally efficient modeling tools capable of modeling sound propagation in an urban environment for creating auralizations of UAM vehicles.

A1.07 Electrified Aircraft Propulsion & Concepts (SBIR)
Lead Center: GRC
Participating Center(s): AFRC, LaRC

Proposals are sought for the development of enabling power systems, turbofan engines, range extenders, electric machines, batteries, power converters, electrical fault management systems, protective devices (such as circuit breakers), and related materials that will be required for future thin/short haul aviation or commercial transport vehicles which use turboelectric, hybrid electric, or all electric power generation as part of the propulsion system. Electrified Aircraft Propulsion work for urban air mobility (UAM) should be proposed against subtopic A1.06 Vertical Lift Technology and Urban Air Mobility. Turboelectric, hybrid electric, and all electric power generation as well as distributed propulsive power have been identified as candidate transformative aircraft configurations with reduced fuel consumption/energy use and emissions. However, components and management methods for power generation, distribution, and conversion are not currently available in the high-power ranges with the necessary efficiency, power density, electrical stability and safety required for thin haul/short haul, or transport-class aircraft. Novel developments are sought in: aircraft power systems operating at or above 1000V, turbofan engines in which >20% of power is extracted electrically, range extenders which consume fuel and produce electricity with significantly higher efficiency than available turbogenerator or diesel generators, batteries and other energy storage systems with specific energy>400Whr/kg at the system level and cycle life>10,000 cycles, electric machines (motors/generators) with efficiency >98% and specific power>13 kW/kg, converters (inverters/rectifiers) with efficiency>99% and specific power>19kW/kg, light weight AC and DC electrical fault management systems and protective devices (such as circuit breakers), soft magnetic material with high magnetic saturation and/or lower losses for 100kHz-300kHz operation, hard magnetic materials with an energy product greater than neodymium iron boron, conductors with a specific resistivity less than copper or aluminum and cable insulation materials with increased dielectric breakdown strength, and significantly higher thermal conductivity ($\geq$ 1W/m·K) and resistance to ageing effects such as corona, ozone, humidity and dust operating at greater than 3kV. Individual components should target the 15kW-3MW size range and would be combined into power systems in the range of 200kW-10MW total power.

Areas of particular interest this year are: turbofans in which >20% of power is extracted electrically, range extenders which burn fuel and produce electricity with significantly higher efficiency than available turbogenerator or diesel generators, and light weight AC and DC electrical fault management systems.

A1.08 Aeronautics Ground Test and Measurement Technologies (SBIR)
Lead Center: LaRC
Participating Center(s): ARC, GRC
Related Subtopic Pointer(s): T13.01

NASA's aeroscience ground test facilities include wind tunnels, air-breathing engine test facilities, and simulation and loads laboratories. They play an integral role in the design, development, evaluation, and analysis of advanced aerospace technologies and vehicles. These facilities provide critical data and fundamental insight required to understand complex phenomena and support the advancement of computational tools for modeling and simulation. The primary objective of the Aeronautics Ground Test and Measurements Technologies subtopic is to develop innovative tools and technologies that can be applied in NASA's aeroscience ground test facilities to revolutionize testing and measurement capabilities and improve utilization and efficiency. Of primary interest are technologies which can be applied to NASA's portfolio of large-scale ground test facilities [1]. For this solicitation, NASA seeks proposals for innovative research and development in the following areas:

- *Wind Tunnel Calibration and Characterization* - Capabilities for wind tunnel calibration and characterization are critical for overall enhancement of facilities and will play a critical role in achieving the CFD 2030 Vision [2]. Systems that can provide planar or volumetric measurements of flow quantities such as velocity, density, temperature, and pressure in the airflow upstream, around, and downstream of test articles are required to quantify tunnel inflow and outflow conditions and specify boundary conditions for numerical simulations.
- *Model Attitude, Position and/or Shape Sensing* - Measurements of test article attitude and position (e.g., roll, pitch, and yaw angles and spatial coordinates X, Y, Z of a wind tunnel model or other structure under test) are critical but are often difficult to make due to packaging constraints and model orientations where gravity based sensors are not applicable. To address some of these limitations, optical and non-optical techniques are needed to provide real-time or near real-time measurements of model attitude at data rates of up to 100 Hz and with sufficient accuracy (0.005± 0.0025 degrees in pitch 0.025±0.025 degrees in roll and yaw). For some applications, dynamic surface shape measurement techniques are needed at rates exceeding 10 kHz.
- *Technologies for Engine Simulators* - The need to assess aerodynamic performance at higher system levels with respect to fuel-burn and noise has created a great demand for propulsion-airframe integration (PAI) testing. Such tests use engine simulators which generate properly-scaled flows in the model. Currently, PAI tests can be quite expensive due to issues related to the integration of the simulator into the model, reliability, complexity of the calibration, and the high-pressure air and/or power which must cross the force and moment balance. NASA seeks innovative propulsion simulators that are more compact and capable of recreating the speed and volume of actual propulsion systems, including approach and landing conditions for the assessment of airframe noise. Hydraulic, pneumatic, electric, or hybrid approaches are solicited. NASA also seeks innovative measurement systems and techniques for monitoring and evaluating the performance of these simulators. Of interest are systems that can measure loads on individual blades for studies involving boundary layer ingestion, and balances capable of transferring high pressure air and/or power across the balance and operating at high temperatures (up to 350° F).

In addition to the areas listed above, proposals for especially innovative measurement systems and techniques which are broadly applicable to common problems in aerodynamic ground testing will also be considered.

[1] https://www.nasa.gov/aeroresearch/programs/aavp/aetc/ground-facilities.

[2] https://ntrs.nasa.gov/search.jsp?R=20140003093.

A1.09 Vehicle Safety - Inflight Icing Hazard Mitigation Technology (SBIR)
Lead Center: GRC

NASA is concerned with the prevention of encounters with hazardous in-flight conditions and the mitigation of their effects when they do occur. Under this subtopic, proposals are invited that explore new and dramatically improved icing mitigation technologies and research tools related to inflight icing hazards for manned and unmanned vehicles. Of particular interest are technologies that can address emerging icing issues applicable to future On-Demand Mobility vehicles. Taken together, these hazards require a systems-level approach for integration with the airframe, propulsion system and control/avionics system. Technologies of interest should address the detection, measurement, and/or the mitigation of the hazards of flight into supercooled liquid water clouds and regions of freezing rain/drizzle. These technologies include but are not limited to on-board remote-sensing of environment, sensing of local environment, system identification, adaptive control and threat mitigation/protection, as well as new, very-low-power, ice-protection systems.

A1.10 Hypersonic Seal Technology Development (SBIR)
Lead Center: LaRC
Participating Center(s): GRC

NASA is developing advanced high temperature seals for a variety of applications. The seals must operate in high heat flux, oxidizing environments and restrict the flow of hot gases at temperatures on the order of 2000° F. To stay in contact with opposing sealing surfaces, the seals must remain resilient after repeated loading as the high-temperature surfaces around them move. Seal preloading elements, in various spring-like forms, can be incorporated within or behind a seal to provide the required resiliency. Spring tubes knitted from high temperature wire materials have been used inside high temperature seals, but they have been shown to lose resiliency and take on a permanent set at temperatures as low as 1200° F. Compression springs, canted coil springs, wave springs, and other unique configurations have all been evaluated as preload devices behind a seal with varying levels of success. For each design, though, material selection was a driving factor in the amount of resiliency exhibited by each type of seal preload device. Therefore, unique combinations of materials and designs will be required to achieve improved resiliency at the higher temperatures anticipated for future seal applications. NASA is interested in developing spring-like devices made of ceramic materials (e.g., silicon nitride) to use as preloading-seal elements applicable to these challenging environments. The overall goal is to develop seals that remain in contact with opposing sealing surfaces at higher temperatures for longer periods of time than current state of the art designs thus making them more reusable.

T15.01 Aircraft Design, Optimization, and Scaled Model Test (STTR)
Lead Center: AFRC
Participating Center(s): ARC, LaRC

This subtopic addresses an advanced aeroelastic design concept for dynamic elastic flight systems. Methods include prototype design and optimization and scaled model design, optimization, manufacturing, and ground and flight (or wind tunnel) tests. Both a baseline configuration (using traditional approach) and a new (or state-of-art) design concept aircraft should be studied to demonstrate the innovation. The followings are recommended as candidate flight systems to be designed, optimized, and tested:

- Demonstration of new design concept:
  - Test articles designed using advanced design concept.
- Or application of state-of-art design concept:
  - NASA X-plane: such as hybrid wing body aircraft, low-boom supersonic commercial transport aircraft, etc.: https://www.nasa.gov/aero/nasa-moves-to-begin-historic-new-era-of-x-plane-research.
  - Unmanned aerial vehicles: https://www.nasa.gov/subject/9566/unmanned-aircraft/ & https://en.wikipedia.org/wiki/Unmanned_aerial_vehicle.
  - Mars plane, & etc.: https://www.nasa.gov/centers/armstrong/features/mars_airplane.html.

This subtopic also addresses capabilities enabling design solutions for performance and environmental challenges of future air vehicles. Research in revolutionary aerospace configurations include lighter and more flexible materials, improved sonic boom performance on the ground, and improved propulsion systems. This subtopic targets efficiency and environmental compatibilities requiring performance challenges and novel structural optimization for aeroelastic considerations which are gaining prevalence in advanced flight vehicles.

Technical elements for the Phase I proposals may also include:

- Introduction of new innovative or state-of art design concept for higher performance flight systems.
- Initial conceptual design (mainly for application of state-of-art design concept):

- Define own design requirement.
- Outer-mold-line shape.
- Target flight envelope for prototype.
- Range.
- Number of passenger (if needed).
- Aircraft configuration, etc.

Proposals should assist in revolutionizing improvements in performance to empower a new generation of air vehicles to meet the challenges of subsonic and supersonic flight concerns with novel concepts and technology developments in systems analysis, integration and evaluation. Higher performance measures include energy efficiency to reduce fuel burn and operability technologies that enable information network decompositions that have different characteristics in efficiency, robustness, and asymmetry of information and control with tradeoff between computation and communication.

Technical elements for the Phase I results and deliverables should be as follows:

- Structural finite element models of the prototype should be delivered (at least preliminary design quality):
  - Baseline shape (use classical approach).
  - New (or state-of-art) design shape (use innovative approach).
- Show performance improvement between the baseline configuration and the new (or state-of-art) design concept configuration with structural optimization:
  - Stress/strain distribution under the critical design load condition with margin of safety information.
  - Primary buckling characteristics and buckling shape.
  - Natural frequencies and mode shapes of prototype models.
  - Flutter boundary information with proposed flight envelope.
  - Sonic boom noise level information on the ground (if used); & etc.
- Computer programs developed during Phase I:
  - Source codes.
  - Executable codes.
  - Quick user guide; & etc.

Technical elements for the Phase I listed above can be performed by small business and research institution as follows:

A sample recommendation
Small business:

- Develop tools or modeling methodology that can be used in initial design of baseline shape and new design shape.
- Develop tools (if needed) that incorporate stress/strain and modal analyses of initial design.
- Design and build test articles.

Research institution:

- Design tools (if needed) that allow optimization of baseline shape and new design shape.
- Perform optimization of baseline shape and new design shape.
- Design tools or a way to model buckling, flutter, and sonic boom (if needed) analyses of initial design to support small business.
- Perform ground based testing.

Technical elements for the Phase II proposals should include followings:

- Scaled model development plan:
  - Detailed description about scaling technique.
  - Finite element model development plan.
  - Manufacturing plan about scaled model hardware.
- Ground test plan:
  - Static test.
  - Ground vibration test.
- Flight (or wind-tunnel) test plan:
  - Detailed description about flight (or wind-tunnel) test plan.
  - Flight (or wind-tunnel) test will be performed if awarded for Phase III.

Technical elements for the Phase II results and deliverables should be as follows:

- Test articles (scaled models) developed under Phase II (baseline configuration and new (or state-of-art) design concept configuration).
- Ground test data should be delivered.
- CAD model of the test articles should be delivered.
- Validated (with respect to ground test data) structural finite element model of the test articles should be delivered.
- Stress/strain distribution under the critical design load condition with margin of safety information; Primary buckling characteristics and buckling shape.
- Natural frequencies and mode shapes of the scaled model.
- Flutter boundary information with proposed flight envelope.
- Sonic boom noise level information on the ground (if used).
- Comparisons and discussions of results between prototype vs. scaled model are needed.
- Computer programs developed during Phase II: source codes; executable codes; quick user guide; & etc.

Links to program/project websites:

- ARMD's Advanced Air Vehicles Program (AAVP): https://www.nasa.gov/aeroresearch/programs/aavp.
- ARMD's Flight Demonstrations and Capabilities (FDC) project under the Integrated Aviation Systems Program (IASP): https://www.nasa.gov/aeroresearch/programs/iasp/fdc.

Focus Area 19: Integrated Flight Systems
Lead MD: ARMD

This focus area includes technologies that contribute to the Integrated Aviation Systems Program's (IASP) objectives to demonstrate integrated concepts and technologies to a maturity level sufficient to reduce risk of implementation for stakeholders in the aviation community through the rigorous execution of highly complex flight tests and related experiments.

A2.01 Flight Test and Measurement Technologies (SBIR)
Lead Center: AFRC
Participating Center(s): ARC, GRC, LaRC
Related Subtopic Pointer(s): T13.01

NASA continues to use flight research as a critical element in the maturation of technology. This includes developing test techniques that improve the control of in-flight test conditions, expanding measurement and analysis methodologies, and improving test data acquisition and management with sensors and systems that have fast response, low volume, minimal intrusion, and high accuracy and reliability. By using state-of-the-art flight test techniques along with novel measurement and data acquisition technologies, NASA and the aerospace industry will be able to conduct flight research more effectively and also meet the challenges presented by NASA's and industry's cutting-edge research and development programs.

NASA's Flight Demonstrations and Capabilities Project supports a variety of flight regimes and vehicle types ranging from low speed, sub-sonic applications and electric propulsion, through transonic and high-speed flight regimes. Therefore, this solicitation can cover a wide range of flight conditions and vehicles. NASA also requires improved measurement and analysis techniques for acquisition of real-time, in-flight data used to determine aerodynamic, structural, flight control, and propulsion system performance characteristics. These data will also be used to provide information necessary to safely expand the flight and test envelopes of aerospace vehicles and components. This requirement includes the development of sensors for both in-situ and remote sensing to enhance the monitoring of test aircraft safety and atmospheric conditions during flight testing. This subtopic supports innovative flight platform development for use in hypersonic ground and flight testing, science missions and related subsystems development.

Flight test and measurement technologies proposals should significantly enhance the capabilities of major government and industry flight test facilities comparable to the following NASA aeronautical test facilities:

- Dryden Aeronautical Test Range.
- Aero-Structures Flight Loads Laboratory.
- Flight Research Simulation Laboratory.
- Research Test Bed Aircraft.

Proposals should address innovative methods and technologies to reduce costs and extend the health, maintainability, communication and test techniques of these types of flight research support facilities.

- Areas of interest emphasizing flight test and measurement technologies include the following:
- High performance, real time reconfigurable software techniques for data acquisition and processing associated with IP based commands and/or IP based data input/output streams.
- High efficiency digital telemetry techniques and/or systems to enable high data rate, high volume IP based telemetry for flight test; this includes Air-to-Air and Air-to-Ground communication.
- Architecture and tools for high integrity data capture and fusion
- Real-time integration of multiple data sources from on-board, off-board, satellite, and ground-based measurement equipment.
- Innovative cybersecurity protocols for safe transmission of measurement data.
- Improved time-constrained situational awareness and decision support via integrated, secure, cloud-based web services for real-time decision making.
- Prognostic and intelligent health monitoring for hybrid and/or all electric propulsion systems using an adaptive embedded control system.

- Methods for accurately estimating and significantly extending the life of electric aircraft propulsion energy source (e.g., batteries, fuel cells, etc.).
- Test techniques, including optical-based measurement methods that capture data in various spectra, for conducting quantitative in-flight boundary layer flow visualization, Schlieren photography, near and far-field sonic boom determination, and atmospheric modeling as well as measurements of global surface pressure and shock wave propagation.
- Measurement technologies for in-flight steady and unsteady aerodynamics, juncture flow measurements, propulsion airframe integration, structural dynamics, stability & control, and propulsion system performance.
- Miniaturized fiber optic-fed measurement systems with low power requirements are desirable for migration to small business class jets or UAS platforms.
- Innovative techniques that enable safer operation of aircraft.
- Wireless sensor/sensing technologies and telecommunication that can be used for flight test instrumentation applications for manned and unmanned aircraft. This includes wireless (non-intrusion) power transferring techniques and/or wirelessly powering remote sensors. Innovative measurement methods that exploit autonomous remote sensing measurement technologies for supporting advanced flight testing.
- Fast imaging spectrometry that captures all dimensions (spatial/spectral/temporal) and can be used on UAS platforms.
- Innovative new flight platforms, airframes and the associated subsystems development for use in all areas of flight tests and missions, e.g., X-planes testing, hypersonic testing, science missions, etc.

The emphasis of this work is on flight test and flight test facility needs.

A2.02 Unmanned Aircraft Systems (UAS) Technologies (SBIR)
Lead Center: AFRC
Participating Center(s): ARC, GRC, LaRC
Related Subtopic Pointer(s): H6.02, A3.02

Unmanned Aircraft Systems (UAS) offer advantages over manned aircraft for applications which are dangerous to humans, long in duration, require great precision, and require quick reaction. Examples of such applications include remote sensing, disaster response, delivery of goods, agricultural support, and many others that are known or yet to be discovered. In addition, the future of UAS promises great economic and operational advantages by requiring less human participation, less human training, an ability to take-off and land at any location, and the ability to react to dynamic situations.

NASA is involved in research that would greatly benefit from breakthroughs in UAS capabilities. Flight research of basic aerodynamics and advanced aero-vehicle concept would be revolutionized with an ability of UAS teams to cooperate and interact while making real time decisions based upon sensor data with little human oversight. Commercial industry would likewise be revolutionized with such abilities.

There are multiple technological barriers that are restricting greater use and application of UAS in NASA research and in civil aviation. These barriers include, but are not limited to, the lack of methods, architectures, and tools which enable:

- The verification, validation, and certification of complex and/or nondeterministic systems.
- Humans to operate multiple UAS with minimal oversight.
- Multi-vehicle cooperation and interoperability.
- High level machine perception, cognition, and decision-making.
- Inexpensive secure and reliable communications.

This solicitation is intended to break through these and other barriers with innovative and high-risk research.

The Integrated Aviation Systems Program's work on UAS Technology for the FY 2018 NASA SBIR solicitation is focused on breaking through barriers to enable greater use of UAS in NASA research and in civil aviation use. The following five research areas are the primary focus of this solicitation, but other closely related areas will also be considered for award. The primary research areas are:

- *Verification, Validation, and Certification* - New inexpensive methods of verification, validation, and certification need to be developed which enable application of complex systems to be certified for use in the national airspace system. Proposed research could include novel hardware and software architectures that enable or circumvent traditional verification and validation requirements.
- *Operation of Multiple UAS with Minimal Human Oversight* - Novel methods, software, and hardware that enable the operation of multiple UAS by a single human with minimal oversight need to be developed which ensure robust and safe operations. Proposed research could include novel hardware and software architectures which provide guarantees of safe UAS operations.
- *Multi-Vehicle Cooperation and Interoperability* - Technologies that enable UAS to interact in teams, including legacy vehicles, need to be developed. This includes technologies that enable UAS to negotiate with others to find optimal routes, optimal task allocations, and optimal use of resources. Proposed research could include hardware and software architectures which enable UAS to operate in large cooperative and interactive teams.
- *Sensing, Perception, Cognition, and Decision Making* - Technologies need to be developed that provide the ability of UAS to detect and extract internal and external information of the vehicle, transform the raw data into abstract information which can be understood by machines or humans, and recognize patterns and make decisions based on the data and patterns.
- *Inexpensive, Reliable, and Secure Communications* - Inexpensive methods which ensure reliable and secure communications for increasingly interconnected and complex networks need to be developed that are immune from sophisticated cyber-physical attacks.

Phase I deliverables should include, but are not limited to:

- A final report clearly stating the technology challenge addressed, the state of the technology before the work was begun, the state of technology after the work was completed, the innovations that were made during the work period, the remaining barriers in the technology challenge, a plan to overcome the remaining barriers, and a plan to infuse the technology developments into UAS application.
- A technology demonstration in a simulation environment which clearly shows the benefits of the technology developed.
- A written plan to continue the technology development and/or to infuse the technology into the UAS market. This may be part of the final report.

Phase II deliverables should include, but are not limited to:

- A final report clearly stating the technology challenge addressed, the state of the technology before the work was begun, the state of technology after the work was completed, the innovations that were made during the work period, the remaining barriers in the technology challenge, a plan to overcome the remaining barriers, and a plan to infuse the technology developments into UAS application.
- A technology demonstration in a relevant flight environment which clearly shows the benefits of the technology developed.

There should be evidence of infusing the technology into the UAS market or a clear written plan for near term infusion of the technology into the UAS market. This may be part of the final report.

Focus Area 20: Airspace Operations and Safety

Lead MD: ARMD

This focus area includes technologies addressing both the Airspace Operations and Safety Program (AOSP), and NASA's ARMD Strategic Thrusts 1, 5, and 6. AOSP is targeting system-wide operational benefits of high impact for NextGen both in the areas of airspace operations and safety management. The SBIR Airspace Operations and Safety Topic is focused on research and technology development for enabling a modernized air transportation system that will achieve much greater capacity and operational efficiency while maintaining or improving safety and other performance measures. This will include the integration of new types of vehicles such as unmanned vehicles, supersonic or commercial space vehicles; new types of business models or operations (i.e., urban air mobility); and new architectures or services for enabling these operations within the NAS.

A3.01 Advanced Air Traffic Management Systems Concepts (SBIR)
Lead Center: ARC
Participating Center(s): LaRC

This subtopic addresses user needs and performance capabilities, trajectory-based operations, and the optimal assignment of humans and automation to air transportation system functions, gate-to-gate concepts and technologies to increase capacity and throughput of the National Airspace System (NAS), and achieving high efficiency in using aircraft, airports, en-route and terminal airspace resources, while accommodating an increasing variety of missions and vehicle types, including wide-spread integration of UAS and ODM operations. Examples of concepts or technologies that are sought include:

- Verification and validation methods and capabilities to enable safe, end-to-end NextGen Trajectory-Based Operations (TBO) functionality and seamless UAS operations, as well as other future aviation system concepts and architectures.
- Performance requirements, functional allocation definitions, and other critical data for integrated, end-to-end NextGen TBO functionality, and seamless UAS operations, as well as other future aviation system concepts and architectures.
- Prognostic safety risk management solutions and concepts for emergent risks.
- TBO concepts and enabling technology solutions that leverage revolutionary capabilities and that enable capacity, throughput, and efficiency gains within the various phases of gate-to-gate operations.
- Networked/cloud-based systems to increase system predictability and reduce total cost of National Airspace System operations.

It is envisioned that the outcome of these concepts and technologies will provide greater system-wide safety, predictability, and reliability through full NextGen (2025-2035 timeframe) functionality.

A3.02 Increasing Autonomy in the National Airspace Systems (NAS) (not vehicles) (SBIR)
Lead Center: ARC
Participating Center(s): LaRC
Related Subtopic Pointer(s): A2.02, H6.02

NASA's research envisions future concepts for air transportation that will significantly expand the current nature of airspace and vehicle management with an increasing reliance on autonomy technologies. Growing numbers of operations and a wider range of vehicle performance and mission goals will not be realizable in the current airspace system, and it is expected that a new service-based architecture, with features derived from NASA's Unmanned Aircraft System (UAS) Traffic Management (UTM) model, will provide the flexibility to support future use cases while establishing the necessary constraints to ensure safe and equitable operations. New technologies will be used to empower user decision making and collaboration with other users and the Air Navigation Service Provider. NASA's near-term goal for UTM itself is the development and demonstration of the concept to safely enable low-altitude airspace and UAS operations within the next five years. For the longer-term (10 to 15 years in the future), the goal is to safely enable the anticipated dramatic increase in density of all low-altitude airspace operations. NASA is partnered with other government agencies, industry, and academia, to perform the research, development, testing, and implementation of UTM.

This subtopic addresses the application of autonomy towards improving mobility, scalability, efficiency, safety, and cost-competitiveness, with particular attention towards the needs of emergent users and their operations (e.g., frequent, domestic supersonic flights, and commercial space launches to Urban Air Mobility and regional air-taxi operations) and enabling human operators to efficiently and effectively manage civilian low-altitude unmanned aircraft system (UAS) operations (UAS traffic management, or UTM) across a range of potential use cases (e.g., public safety/search and rescue, infrastructure inspection/surveillance, agricultural applications, cargo delivery, hobbyist, etc.). Proposals in the following areas are sought, but are not limited to:

- Autonomous or increasing levels of autonomy for, or towards, managing networked vehicle cockpits in all airspace domains (e.g., airport, metroplex, en route, regional/national traffic flow management, integration of multiple domains, on-demand aircraft and operations, and non-towered airports and vertiports).
- Autonomicity (or self-management) -based architectures for the entirety, or parts, of airspace operations.
- Autonomous systems to produce any of the following system capabilities:
  - Prognostics, data mining, and data discovery to identify opportunities for improvement in airspace operations.
  - Weather-integrated flight planning, rerouting, and execution.
  - Fleet, crew, and airspace management to reduce the total cost of operations.
  - Predictions of unsafe conditions for vehicles, airspace, or dispatch operations.
  - Performance driven, all-operations, human-autonomy teaming management.
  - Verification and validation tools for increasingly autonomous operations.
  - Machine learning and/or self-learning algorithms for Shadow Mode Assessment using Realistic Technologies for the National Airspace System (NAS).
  - Autonomy/autonomous technologies and concepts for trajectory management and efficient/safe traffic flows.
- Service-based architecture designs that enable dense urban mobility operations and/or increasingly complex operations at ultra-high altitudes.
- Dynamic route planning that considers changing environmental conditions, vehicle performance and endurance, airspace congestion, and traffic avoidance.
- Dynamic scheduling for on-demand access to constrained resources and interaction between vehicles with starkly different performance and control characteristics.
- Autonomous and safe UAS operations for the last and first 50 feet, under diverse weather conditions.

- Integration of emergent users with legacy users, large commercial transport, including pass-through to and from ultra-high altitudes and interactions around major airports.
- Operational concepts for future vehicle and missions, including vehicle performance, vehicle fleet and network management, market need and growth potential, for future operations and airspace integration.
- Identification of potential certification approaches for new vehicles (such as electric vertical take-off-and landing-VTOL).
- Technologies to demonstrate the scalability of the UTM concept to potentially 10M+ users/operators.
- The development of low size, weight, and power sense-and-avoid technologies for safe, heterogeneous (manned/unmanned) aircraft operations in the National Airspace System.
- The development of UTM-focused track and locate functions.

A3.03 Future Aviation Systems Safety (SBIR)
Lead Center: ARC
Participating Center(s): LaRC

Public benefits derived from continued growth in the transport of passengers and cargo are dependent on the improvement of the intrinsic safety attributes of the Nation's and the world's current and future air transportation system. Recent developments to address increasing demand are leading to greater system complexity, including airspace systems with tightly coupled air and ground functions as well as widely distributed and integrated aircraft systems. Current methods of ensuring that designs meet desired safety levels will likely not scale to these levels of complexity (Aeronautics R&D Plan, p. 30). The Airspace Operations and Safety Program (AOSP) is addressing this challenge with a major area of focus on real-time system-wide safety assurance (RSSA). A proactive approach to managing system safety requires:

- The ability to monitor the system continuously and to extract and fuse information from diverse data sources to identify emergent anomalous behaviors after new technologies, procedures, and training are introduced.
- The ability to reliably predict probabilities of the occurrence of hazardous events and of their safety risks.

Understanding and predicting system-wide safety concerns of the airspace system and the vehicles as envisioned by NextGen is paramount. Such a system would include the emergent effects of increased use of automation and autonomy to enhance system capabilities, efficiency and performance beyond current, human-based systems, through health monitoring of system-wide functions that are integrated across distributed ground, air, and space systems. Emerging highly autonomous operations such as those envisioned for UAS and on-demand air mobility (ODM) will play a major role in future airspace systems. In particular, operating beyond the operator's visual line-of-sight (BVLOS) and near or over populated areas are topics of concern. Safety-critical risks include:

- Flight outside of approved airspace.
- Unsafe proximity to people/property.
- Critical system failure (including loss of C2 link, loss or degraded GPS, loss of power, and engine failure).
- Loss-of-control (i.e., outside the envelope or flight control system failure).

Tools are being sought for use in creating prototypes of RSSA capabilities. The ultimate vision for RSSA is the delivery of a progression of capabilities that accelerate the detection, prognosis and resolution of system-wide threats.

Proposals under this subtopic are sought, but not limited to, these areas (with an emphasis on safety applications):

- Develop data collection architecture, data exchange model and data collection mechanism (for example via UTM TCL-4).

- Develop and demonstrate data mining tools and techniques to detect and identify anomalies and precursors to safety threats system-wide.
- Develop and demonstrate tools and techniques to assess and predict safety margins system-wide to assure airspace safety.
- Develop and demonstrate prognostic decision support tools and techniques capable of supporting real-time safety assurance.
- Develop and demonstrate V&V tools and techniques for assuring the safety of air traffic applications during certification and throughout their lifecycles, and, techniques for supporting the real-time monitoring of safety requirements during operation.
- Develop and demonstrate products to address technologies, simulation capabilities and procedures for reducing flight risk in areas of attitude and energy aircraft state awareness.
- Develop and demonstrate decision support tools and automation that will reduce safety risks on the airport surface for normal operations and during severe weather events.
- Develop and demonstrate alerting strategies/protocols/techniques that consider operational context, as well as operator state, traits, and intent.
- Develop methodologies and tools for integrated prevention, mitigation, and recovery plans with information uncertainty and system dynamics in a UAS and in a TBO environment.
- Develop and demonstrate strategies for optimal human-machine coordination for real-time hazard mitigation.
- Develop and demonstrate methods and technologies enabling transition from a dedicated pilot-in-command or operator for each aircraft (as required per current regulations) to single operators safely and efficiently managing multiple unmanned and ODM aircraft in civil operations.
- Develop measurement methods and metrics for human-machine team performance and mitigation resolution.
- Develop system-level performance models and metrics that include interdependencies and relationships among human and machine system elements.

Focus Area 21: Small Spacecraft Technologies

Lead MD: STMD
Participating MD(s): SMD

The concept of distributed spacecraft missions (DSM) involves the use of multiple spacecraft to achieve one or more science mission goals. Small distributed spacecraft acting in cooperation can execute science and exploration missions that would be impossible by traditional large spacecraft operating alone, and offer the potential for new concepts in mission design. The goal of this topic is to develop enabling technologies for small spacecraft DSM configurations operating over large distances beyond low Earth orbit (LEO).

The term DSM or "swarm" refers to a group of cooperatively distributed spacecraft, scalable up to 100s of spacecraft, in a specific configuration, which has three distinct characteristics. First, as opposed to a constellation, where spacecraft are distributed across multiple orbits, a DSM is comprised of small spacecraft orbiting relatively close to one another, with intersatellite ranges on the order of tens to hundreds of kilometers. Second, the DSM requires inter-spacecraft communications where each spacecraft is capable of sharing data and relative position information so that all swarm members are aware of the overall topology. The swarm topology would be dependent on the spatial and temporal distribution, orbit, ground reference, or other requirements of the science mission. Third, the swarm is commanded from the ground as an entity rather than each spacecraft individually. Thus, the swarm has inherent autonomous capabilities to control individual or complete swarm topology redistribution depending or requirements or in response to commands.

Small spacecraft, for the purpose of this solicitation, are defined as those with a mass of 180 kilograms or less and capable of being launched into space as an auxiliary or secondary payload. Small spacecraft are not limited to Earth orbiting satellites but might also include interplanetary spacecraft, planetary re-entry vehicles, and landing craft.

Specific innovations being sought in this solicitation will be outlined in the subtopic descriptions. Proposed research may focus on development of new technologies but there is particular interest in technologies that are approaching readiness for spaceflight testing. NASA's Small Spacecraft Technology Program will consider promising SBIR technologies for spaceflight demonstration missions and seek partnerships to accelerate spaceflight testing and commercial infusion. Some of the features that are desirable for small spacecraft technologies across all system areas are the following:

- Simple design.
- High reliability.
- Tolerant of extreme thermal and/or radiation environments.
- Low cost or short time to develop.
- Low cost to procure flight hardware when technology is mature.
- Small system volume or low mass.
- Low power consumption in operation.
- Suitable for rideshare launch opportunities or storage in habitable volumes (minimum hazards).
- Able to be stored in space for several years prior to use.
- High performance relative to existing system technology.

The following references discuss some of NASA's small spacecraft technology activities:

- www.nasa.gov/smallsats.
- https://www.nasa.gov/smallsat-institute.

Another useful reference is the Small Spacecraft Technology State of the Art Report at:
http://www.nasa.gov/sites/default/files/atoms/files/small_spacecraft_technology_state_of_the_art_2015_tagged.pdf.

Z8.01 Cubesat Propulsion Systems (SBIR)
Lead Center: GRC
Participating Center(s): GSFC, JPL, MSFC
Related Subtopic Pointer(s): Z10.02

The CubeSat market shows significant promise to enable low cost science and exploration missions. However, at present many CubeSat technology development activities do not reach flight, and missions that are flown are often selected for concept or component demonstration activities as the primary objectives. Several technology limitations challenge high value science from low-cost CubeSat missions. Limitations include, but are not limited to, post-deployment propulsion capabilities, radiation hardened flight computers, deep space communication, and available instruments. Additionally, propulsion systems often place restrictions on handling, storage, and operations that may limit a CubeSat's ability to launch as a secondary payload. Nevertheless, opportunities are anticipated in the near future to conduct a larger percentage of CubeSat missions based on application goals and pursue exploration and science return as the primary objectives.

Towards that end, this subtopic seeks to develop innovative long-life, reliable, and low-cost electric/chemical propulsion technologies that can enable small satellite science and exploration missions. This year, proposals are specifically sought for complete propulsion system solutions (thrusters, valves, propellant, sensors, electronics, etc.) capable of full scale flight demonstration on 27U, 12U, 6U, or 3U CubeSats in support of deep space and/or swarm topology missions. Proposers should place special emphasis on propulsion system solutions offering long life, reliability, and minimalistic use of CubeSat resources (power, energy, volume, and mass), while delivering propulsion capabilities within the scope of interests described below. Proposals will not be considered that focus purely on features, benefits, and advantages of a new technology, without addressing how their innovative propulsion solution supports improved mission outcome, cost, and productivity.

Proposers are expected to show a clear understanding of the current state-of-the-art (SOA) and quantitatively (not qualitatively) describe improvements over relevant SOA technologies that will substantiate the investments in the new technology. Quantification of improvement over the SOA should include any significant advancements that improves the capability of a CubeSat to carry out high-value science missions. For example, advancements are desirable in propulsion system lifetime, reliability, radiation tolerance, cost, energy utilization, miniaturization, thermal management, safety, propellant storage, etc. Potential opportunities for mission infusion for both technology demonstration and long-term mission application should be identified along with potential technology gaps that need to be addressed or assessed. Extensibility of technologies up to 180 kg satellites may be identified, though extensibility beyond 27U CubeSats is not required.

Green propellants are a subset of the propulsion technologies of interest. Green considerations may aid in reducing system mass, increase system safety, reduce cost of handling, and reduce integration risks in secondary payloads. Regardless of toxicity or propellant hazards, propulsion systems must show clear consideration for safe containment of the propellant through launch and system operations. These considerations may include the number of inhibits, post-launch pressurization schemes, etc.

Proposals are sought that can deliver hardware products and proof-of-concept demonstrations in Phase I. Proposals are sought that can deliver hardware at or greater than TRL 6 suitable for flight demonstration within the Phase II resources provided. Propulsion systems requiring Phase II-E or II-X funding will be considered if justified through mission enabling capabilities. Component level development proposals shall be considered, but must enable important new CubeSat mission capability and identify opportunities for near-term infusion. While component level development shall be considered, preference will be given to complete propulsion system solutions.

Specific propulsion capabilities of interest follow below. Metrics are provided either per unit of anticipated spacecraft volume (Usc) or per unit of propulsion system volume (Up). Where one unit of volume is defined as 10 cm cubed. Assume CubeSat wet mass as 2 kg/Usc. Proposers should specify to what S/C size (27U, 12U, 6U, and/or 3U) their propulsion system solution scales to meet or exceed the metrics below. If the propulsion solution can scale to satisfy multiple needs, proposers should quantitatively evaluate their solutions at each applicable scale and concisely present those capabilities in tables or figures. Proposers should also specify at what scale they intend to develop their demonstration hardware. Propulsion systems proposed should conceptually utilize no more than 1/3 the S/C total volume (e.g., propulsion system solutions for a 12U S/C should fit in 4U or less):

- High impulse propulsion systems meeting the following criteria:
  - Example applications: deep space, interplanetary, orbit capture.
  - Total impulse per unit of propulsion system volume > 4000 N-sec/Up.
  - Electric propulsion with thrust per S/C volume > 0.1 mN/Usc.
  - Lifetime > 2 years.
  - Propulsion system peak power per S/C volume < 5 W/Usc.
  - Design for deep space application (radiation tolerance, thermal attributes, etc.).
  - Propulsion systems including ACS.
- High thrust propulsion systems meeting the following criteria:
  - Example applications: Orbit raising (MEO, GEO), long life LEO.
  - Total impulse per unit of propulsion system volume > 750 N-sec/Up.

- Chemical propulsion thrust per S/C volume > 5 mN/Usc.
- Electric propulsion thrust per S/C volume > 0.5 mN/Usc.
- Lifetime > 2 years.
- Propulsion system peak power per S/C volume < 5 W/Usc.
- Low soakback (i.e., minimal increase to local bus temperature).
- Propulsion systems including ACS.

- Precision Control:
  - Example applications: formation flying, tight pointing requirements.
  - Minimum impulse bit per S/C volume < 0.1 microN-sec/Usc.
  - Lifetime > 2 years.
  - Propulsion system peak power per S/C volume < 5 W/Usc.

Preference for systems:

- Optimized for the rigors of interplanetary / deep space missions (i.e., radiation, thermal, etc.).
- placing no demanding storage or handling requirements prior to launch.
- Remaining quiescent under ambient conditions for > 6 months prior to launch.
- remaining quiescent under post-deployment conditions.

For small satellite propulsion technologies applicable to satellites larger than 27U (54 kg), please see subtopic Z10.02, "Propulsion Systems for Robotic Science Missions."

Z8.02 Communications for Distributed Small Spacecraft Beyond LEO (SBIR)
Lead Center: GRC
Participating Center(s): ARC, GSFC, JPL, JSC, LaRC
Related Subtopic Pointer(s): H9.01, S2.02, T4.03

Space communications and position knowledge and control are enabling capabilities required by spacecraft to conduct all NASA missions. The concept of distributed spacecraft missions (DSM) involves the use of multiple spacecraft to achieve one or more science mission goals. DSM configurations include widely dispersed configurations of spacecraft, constellations, free-flying swarms, formation flying swarms clusters, swarms of common elements, and disaggregated science mission elements, all operating in the space environments beyond low Earth orbit (LEO). The term, "swarm" refers to a configuration of spacecraft that communicate and exchange data and location information with each other and act a one controllable entity. In contrast, 'constellations' are loosely grouped spacecraft which may communicate with other but are flown individually. A swarm of dozens to hundreds of spacecraft located 10s to 100s km apart must be able to act as one unit. Small distributed spacecraft acting in cooperation can execute science and exploration missions that would be impossible by traditional large spacecraft, and offer the potential for new concepts in mission design. Innovations in communications and navigation technologies for distributed small spacecraft are essential to fulfill the envisioned science missions within the decadal surveys and contribute to the success of human exploration missions. The goal of this subtopic is to develop DSM-enabling technologies for communications, relative and/or absolute position knowledge, and control of small spacecraft (or other directly related technologies) for configurations of small spacecraft operating over large distances beyond LEO. This subtopic is a direct enabler of deep space distributed spacecraft science missions.

DSM Communications
Communications among spacecraft in the DSM configuration and between the configuration and the Earth become more challenging beyond LEO distances. Collaborative configurations of widely distributed (10s to 100s km apart) small spacecraft (180 kg or less) will operate far into the near-Earth region of space and beyond into deep space,

further stressing the already limited communications capabilities of small spacecraft. The communications links to/from DSM spacecraft beyond LEO distances are closed via either NASA's near-Earth network (NEN) or deep space network (DSN) ground station infrastructure, depending on the distance of the spacecraft from Earth (i.e., NEN for < 2 million km, DSN for > 2million km).

The DSM communications portion of this subtopic invites innovative system level communications architecture and concepts of operation and an integrated communications payload design taking into consideration the following capabilities:

- *DSM configuration control* – For distributed operations of the DSM configuration and of individual small spacecraft. Identify alternatives, provide rationale for selection, and develop proposed approaches for: science data time and location stamping; temporary data storage; distributed network control and data planes; networking protocols; and any other considerations associated with control of the configuration.
- *Inter-satellite links (space-space)* – For coordinated exchange of science instrument data and spacecraft telemetry and command (T&C) data among small spacecraft in the DSM configuration. Identify alternatives and provide rationale for selection of proposed: frequency band(s) of operation or optical communications; multiple access and addressing techniques; minimum and maximum data rates; expected link bit error rate, maximum expected range between spacecraft, maximum spacecraft field of regard; and pointing stability requirements.
- *Uplinks (Earth-space) and Downlinks (space-Earth)* – For coordinated command and control of the DSM configuration and individual small spacecraft from Earth and return of science and telemetry data to Earth. Identify alternatives and provide rationale for selection of proposed: frequency band(s) of operation or optical communications; ground terminal network; coordination with other users of the band(s); multiple access and addressing techniques; minimum and maximum data rates; expected link bit error rate, maximum expected range between spacecraft, ground terminal and maximum spacecraft field of regard; and pointing stability requirements.
- *Integrated communications payload* – For the common and unique capabilities of each small spacecraft in the DSM configuration. Identify proposed hardware and software designs of the small spacecraft communications payload(s) required to implement the proposed communications links and operational controls.

In addition *to* the system level concepts of operation and integrated communications payload design, innovations and advancements in technology readiness in one or more of the following constituent small distributed spacecraft technologies is also requested:

- *Small Spacecraft Antennas* – Development of antennas optimized for either inter-satellite or uplink/downlink communications are sought across a broad range of technologies including but not limited to deployable parabolic or planar arrays, active electronically steered arrays, novel antenna steering/positioning subsystems, and others suitable for use in high data rate transmission among small spacecraft over large distances. Operations compatible with NASA's space communications infrastructure [1] and Government exclusive or Government/non-Government shared frequency spectrum allocations is required. [See References for applicable Government frequency spectrum allocations in the near Earth and deep space regions].
- *Optical Communications* – Point-to-point communications are the most common approach for optical communications. This focus area seeks innovations that enable optical communications among many spacecraft simultaneously operating in a distributed spacecraft network. Technologies and integrated solutions for beaconless one-way and/or bidirectional two-way optical communications from beyond LEO to Earth-based optical terminals are also sought. Technology advancements in integrated solutions are sought

that increase the data rate or availability of optical communications for small spacecraft, or reduce mission risk, pointing requirements, complexity or cost at a minimally-acceptable Quality of Service.

- *Transceivers and Radios* – This area includes but is not limited to: multiple access techniques; radio frequency (RF) transmitters; amplifiers; low noise receivers, full duplex frequency selectable RF front-ends, integrated navigation and communications receivers, software defined or reconfigurable radios, or integrated transceivers and radios for inter-satellite links among distributed spacecraft and/or uplink/downlink via the NEN or DSN. Small satellites are particularly constrained in terms of power, mass and volume, therefore significant improvements in these areas are highly effective. In addition to reductions in mass, power consumption, volume and cost, increases in power and bandwidth efficiency, operational flexibility and frequency select-ability are sought. Small spacecraft transceivers and radios must be compatible with the operations of NASA's space communications infrastructure. [1] [See References for applicable NASA near Earth and deep space infrastructure guidelines and specifications].
- *Networking Protocols and Processing* – Standard Internet protocols don't work well over communication links that are subject to the frequent, transient service outages and/or long signal propagation delays that are characteristic of missions beyond LEO. Innovations or advancements are sought in networking protocols and distributed data processing (routing/switching) and storage systems that enable secure, low-power networked communications among small spacecraft within the DSM configuration and/or between the configuration or individual spacecraft and network service users and operators on Earth and/or on the surfaces of other Solar System objects. Implementation of NASA's delay/disruption tolerant networking (DTN) standards to support scalable, robust and secure mission communications for small spacecraft links from beyond LEO to Earth are also invited. Interoperability between spacecraft operating with NASA and commercial space networks is an additional opportunity for innovation. [See References for applicable NASA and commercial networking standards].

Low mass, power, volume, cost and complexity are overarching goals. Leverage of commercial technologies or best commercial standards and practices (e.g., DVB-S2 standard, CubeSat form factors, 5G wireless technologies) that can demonstrably improve performance and be applied or adapted for use in Government, non-Government or commercial networks is also desirable.

Note: *Proposed Earth-Space and Earth-Space communications links must be designed to operate in and comply with the frequency spectrum bands implemented by the NEN and/or DSN and/or comply with other frequency spectrum bands allocated by the U.S. National Telecommunications Information Administration (NTIA) tables of frequency allocations for space research. Links among distributed spacecraft must use frequency spectrum allocated by the NTIA in the U.S. for inter-satellite communications service (e.g., ~23 GHz, ~24.5 GHz, ~26 GHz, ~60 GHz).*

Finally, small spacecraft communication systems operating beyond LEO must be robust, flexible and diverse to support a wide variety of interconnected configurations of spacecraft used by NASA to conduct space science, Earth science and exploration of the universe. Communication system components need to be able to operate over a range of environmental conditions, such as those imposed by launch vehicles and operations in space with appropriate levels of radiation tolerance in the space environment beyond LEO. A clear path to space qualification for potential operation in those regions of space is required of all proposed technologies.

DSM Position Knowledge and Control

Science measurements of DSMs are based on temporal and spatially distributed measurements where position knowledge and control are fundamental to the science interpretation. Current space navigation technologies are not adequate when relative or absolute position knowledge of multiple spacecraft are involved. Global navigation satellite services like the U.S. global positioning satellites (GPS) provide very limited services beyond GEO distances and no practical services in deep space. Autonomous navigation capabilities are fundamental to DSMs to ensure topography of the configuration is known at the time of data acquisition. Control of the distributed configuration requires robust absolute and relative position knowledge of each spacecraft within the configuration and the ability to control spacecraft position and movement according to mission needs.

The navigation portion of this subtopic solicits methods for determining and maintaining spacecraft position within a configuration of small spacecraft. DSM navigation solutions may be addressed via hardware or software solutions, or combinations of the two. Innovations and advancements in technologies for determining relative and absolute position knowledge include but are not limited to:

- *Radiometric measurements* **-** Exploitation of intersatellite communication links allows for measurements via one-, two-, or three-way ranging and/or Doppler shift measurements. Such measurements may allow for accurate estimation of the relative satellite position and velocity vectors in certain DSM topographies. Alternatively, solutions may adapt the proven signal designs of the Global Navigation Satellite Systems (GNSS, i.e., GPS, GLONASS, Galileo) for the purpose of deep space relative navigation. Novel estimation techniques that are feasible for small satellite processing platforms are also opportunities for innovation.
- *Laser based measurements* **-** Similar to the exploitation of radio communication systems mentioned above, an optical communication system may also provide range and/or range-rate measurements for relative orbit estimation. Innovations that leverage LIDAR technology for relative navigation of small satellites are also invited. Proposals that include satellite design enhancements for improved tracking are sought.
- *Optical navigation* - Solutions are sought for visual based systems that leverage advances in optical sensors (i.e., cameras, star trackers) to observe and track a target spacecraft and perform pose and relative position estimation. Opportunities for innovation include methods that do not require the execution of satellite maneuvers are/or the design of external satellite features that enhance observability. Innovations may be appropriate for only certain regimes, such as near, medium, or far range; this context should be described. Solutions for various mission operations concepts are of interest.
- *Other novel navigation methods* **-** Stellar navigation aids, such as navigation via quasars, X-rays and pulsars, may provide enabling capabilities in deep space. Earth-based navigation aids, such as systems detecting radio beacons or terrestrial landmarks, are invited.

Methods for autonomous position control are also of interest. Note: Small spacecraft propulsion technologies are not included in this subtopic as those are addressed in subtopic Z8.01, Cubesat Propulsion Systems. Technologies that accomplish autonomous relative orbit control among the spacecraft are invited. Control may be accomplished as part of an integrated system that includes one or more of the measurement techniques described above. Of particular interest are autonomous control solutions that do not require operator commanding for individual spacecraft. That is, control solutions should accept as input swarm-level constraints and parameters, and provide control for individual spacecraft. Opportunities for innovation include the application of optimization techniques that are feasible for small satellite platforms and do not assume particular orbit eccentricities.

Phased Development Guidance to Proposers

A typical approach to advance the technology readiness level (TRL) leading to future flight hardware/ software demonstration of any of the DSM small spacecraft communications and navigation technologies intended for the beyond LEO environment would include:

Phase I - Identify and explore options for the DSM configuration control, conduct trade analysis and simulations, define operating concepts, and provide justification for proposed multiple access techniques, frequency bands of operation, command and data handling and networking solutions. Also identify, evaluate and develop design for integrated communications payload(s) and one or more constituent technologies that enable distributed spacecraft operations in the relevant space environment beyond LEO. Integrated communications system solutions and constituent components offer potential advantages over the state of the art, demonstrate their technical feasibility, and show a path towards a hardware/software infusion into practice. Bench-level or lab-environment level demonstrations or simulations are anticipated deliverables. The Phase I proposal should outline a path that shows how the technology can be developed into space-qualifiable and commercially available small spacecraft communications payloads through Phase II efforts and beyond.

Phase II - Emphasis should be placed on developing and demonstrating the candidate integrated communications payload and/or selected technologies under simulated constellations or swarms of small distributed spacecraft in the relevant beyond LEO environment. A demonstration unit for functional and environmental testing is an anticipated deliverable at the completion of the Phase II contract. Some of the products resulting from this subtopic may be included in a future flight opportunity for on-orbit testing or application demonstration.
All integrated communications systems and constituent technologies developed under this subtopic area should be compatible with existing NASA space communications infrastructure [1], frequency spectrum allocations, and applicable standards. However, applicability or adaptability to non-Government and commercial use as well is desirable.

[1] NASA's space communications infrastructure includes the Near-Earth network (NEN) of ground stations, the Space Network (SN) of tracking and data relay satellites in geostationary Earth orbit, and the Deep Space Network (DSN) of ground stations.

References:

- National Telecommunications and Information Administration Frequency Allocation Chart: https://www.ntia.doc.gov/page/2011/united-states-frequency-allocation-chart.
- National Telecommunications and Information Administration Tables of Frequency Allocations: https://www.ntia.doc.gov/legacy/osmhome/alloctbl/alloctbl.html.
- NASA Spectrum Policy: http://www.nasa.gov/directorates/heo/scan/spectrum/policy_and_guidance.html.
- Spectrum Guidance for NASA Small Satellite Missions: https://www.nasa.gov/sites/default/files/atoms/files/smallsat_workshop_ames_spectrum_presentation.pdf.
- Near Earth Network (NEN) Users Guide: https://sbir.gsfc.nasa.gov/sites/default/files/453-NENUG%20R2.pdf.
- Space Network Users Guide (SNUG): https://evt.grc.nasa.gov/rfp-industry-briefing-2016/wp-content/blogs.dir/52/files/sites/10/Space-Network-Users-Guide-SNUG-Rev-10.pdf.
- Deep Space Network (DSN): http://deepspace.jpl.nasa.gov/advmiss/missiondesigndocs/.
- Delay/Disruption Tolerant Networking (DTN):
  - NASA DTN: http://www.nasa.gov/content/dtn.
  - InterPlanetary Networking Special Interest Group (IPNSIG) DTN www.ipnsig.org.

Z8.03 Low Cost Radiation Hardened Integrated Circuit Technology (SBIR)
Lead Center: LaRC
Participating Center(s): ARC, GRC, GSFC, JPL
Related Subtopic Pointer(s): S3.08, S4.04

As small spacecraft develop in capability, they have the need for more advanced supporting electronics. Low-cost, capable Integrated Circuit (IC) core chipsets are needed that are suitable for use in government and commercial small spacecraft, and other radiation-affected environments. In keeping with the small spacecraft design philosophy and general mission costing profiles, chipsets associated with state-of-the-art IC devices offer a significant potential for improved functionality in space capabilities and cost reduction. However, these devices usually have not been certified for use in the space environment and often have issues with the radiation found in space. As small satellite designers consider mission opportunities beyond low Earth orbit, there is a growing need for IC approaches that provide the functionality found in terrestrial applications and are able to perform their functions over the lifetime of a small satellite mission. Advancing commercial-type functionality to meet these operational needs is desired.

There are multiple potential development areas within the suite of spacecraft avionics functions, power systems, and instrument support functions can benefit from taking commercial IC concepts and making them space-ready, specific core chipset capabilities and requirements are not specified in this subtopic. Proposers should consider functions normally found within spacecraft systems (such as avionics, power systems, etc.) and propose solutions to make available for new spacecraft designers. Examples of technology development areas include, but are not limited to:

- *Fault tolerant FPGA/ASIC IP Cores* – To enable low cost radiation hardened integrated circuit development, fault tolerant intellectual property cores are sought that can be used to compose fault tolerant System-On-a-Chip (SOC) devices. These SOC devices may be used for spaceflight applications including, command and data handling, embedded power system controllers, embedded motor/actuator controllers, and instrument controllers. IP cores should be AMBA bus compatible, incorporate built-in test, and employ fault tolerance techniques. The IP cores should be sufficiently modular and reusable to allow the implementation of a wide variety of applications.
- *Software Mitigation for Single Event Upset Recovery* – Advanced methods to improve Single Event Upset (SEU) recovery in devices that can be demonstrated to comparable or better performance than hardware techniques across several metrics, such as mass and power, and have minimal impact to system speed performance.
- *ASIC Demonstrator* - Show how a specific rad hard IC for a defined application can be developed and evaluated by using a low-cost ASIC development approach.

In response to this topic, the proposer should:

- Identify the specific function to be advanced and demonstrate how it is not currently available at the full level performance needed.
- Identify the intended application environment(s), e.g., GEO, Cis-lunar space, deep space, etc.
- Explain how the proposed approach exceeds the state of the art in key metrics such as available functionality, power requirements, mass, radiation resistance, temperature range, etc.
- Identify the technology development necessary to get the proposed IC to the performance needed for the proposed environment and application.

The technology development plan needs to include test and verification to include full environmental testing so that the end customer can readily incorporate the chipsets into new vehicles without additional testing. Low-cost chipsets that are used both for space applications as well as terrestrial applications such as DoD, commercial aircraft, etc. are the primary emphasis for this call.

General purpose computing processors are explicitly excluded in this call.

Proposers are referred to topics S3.08 Command, Data Handling, and Electronics and S4.04 Extreme Environments Technology for related topics of potential interest.

Z9.01 Small Launch Vehicle Technologies and Demonstrations (SBIR)
Lead Center: AFRC
Participating Center(s): KSC, LaRC, MSFC

NASA is recognizing a growing demand for dedicated, responsive small spacecraft launch systems and seeks to facilitate the establishment of a robust launch service provider market sector. The movement toward small spacecraft missions is largely driven by rising development/launch costs associated with conventional spacecraft, which poses severe threats to future science/commercial mission cadence, and by rapidly evolving miniaturization innovations that are revolutionizing small spacecraft platform capabilities. This topic seeks innovative technologies, subsystems, and efficient streamlined processes that will support the development of affordable small spacecraft launch systems having a 5-180 kg payload delivery capacity to 350 to 700 km at inclinations between 28 to 98.2 degrees to support both CONUS and sun synchronous operations. Affordability objectives are focused on reducing launch costs to below $1.5M/launch for payloads ranging up to 50 kg or below $30,000/kg for payloads in excess of 50 kg. It is recognized that no single enabling technology is likely to achieve this goal and that a combination of multiple technologies and production practices are likely to be needed. Therefore, it is highly desirable that disparate but complementary technologies formulate and use standardized plug-and-play interfaces to better allow for transition and integration into small spacecraft launch systems.

Technology areas of specific interest are as follows:

- Innovative Propulsion Technologies & Prototype Stages.
- Affordable Guidance, Navigation & Control.
- Manufacturing Innovations for Launch Vehicle Structures & Components.
- Reusability Innovations.
- Dual Use Hypersonic Flight Testbeds.

Proposers are expected to quantify improvements over relevant SOA technologies and substantiate the basis for investment. Potential opportunities for technology demonstration and commercialization should be identified along with associated technology gaps. Ideally, proposed technologies would be matured to TRL 4 to 6 by the end of Phase II effort. Efforts leading to Phase II delivery of integrated prototype stages that could either be ground tested or flight-testing as part of a post-Phase II effort are of particular interest. A brief descriptive summary of desired technical objectives and goals are provided below.

Innovative Propulsion Technologies & Prototype Stages
Innovative chemical propulsion technologies/subsystem and integrated stage concepts are sought that can serve as the foundational basis of an affordable ground-launch or air-launch system architecture. The scope of interest includes main propulsion systems and novel reaction control systems based on conventional or novel propellants. Technologies or subsystems are expected to demonstrate proof-of-concept by the end of Phase II as a minimum and proposals should include a development roadmap for achieving this goal. Efforts aimed at Phase II delivery of integrated prototype stages that could either be ground tested or flight tested as part of a post Phase II effort are highly encouraged and desired. Technical approaches that address the critical challenges associated with downward scaling of launch vehicles are also highly sought. Solutions that directly address staging sensitivities on deliverable payload mass, for instance, would be of keen interest. Design simplicity, reliability, and reduced development and recurring costs are all important factors. Proposers should explain how their technology works and provide a quantitative assessment of State-of-Art (SOA) in terms of key performance and/or cost metrics. The degree to which the proposed technology or concept is new, different, and important should also be made evident.

Affordable Guidance, Navigation, & Control

Affordable guidance, navigation & control (GN&C) is a critical enabling capability for achieving small launch vehicle performance and cost goals. Innovative GN&C technologies and concepts are therefore sought to reduce the significant costs associated with avionics hardware, software, sensors, and actuators. The scope of interest includes embedded computing systems, sensors, actuators, algorithms, as well as modeling & design tools. Low cost commercially available components and miniaturized devices that can be repurposed as a basis for low-SWaP GN&C systems are of particular interest. Special needs include sensors that can function during prolonged periods of high-g and high-angular rate (i.e., spin-stabilized) flight, while meeting the stringent launch system environment requirements pertaining to stability and noise. A low-cost GPS receiver capable of maintaining lock, precision, and accuracy during ascent would be broadly beneficial, for example. Sensors that can withstand these conditions might be sourced from industrial and tactical applications, and performance requirements may be achievable by fusing multiple measurements, e.g., inertial and optical (sun, horizon) sensors. Modular actuator systems are also needed that can support de-spin and turn-over maneuvers during ascent. These can include cold-gas or yo-yo type mechanisms. Improved designs are needed to reduce the overall power and volume requirements of these types of actuator systems, while still providing enough physical force to achieve the desired maneuver and enable orbital insertion. Programmable sequencers are required to trigger actuators for events such as stage sequencing, yo-yo and shroud deployment. In addition to hardware, software algorithms for autonomous vehicle control are needed to support in-flight guidance and steering. Robust control laws and health management software are of interest, particularly those that address performance and reliability limitations of affordable hardware. This is especially important in the typical high dynamics (acceleration and angular velocity) conditions of proposed small launch vehicles. Algorithms that are able to merge data from redundant onboard sensors could improve reliability compared to expensive single-string sensors. Similarly, advanced ground-alignment, initialization, and state estimation routines that integrate noisy data are desired to support ascent flight. These algorithms take advantage of improved onboard computational capability in order to process observations from lower accuracy sensors to provide higher fidelity information. Implementations of state-of-the-art Unscented Kalman Filters, and Square-Root-Information Filters with robust noise and sensor models are particularly applicable. Successful technologies should eventually be tested in relevant environments and at relevant flight conditions. Potential testbeds include a variety of spacecraft and aircraft at a variety of scales. Capabilities include reduced gravity, suborbital reusable launch vehicles, high altitude balloons, subscale to ultra-high-altitude aircraft, and inflight simulation.

Manufacturing Innovations for Launch Vehicle Structures & Components

The development of more efficient vehicle structures and components are sought to improve small launch vehicle affordability. This may include the adoption and utilization of modern lightweight materials, advanced manufacturing inspired design innovations, or systems for actively alleviating launch loads and environments. Approaches for achieving life-cycle cost reductions might also include reduced part count by substitution of multifunctional components; additive and/or combined additive and subtractive manufacturing; repurposing launch structure for post-launch mission needs; incorporating design features that reduce operating costs; adoption of lean best practices for production and manufacturing; and shifting towards commercial practices and/or componentry. Alternatively, approaches based on the utilization of heavier materials could lead to simpler parts, fewer components, and more robust design margins. Although this could yield a larger rocket and impose performance penalties, significantly reduced life-cycle costs could be realized due to overall lower manufacturing and integration cost. Proposers should provide a quantitative assessment of State-of-Art (SOA) in terms of key performance and/or cost metrics. The degree to which the proposed technology or concept is new, different, and important should also be made evident.

Reusability Innovations

Reusability innovations and subsystem concepts are sought that can serve as the foundational basis of a high flight rate, gas-and-go launch system architecture. Various subsystem technologies are amenable to development and testing via the SBIR program that could then be infused into commercial RLV developments. The scope of interest includes highly reusable propulsion systems that are capable of multiple flights without significant degradation and with minimal inspection/refurbishment requirements. Reusability solutions that directly address vehicle integration, mission profile/transition sensitivities and projected life cycle effects would be of keen interest. This could include quick turnaround ground servicing technologies that enable rapid inspection, maintenance/repair, reloading, and re-flight of stages. Design simplicity, reliability, and reduced development and recurring costs are all important factors. Proposers should explain how their technology works and provide a quantitative assessment of State-of-Art (SOA) in terms of key performance and/or cost metrics. The degree to which the proposed technology or concept is new, different, and important should also be made evident.

Dual Use Hypersonic Flight Testbeds

The potential repurposing and dual use applications of small launch vehicles as hypersonic flight technology testbeds is of great interest. If low cost small launch vehicle concepts can be dual purposed as affordable hypersonic flight testing platforms with a high degree of commonality, it would open up a highly lucrative sector with significant commercial and defense market potential. The scope of interest is on launch vehicle derived concepts that could boost or gravity turn into a cruise altitude in the range of 75-100 Kft and accelerate a hypersonic testbed stage to a speed of Mach 4 or higher. Because small launch vehicle boosters typically undergo stage-1 to stage-2 separation in the Mach 8-10 range, it is conceivable that these vehicles could serve as low-cost boost phase systems for hypersonic flight testbeds equal in weight to the fully loaded orbital upper stage. Testbed concepts adaptable for a wide range of hypersonic technology investigations, including air breathing propulsion systems and thermal protection systems, while also offering payload recovery and partial testbed stage reusability, are strongly encouraged.

T1.01 Affordable Nano/Micro Launch Propulsion Stages (STTR)
Lead Center: MSFC
Participating Center(s): AFRC

NASA is recognizing a growing demand for dedicated, responsive small spacecraft launch systems and seeks to facilitate the establishment of a robust launch service provider market sector. The movement toward small spacecraft missions is largely driven by rising development/launch costs associated with conventional spacecraft, which poses severe threats to future science/commercial mission cadence, and by rapidly evolving miniaturization innovations that are revolutionizing small spacecraft platform capabilities. This topic seeks innovative technologies, subsystems, and efficient streamlined processes that will support the development of affordable small spacecraft launch systems having a 5-180 kg payload delivery capacity to 350 to 700 km at inclinations between 28 to 98.2 degrees to support both CONUS and sun synchronous operations. Affordability objectives are focused on reducing launch costs below \$1.5M/launch for payloads ranging up to 50 kg or below \$30,000/kg for payloads in excess of 50 kg. It is recognized that no single enabling technology is likely to achieve this goal and that a combination of multiple technologies and production practices are likely to be needed. Therefore, it is highly desirable that disparate but complementary technologies formulate and use standardized plug-and-play interfaces to better allow for transition and integration into small spacecraft launch systems.

This subtopic seeks to mature innovative ideas providing a pipeline of components, processes, technologies, propellants, and materials that enhance propulsive performance or that enable adequate propulsive performance at a significant cost savings. Innovations submitted under this subtopic must focus on meeting the affordability objectives. Each innovation must be linked to an existing or proposed launch architecture and operational paradigm. A develop path must be outlined that defines the current development state of the innovation(s) and outlines the improvements sought that will enable a launch system to meet the affordability objectives.

Proposed ideas must lead to a proof of concept test during Phase II. The test results should provide measurements of the propulsive performance required for the proposed launch architecture. Test article costs must be disclosed and linked to the affordability objectives.

The pipeline is meant to feed SBIR topic Z9.01, Small Launch Vehicle Technologies and Demonstrations.

Technology areas of specific interest from Z9.01 are as follow:

- Innovative Propulsion Technologies & Prototype Stages.
- Affordable Guidance, Navigation & Control.
- Manufacturing Innovations for Launch Vehicle Structures & Components.
- Reusability Innovations.
- Dual Use Hypersonic Flight Testbeds.

Proof of concept testing that mature technologies for inclusion in these areas of interest are specifically sought.

Focus Area 22: International Space Station (ISS) Utilization

Lead MD: HEOMD

The Human Exploration and Operations Mission Directorate (HEOMD) provides mission critical space exploration services to both NASA customers and to other partners within the U.S. and throughout the world: operating the International Space Station (ISS); ensuring safe and reliable access to space; maintaining secure and dependable communications between platforms across the solar system; and ensuring the health and safety of astronauts. Additionally, the HEOMD is chartered with the development of the core transportation elements, key systems, and enabling technologies required for beyond-Low Earth Orbit (LEO) human exploration that will provide the foundation for the next half-century of American leadership in space exploration. In this topic area, NASA is seeking technologies that address how to improve and lower costs related to use of flight assets; maximize the utilization of the ISS for in-situ research; and utilize the ISS as a platform for in-space commercial science and technology opportunities.

NASA seeks to accomplish these objectives by achieving following goals:

- Investing in the near- and mid-term development of highly-desirable system and technologies that provide innovative ways to leverage existing ISS facilities for new scientific payloads.
- Increasing investments in Human Operations and research to prepare for long-duration missions in deep space.
- Enabling U.S. commercial spaceflight opportunities and technology development to support the commercialization of low Earth orbit.

Through the potential projects spurred by this topic, NASA hopes to incorporate SBIR-developed technologies into current and future systems to contribute to the expansion of humanity across the solar system while providing continued cost effective ISS operations and utilization for its customers, with a high standard of safety, reliability, and affordability.

H8.01 ISS Utilization and Microgravity Research (SBIR)
Lead Center: JSC
Participating Center(s): ARC, GRC, JPL, KSC, LaRC, MSFC
Related Subtopic Pointer(s): Z4.01

NASA continues to invest in the near- and mid-term development of highly-desirable systems and technologies that provide innovative ways to leverage existing ISS facilities for new scientific payloads and to provide on orbit analysis to enhance capabilities. Additionally, NASA is supporting commercial science, engineering, and technology to provide low earth orbit commercial opportunities utilizing the ISS. Utilization of the ISS is limited by available up-mass, down-mass, and crew time as well as by the capabilities of the interfaces and hardware already developed and in use. Innovative interfaces between existing hardware and systems, which are common to ground research, could facilitate both increased and faster payload development and subsequent utilization. Technologies that can be matured rapidly for flight demonstration on the International Space Station are of particular interest.

Desired capabilities that will continue to enhance improvements to existing ISS research and support hardware, with the potential of reducing crew time needs, and those that promote commercial enterprise ventures include but are not limited to, the below focus areas:

- Projects that improve, enhance and/or augment science investigations being conducted or planned to be conducted on the ISS.
- Projects leading to the development of new research facilities and the enhancement of others in focus areas involving material science for polymerization, soldering, thermal diffusivity of organic liquids, particles suspension in plasma, and safe containment of samples while undergoing microscopy imaging. Facility enhancements that are efficient and enable high experiment throughput are of major importance.
- Technologies and flight projects that can enable significant terrestrial applications from microgravity development and lead to private sector and/or government agency product development within a number of discipline areas, including biotechnology, medical applications, material sciences, electronics, and pharmaceuticals. This includes modifications to existing flight instruments as well as the development of novel flight hardware for deployment on the ISS.

For the above, research should be conducted to demonstrate technical feasibility and prototype hardware development during Phase I and show a path toward Phase II hardware and software demonstration and delivering an engineering development unit or software package for NASA testing at the completion of the Phase II contract that could be turned into a proof-of-concept system which can be demonstrated in flight.

Appendices

Appendix A: Technology Readiness Level (TRL) Descriptions

The Technology Readiness Level (TRL) describes the stage of maturity in the development process from observation of basic principles through final product operation. The exit criteria for each level documents that principles, concepts, applications or performance have been satisfactorily demonstrated in the appropriate environment required for that level. A relevant environment is a subset of the operational environment that is expected to have a dominant impact on operational performance. Thus, reduced-gravity may be only one of the operational environments in which the technology must be demonstrated or validated in order to advance to the next TRL.

TRL	Definition	Hardware Description	Software Description	Exit Criteria
1	Basic principles observed and reported.	Scientific knowledge generated underpinning hardware technology concepts/applications.	Scientific knowledge generated underpinning basic properties of software architecture and mathematical formulation.	Peer reviewed publication of research underlying the proposed concept/application.
2	Technology concept and/or application formulated.	Invention begins, practical application is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture.	Practical application is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture. Basic properties of algorithms, representations and concepts defined. Basic principles coded. Experiments performed with synthetic data.	Documented description of the application/concept that addresses feasibility and benefit.
3	Analytical and experimental critical function and/or characteristic proof of concept.	Analytical studies place the technology in an appropriate context and laboratory demonstrations, modeling and simulation validate analytical prediction.	Development of limited functionality to validate critical properties and predictions using non-integrated software components.	Documented analytical/experi-mental results validating predictions of key parameters.
4	Component and/or breadboard validation in laboratory environment.	A low fidelity system/component breadboard is built and operated to demonstrate basic functionality and critical test environments, and associated performance predictions are defined relative to the final operating environment.	Key, functionally critical, software components are integrated, and functionally validated, to establish interoperability and begin architecture development. Relevant Environments defined and performance in this environment predicted.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of relevant environment.

5	Component and/or breadboard validation in relevant environment.	A medium fidelity system/component brassboard is built and operated to demonstrate overall performance in a simulated operational environment with realistic support elements that demonstrates overall performance in critical areas. Performance predictions are made for subsequent development phases.	End-to-end software elements implemented and interfaced with existing systems/simulations conforming to target environment. End-to-end software system, tested in relevant environment, meeting predicted performance. Operational environment performance predicted. Prototype implementations developed.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of scaling requirements.
6	System/sub-system model or prototype demonstration in a relevant environment.	A high fidelity system/component prototype that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate operations under critical environmental conditions.	Prototype implementations of the software demonstrated on full-scale realistic problems. Partially integrate with existing hardware/software systems. Limited documentation available. Engineering feasibility fully demonstrated.	Documented test performance demonstrating agreement with analytical predictions.
7	System prototype demonstration in an operational environment.	A high fidelity engineering unit that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate performance in the actual operational environment and platform (ground, airborne, or space).	Prototype software exists having all key functionality available for demonstration and test. Well integrated with operational hardware/software systems demonstrating operational feasibility. Most software bugs removed. Limited documentation available.	Documented test performance demonstrating agreement with analytical predictions.
8	Actual system completed and "flight qualified" through test and demonstration.	The final product in its final configuration is successfully demonstrated through test and analysis for its intended operational environment and platform (ground, airborne, or space).	All software has been thoroughly debugged and fully integrated with all operational hardware and software systems. All user documentation, training documentation, and maintenance documentation completed. All functionality successfully demonstrated in simulated operational scenarios. Verification and Validation (V&V) completed.	Documented test performance verifying analytical predictions.

9	Actual system flight proven through successful mission operations.	The final product is successfully operated in an actual mission.	All software has been thoroughly debugged and fully integrated with all operational hardware/software systems. All documentation has been completed. Sustaining software engineering support is in place. System has been successfully operated in the operational environment.	Documented mission operational results.

Definitions

Proof of Concept: Analytical and experimental demonstration of hardware/software concepts that may or may not be incorporated into subsequent development and/or operational units.

Breadboard: A low fidelity unit that demonstrates function only, without respect to form or fit in the case of hardware, or platform in the case of software. It often uses commercial and/or ad hoc components and is not intended to provide definitive information regarding operational performance.

Brassboard: A medium fidelity functional unit that typically tries to make use of as much operational hardware/software as possible and begins to address scaling issues associated with the operational system. It does not have the engineering pedigree in all aspects, but is structured to be able to operate in simulated operational environments in order to assess performance of critical functions.

Proto-type Unit: The proto-type unit demonstrates form, fit, and function at a scale deemed to be representative of the final product operating in its operational environment. A subscale test article provides fidelity sufficient to permit validation of analytical models capable of predicting the behavior of full-scale systems in an operational environment

Engineering Unit: A high fidelity unit that demonstrates critical aspects of the engineering processes involved in the development of the operational unit. Engineering test units are intended to closely resemble the final product (hardware/software) to the maximum extent possible and are built and tested so as to establish confidence that the design will function in the expected environments. In some cases, the engineering unit will become the final product, assuming proper traceability has been exercised over the components and hardware handling.

Mission Configuration: The final architecture/system design of the product that will be used in the operational environment. If the product is a subsystem/component, then it is embedded in the actual system in the actual configuration used in operation.

Laboratory Environment: An environment that does not address in any manner the environment to be encountered by the system, subsystem, or component (hardware or software) during its intended operation. Tests in a laboratory environment are solely for the purpose of demonstrating the underlying principles of technical performance (functions), without respect to the impact of environment.

Relevant Environment: Not all systems, subsystems, and/or components need to be operated in the operational environment in order to satisfactorily address performance margin requirements. Consequently, the relevant environment is the specific subset of the operational environment that is required to demonstrate critical "at risk" aspects of the final product performance in an operational environment. It is an environment that focuses specifically on "stressing" the technology advance in question.

Operational Environment: The environment in which the final product will be operated. In the case of space flight hardware/software, it is space. In the case of ground-based or airborne systems that are not directed toward space flight, it will be the environments defined by the scope of operations. For software, the environment will be defined by the operational platform.

Appendix B: SBIR/STTR and the Space Technology Roadmaps

Research and technology topics/subtopics for the SBIR Program are identified annually by Mission Directorates and Center Programs. The Directorates identify high priority research and technology needs for respective programs and projects. Research and technology topics for the STTR Program are aligned with needs associated with the research interest and core competencies across NASA Centers. Both programs support a broad range of technologies defined by a list of topics and subtopics that vary in content within each annual solicitation.

The following table relates these SBIR/STTR topics and subtopics to the Technology Area Breakdown Structure (TABS) in the Space Technology Roadmaps (STR). The table is organized by the OCT Technology Area level one (first column) and level 2 (third column), with the related SBIR Select subtopic description (fourth column) and subtopics ID (fifth column) listed as well. The Aeronautics area is included for completeness, though this is beyond the scope of the STR.

TA	STR Technology Area (TA) Level 1 Description	STR Technology Area (TA) Level 2 Description	Subtopic Description	Subtopic
TA01	1.0.0 Launch Propulsion Systems	1.5.0 Unconventional/Other Propulsion Systems	Small Launch Vehicle Technologies and Demonstrations	Z9.01
			Affordable Nano/Micro Launch Propulsion Stages	T1.01
TA	**STR Technology Area (TA) Level 1 Description**	**STR Technology Area (TA) Level 2 Description**	**Subtopic Description**	**Subtopic**
TA02	2.0.0 In-Space Propulsion Technologies	2.1.0 Chemical Propulsion	Spacecraft Technology for Sample Return Missions	S4.03
			Cryogenic Fluid Management	Z10.01
		2.2.0 Non-Chemical Propulsion	Propulsion Systems for Robotic Science Missions	Z10.02
			Nuclear Thermal Propulsion (NTP)	Z10.03
			Cubesat Propulsion Systems	Z8.01
		2.4.0 Supporting Technologies	Terrestrial Balloons and Planetary Aerial Vehicles	S3.05
TA	**STR Technology Area (TA) Level 1 Description**	**STR Technology Area (TA) Level 2 Description**	**Subtopic Description**	**Subtopic**
TA03	3.0.0 Space Power and Energy Storage	3.1.0 Power Generation	Power Generation and Conversion	S3.01
			High Power Arrays for Solar Electric Propulsion	Z1.01
			Fission Surface Power Generation	Z1.03
		3.3.0 Power Management and Distribution	Intelligent/Autonomous Electrical Power Systems	T3.02
		3.4.0 Cross Cutting Technology	Power Electronics and Management, and Energy Storage	S3.03
			Bio-inspired Concepts for the Development of Power, Energy and Storage Technologies for Air and Space	T3.03

TA	STR Technology Area (TA) Level 1 Description	STR Technology Area (TA) Level 2 Description	Subtopic Description	Subtopic
TA04	4.0.0 Robotics, Telerobotics and Autonomous Systems	4.1.0 Sensing & Perception	Extreme Environments Technology	S4.04
			Contamination Control and Planetary Protection	S4.05
		4.3.0 Manipulation	Robotic Mobility, Manipulation and Sampling	S4.02
			Sample Collection for Life Detection in Outer Solar System Ocean World Plumes	S4.06
			Robotic Systems - Mobile Manipulation	Z5.02
		4.4.0 Human-Systems Integration	Augmented Hybrid and Virtual Reality (XR) Technology for Human & Robotics Exploration	Z5.01
		4.5.0 Autonomy	Autonomous Control Technologies (ACT) for Ground Operations	H10.02
			Resilient Autonomous Systems	H6.02
			Guidance, Navigation and Control	S3.04
			Command, Data Handling, and Electronics	S3.08
			Payload Technologies for Free-Flying Robots	Z5.03
			Information Technologies for Intelligent and Adaptive Space Robotics	T4.01
			Coordination and Control of Swarms of Space Vehicles	T4.03
		Not Mapped	Unmanned Aircraft Systems (UAS) Technologies	A2.02
TA	**STR Technology Area (TA) Level 1 Description**	**STR Technology Area (TA) Level 2 Description**	**Subtopic Description**	**Subtopic**
TA05	5.0.0 Communication and Navigation	5.1.0 Optical Comm. And Navigation	Long Range Optical Telecommunications	H9.01
		5.4.0 Position, Navigation, and Timing	Flight Dynamics and Navigation Technology	H9.03
		5.5.0 Integrated Technologies	Communications for Distributed Small Spacecraft Beyond LEO	Z8.02
		5.6.0 Revolutionary Concepts	Transformational/Over-the-Horizon Communications Technology	H9.05
TA	**STR Technology Area (TA) Level 1 Description**	**STR Technology Area (TA) Level 2 Description**	**Subtopic Description**	**Subtopic**
TA06	6.0.0 Human Health, Life Support and Habitation Systems	6.1.0 Environmental Control Life Support & Habitation Systems	Wash System to Disinfect Fresh Fruit & Vegetables Grown in Spaceflight	H12.04
			Process Technologies for Water Recycling in Space	H3.01
			Waste Management and Resource Recovery	H3.02

			Integrated System Health Management for Sustainable Habitats	H6.01
			ISS Utilization and Microgravity Research	H8.01
			Innovative Solutions to Carbon Dioxide Removal for Spacecraft, Surface Systems, and EVA Systems	T6.01
		6.2.0 Extravehicular Activity Systems	Advanced Space Suit Portable Life Support System (PLSS)	H4.01
			Controllable, Tinting, Polycarbonate Compatible Coatings for Advanced EVA Spacesuit Visor	H4.02
			Mass Produced, Minimal Capability, Disposable EVA Life Support System	H4.03
		6.3.0 Human Health and Performance	Crew Worn Accelerometers in spaceflight environment	H12.03
		6.5.0 Radiation	Radioprotectors and Mitigators of Space Radiation-induced Health Risks	H12.01
TA	**STR Technology Area (TA) Level 1 Description**	**STR Technology Area (TA) Level 2 Description**	**Subtopic Description**	**Subtopic**
TA07	7.0.0 Human Exploration Destination Systems	7.1.0 In-Situ Resource Utilization	Mars Atmosphere ISRU for Mission Consumables	H1.01
			Lunar Resources	H2.01
			Advanced Bioreactor Development for In Situ Microbial Manufacturing	T7.01
		7.2.0 Sustainability & Supportability	Space Exploration Plant Growth	T7.02
TA	**STR Technology Area (TA) Level 1 Description**	**STR Technology Area (TA) Level 2 Description**	**Subtopic Description**	**Subtopic**
TA08	8.0.0 Science Instruments, Observatories & Sensor Systems	8.1.0 Science Instruments	Lidar Remote Sensing Technologies	S1.01
			Technologies for Active Microwave Remote Sensing	S1.02
			Technologies for Passive Microwave Remote Sensing	S1.03
			Particles and Field Sensors and Instrument Enabling Technologies	S1.06
			In Situ Instruments/Technologies for Planetary Science	S1.07
			Atomic Interferometry	S1.10
			In Situ Instruments/Technologies and Sample Processing for Ocean Worlds Life Detection	S1.11
			NDE Sensors	Z11.01
		8.2.0 Observations	Proximity Glare Suppression for Astronomical Direct Detection	S2.01
			Advanced Optical Systems and Fabrication/Testing/Control Technologies for EUV/Optical and IR Telescope	S2.03

			X-Ray Mirror Systems Technology, Coating Technology for X-Ray-UV-OIR, and Free-Form Optics	S2.04
		8.3.0 Sensor Systems	Sensor and Detector Technology for Visible, IR, Far IR and Submillimeter	S1.04
			Detector Technologies for UV, X-Ray, Gamma-Ray and Cosmic-Ray Instruments	S1.05
			In-situ Sensors and Sensor Systems for Earth Science	S1.08
			Cryogenic Systems for Sensors and Detectors	S1.09
			Photonic Integrated Circuits	T8.02
TA	**STR Technology Area (TA) Level 1 Description**	**STR Technology Area (TA) Level 2 Description**	**Subtopic Description**	**Subtopic**
TA09	9.0.0 Entry, Descent and Landing Systems	9.1.0 Aeroassist & Entry	Entry Descent & Landing Sensors for Environment Characterization, Vehicle Performance, and Guidance, Navigation and Control	Z7.01
			Deployable Aerodynamic Decelerator Technology	Z7.03
		9.3.0 Landing	Lander Systems Technology	T9.01
TA	**STR Technology Area (TA) Level 1 Description**	**STR Technology Area (TA) Level 2 Description**	**Subtopic Description**	**Subtopic**
TA11	11.0.0 Modeling, Simulation, Information Technology and Processing	11.1.0 Computing	Spacecraft Autonomous Agent Cognitive Architectures for Human Exploration	H6.03
			Low Cost Radiation Hardened Integrated Circuit Technology	Z8.03
		11.2.0 Modeling	Integrated Science Mission Modeling	S5.04
			Fault Management Technologies	S5.05
			Space Weather R2O/O2R Technology Development	S5.06
		11.3.0 Simulation	Technologies for Large-Scale Numerical Simulation	S5.01
		11.4.0 Information Processing	Earth Science Applied Research and Decision Support	S5.02
			Machine Learning and Deep Learning for Science and Engineering	S5.03

TA	STR Technology Area (TA) Level 1 Description	STR Technology Area (TA) Level 2 Description	Subtopic Description	Subtopic
TA12	12.0.0 Materials, Structures, Mechanical Systems and Manufacturing	12.1.0 Materials	Development of Higher Strength Feedstocks for In-Space Manufacturing	H7.01
			Thin-Ply Composite Technology and Applications	T12.01
		12.2.0 Structures	Mars Surface Solar Array Structures	H5.01
			Hot Structure Technology for Atmospheric Entry Vehicles	H5.02
			Precision Deployable Optical Structures and Metrology	S2.02
			In-Space Sub-Modular Assembly	Z4.02
		12.4.0 Manufacturing	In-situ monitoring and development of in-process quality control for in-space manufacturing (ISM) applications	H7.02
			Plasma Jet Printing Technology for Printable Electronics in Space	H7.03
		12.5.0 Cross-Cutting	Advanced Metallic Materials and Processes Innovation	Z3.01
			MISSE Experiments	Z4.01
			Extensible Modeling of Metallurgical Additive Manufacturing Processes	T12.02
TA	**STR Technology Area (TA) Level 1 Description**	**STR Technology Area (TA) Level 2 Description**	**Subtopic Description**	**Subtopic**
TA13	13.0.0 Ground and Launch Systems Processing	13.1.0 Technologies to Optimize the Operational Life-Cycle	Advanced Propulsion Systems Ground Test Technology	H10.01
			Intelligent Sensor Systems	T13.01
TA	**STR Technology Area (TA) Level 1 Description**	**STR Technology Area (TA) Level 2 Description**	**Subtopic Description**	**Subtopic**
TA14	14.0.0 Thermal Management Systems	14.2.0 Thermal Control Systems	Thermal Management	Z2.01
		Not Mapped	Hypersonic Seal Technology Development	A1.10
TA	**STR Technology Area (TA) Level 1 Description**	**STR Technology Area (TA) Level 2 Description**	**Subtopic Description**	**Subtopic**
TA15	15.0.0 Aeronautics	15.1.0 Safe, Efficient Growth in Global Aviation	Vehicle Safety - Inflight Icing Hazard Mitigation Technology	A1.09
			Advanced Air Traffic Management Systems Concepts	A3.01
			Aircraft Design, Optimization, and Scaled Model Test	T15.01
		15.3.0 Ultra-Efficient Commercial Vehicles	Quiet Performance - Propulsion Noise Reduction Technology	A1.02
			Computational Tools and Methods	A1.05

			Vertical Lift Technology and Urban Air Mobility	A1.06
		15.4.0 Transition to Low-Carbon Propulsion	Low Emissions/Clean Power - Combustion Technology/Emissions Measurement Techniques	A1.03
			Electrified Aircraft Propulsion & Concepts	A1.07
		15.5.0 Real-Time System-Wide Safety Assurance	Future Aviation Systems Safety	A3.03
		15.6.0 Enable Assured Machine Autonomy for Aviation	Increasing Autonomy in the National Airspace Systems (NAS) (not vehicles)	A3.02
		Not Mapped	Structural Efficiency - Aeroelasticity and Aeroservoelastic Control	A1.01
			Supersonic Technology - Reduce Take-off and Landing Noise	A1.04
			Aeronautics Ground Test and Measurement Technologies	A1.08
			Flight Test and Measurement Technologies	A2.01