National Aeronautics and Space Administration

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

Fiscal Year 2017 General Solicitation

Opening Date: November 17, 2016
Closing Date: January 20, 2017

Fiscal Year 2017 SBIR/STTR Solicitation Noteworthy Changes

NASA SBIR/STTR Subtopic Workshop

From September 12th to 13th of 2016, NASA held a Subtopic Workshop. This event was held to build NASA's relationship with the small business community and increase communication between NASA and potential proposers, and provide an opportunity for the small business community to explore and share ideas related to the general technical topic areas. Workshop content can be found at the following address: http://sbir.nasa.gov/events/2016-subtopic-workshop.

1.3 Three-Phase Program

NASA is offering a separate opportunity for SBIR/STTR Phase II awardees (from any Agency) to submit applications to NASA's FY17 Civilian Commercialization Readiness Pilot Program (CCRPP) related to NASA interests. Preliminary information about the CCRPP will be released in late 2016. The official release, including information related to the proposal requirements and evaluation criteria, will be posted in early 2017.

1.8 I-Corps

The NASA SBIR/STTR Program is partnering with the National Science Foundation (NSF) to offer selected teams the opportunity for Phase I contractors to participate in the NSF Innovation Corps program (I-Corps TM) (hereinafter I-Corps). I-Corps educates teams on how to translate technologies from the lab into the marketplace.

4.3.2 Phase II Evaluation Criteria

For Phase II proposals, commercial merit is a critical factor. As such, for Phase II proposals the scoring breakdown and weights have slightly changed. Commercialization had previously been rated as adjectival but will now contribute into proposals overall score at a weight of 5%.

9. Research Topics for SBIR and STTR

The subtopics are being organized in a different way within Chapter 9 of the solicitation this year. Instead of being grouped by NASA Mission Directorate as in previous solicitations, subtopics are now being organized into groupings called "Focus Areas". Focus areas are a way of grouping NASA interests and related technologies. This change is intended to make 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. If any proposer wishes to view subtopics as sorted by Mission Directorate, this listing will still be accessible on the website, but will not appear organized this way in Chapter 9 of the solicitation.

1. Program Description

1.1 Introduction

This document includes two NASA program solicitations with separate research areas 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. 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 2017 Solicitation period for Phase I proposals begins November 17, 2016 and ends January 20, 2017.

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 April 2017. Historically, the percentage of Phase I proposals to awards is approximately 13-15% for SBIR and STTR, 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 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.

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

A contractor must have a registration in the System for Award Management (SAM) website at SAM.gov before receiving an SBIR/STTR award from NASA. Registration in SAM is free but does require a Dun and Bradstreet (DUNS) Number. More information on all required contractor registrations, including SAM registration, can be found in section 5.14.

1.2 Program Management and Alignment

The Space Technology Mission Directorate 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 the current needs. See section 9.1 for details on the Mission Directorate research topic descriptions in the SBIR Program.

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 needs. See section 9.2 for details on the research topic descriptions in the STTR Program.

For more information on the NASA SBIR/STTR Programs, please visit the NASA SBIR/STTR Website: http://sbir.nasa.gov.

Information regarding the Mission Directorates and the NASA Centers can be obtained in section 7.1.

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.

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	12 months
Phase II Contracts	**SBIR**	**STTR**
Maximum Contract Value	$750,000	$750,000
Maximum Period of Performance	24 months	24 months

Opportunities for Continued Technology Development Post-Phase II

The NASA SBIR/STTR program has two initiatives for supporting its small business partners beyond the basic Phase II award. The NASA SBIR/STTR program has the Phase II Extended (Phase II-E) contract option, and the Civilian Commercialization Readiness Pilot Program (CCRPP). Preliminary information about the CCRPP will be released in late 2016. The official release, including information related to the proposal requirements and evaluation criteria, will be posted in early 2017.

Please refer to http://sbir.nasa.gov/content/post-phase-ii-initiatives for matching levels and other related information.

1.4 Eligibility Requirements

1.4.1 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.

1.4.2 Place of Performance

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.

1.4.3 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 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 fulltime workweek to be nominally 40 hours and we consider 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 an prior approval from NASA	Requires an prior approval from NASA

1.4.4 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 of 13 CFR part 121 sets 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. Please note that 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. **At the current time, such firms are not eligible to submit proposals to the NASA SBIR / STTR Solicitation.**

1.4.5 Required Benchmark Transition Rate

The Phase I to Phase II Transition benchmark requirement applies to SBIR and STTR Phase I applicants that have received more than 20 Phase I awards over the past 5 fiscal years, excluding the most recently-completed fiscal year. The required benchmark Transition Rate is 0.25. For these companies, this benchmark rate establishes a minimum number of Phase II awards the SBC must have received for a given number of Phase I awards received during the 5-year time period. Additional information can be found at: https://www.sbir.gov/faqs/performance-benchmarks.

Companies with more than 20 Phase I awards during the past 5 years can view their Transition Rate if they log onto their Company Registry account at: www.SBIR.gov.

1.5 NASA SBIR/STTR Technology Available (TAV)

Proposers have the option of using technology developed by NASA (Technology Available (TAV)) with the applicable subtopic being proposed. 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 TAVs are identified in a subtopic or 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 a proposer 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. 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.

1.6 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 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 on-line data bases, 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 Budget Summary (Form C). 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. Please note that this commercialization assistance does not count toward the maximum award size of your Phase II.

1.7 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.

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.

1.8 I-Corps

The NASA SBIR/STTR Program is partnering with the National Science Foundation (NSF) to offer the NSF Innovation Corps program (I-Corps TM) (hereinafter 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 20 grants to SBIR and

STTR Phase I contractors. The amount of funding is $50,000 for the full I-Corps program for STTR firms, and up to $35,000 for the shortened version for SBIR firms.

1.9 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:

William Roets
Director, Contracts and Grants Policy Division
Office of Procurement
NASA Headquarters
Washington, DC 20546
Telephone: 202-358-4483
Fax: 202-358-3083
Email: william.roets-1@nasa.gov

1.10 General Information

1.10.1 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:

E-mail: sbir@reisystems.com
Telephone: 301-937-0888 between 9:00 a.m.-5:00 p.m. (Mon.-Fri., Eastern Time)

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 mailed or e-mailed to:

ARC-SBIR-PMO@mail.nasa.gov

1.10.2 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 Phase I solicitation period. Only questions requesting clarification of proposal instructions and administrative matters will be addressed.

The cut-off date and time for receipt of solicitation contract questions and answers is 5:00 p.m. Eastern, January 16, 2017.

2. 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.

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. 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.

STTR: All 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 Research Institution (RI) into a product or service that meets a need described in a Solicitation research topic. SBCs shall submit a research agreement with a Research Institution. This agreement must be completed online through the form provided in the submissions handbook.

3.2 Phase I Proposal Requirements

3.2.1 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: 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.

False Statements:

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 fines and imprisonment of up to five years in prison. The Office of the Inspector General has full access to all proposals submitted to NASA.

3.2.2 Format Requirements

<u>The Government administratively screens all proposals and reserves the right to reject any proposal that does not conform to following formatting requirements.</u>

Page Limitations and Margins

Any page(s) going over the required page limit will be deleted and omitted from the proposal review. A Phase I proposal shall not exceed a total of 23 standard 8 1/2 x 11 inch (21.6 x 27.9 cm) pages, inclusive of the technical content and the required forms. Forms A, B, and C count as one page each, regardless of whether the completed forms print as more than one page. Each page shall be numbered consecutively at the bottom. Margins shall be 1.0 inch (2.5 cm). All required items of information must be covered in the proposal and will count towards the total page count. The space allocated to each part of the technical content will depend on the project chosen and the offeror's approach.

Each proposal submitted shall contain the following items in the order presented:

(1) Cover Sheet (Form A), electronically endorsed, counts as 1 page towards the 23-page limit.
(2) Proposal Summary (Form B), counts as 1 page towards the 23-page limit (and must not contain proprietary data).
(3) Budget Summary (Form C), counts as 1 page towards the 23-page limit.
(4) Technical Content (11 parts in order as specified in section 3.2.4, not to exceed 20 pages for SBIR and 19 pages for STTR), including all graphics, with a table of contents.
(5) R/R&D Agreement between the SBC and RI (STTR only), counts as 1 page towards the 23-page limit.
(6) Briefing Chart, is not included in the 23-page limit (and must not contain proprietary data).
(7) NASA Research License Application, is not included in the 23-page limit (only if TAV is being proposed).
(8) I-Corps Opt-In Form, is not included in the 23-page limit.

Note: Letters of general endorsement 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:

(9) Firm Level Certifications, are not included in the 23-page limit.
(10) Audit Information, is not included in the 23-page limit.
(11) Prior Awards Addendum, is not included in the 23-page limit.
(12) Commercial Metrics Survey, is not included in the 23-page limit.

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.

Please 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.

3.2.3 Forms

All form submissions shall be done electronically, with each form counting as 1 page towards the 23-page limit and accounting for pages 1-3 of the proposal regardless of the length.

3.2.3.1 Cover Sheet (Form A)

A sample Cover Sheet (Form A) 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. 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. Form A counts as one page towards the 23-page limit.

3.2.3.2 Proposal Summary (Form B)

A sample Proposal Summary (Form B) 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 Form B as required in section 6. Form B counts as one page towards the 23-page limit.

Note: Proposal Summary (Form B), including the Technical Abstract, is public information and may be disclosed. Do not include proprietary information on Form B.

3.2.3.3 Budget Summary (Form C)

A sample of the Budget Summary (Form C) 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 I effort shall not exceed $125,000. A text box 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. Form C counts as one page towards the 23-page limit.

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

3.2.4 Technical Proposal

This part of the submission should not contain any budget data and must consist of all eleven (11) parts listed below in the given order. All eleven 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 8: Facilities/Equipment
Part 9: Subcontracts and Consultants
Part 10: Potential Post Applications
Part 11: 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 and should start on page 4 because Forms A, B, and C account for pages 1-3.

Part 2: Identification and Significance of the Proposed Innovation
Succinctly describe:

(1) The proposed innovation.
(2) The relevance and significance of the proposed innovation to an interest, need, or needs, within a subtopic described in section 9.
(3) 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.

TAV 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 at the end of the proposal and will not count towards the 23-page limit (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 Form C.

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. As an option, the offeror may use this section to include bibliographic references.

Please note: On February 26, 2004, the President issued Executive Order 13329 (69 FR 9181) entitled “Encouraging Innovation in Manufacturing.” In response to this Executive Order, NASA encourages the submission of proposals that deal with some aspect of innovative manufacturing technology. **If a proposal has a connection to manufacturing this should be indicated in the Part 5 (Related R/R&D) of the proposal and a brief explanation of how it is related to manufacturing should be provided.**

Energy Independence and Security Act of 2007, section 1203, stated that federal agencies shall give high priority to small business concerns that participate in or conduct energy efficiency or renewable energy system research and development projects. **If a proposal has a connection to energy efficiency or alternative and renewable energy this should be indicated in Part 5 (Related R/R&D) of the proposal. Provide a brief explanation of how it is related to energy efficiency and alternative and renewable energy.**

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 2016 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 1.4.3 for further explanation.

Part 7: Relationship with Future R/R&D
State the anticipated results of the proposed R/R&D effort if the project is successful (through Phase I and Phase II). Discuss the significance of the Phase I effort in providing a foundation for the Phase II R/R&D effort and for follow-on development, application and commercialization efforts (Phase III).

Part 8: Facilities/Equipment

General
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 a NASA or another Federal Department or Agency, and such costs shall result in no increase in the price of this contract.

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 3.2 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, (http://sbir.gsfc.nasa.gov/sbir/firm_library/phase1_proposal.htm), 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, described below, should facilitate executing the SBIR/STTR Use Agreement.

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:

a) 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 Form C of their proposal.
b) 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 Form C of their proposal.

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

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. 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 subcontractor/consultant budget section in Form C and supporting documentation should be uploaded for each (appropriate documentation is specified in Form C). **Note that following:**

a) Proposers should list consultants by name and specify, for each, the number of hours and hourly costs.
b) Breakdown of subcontractor budget should mirror the SBC's own breakdown in Form C and include breakdowns of direct labor, other direct costs, profit, as well as indirect rate agreements.
c) A signed letter of commitment is required for each subcontractor and/or consultant.

Subcontractors' and consultants' work has the same place of performance restrictions as stated in section 1.4.2.

The following restrictions apply to the use of subcontracts/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 30% limitation.

Part 10: Potential Post Applications (Commercialization)
The Phase I proposal shall (1) forecast the potential and targeted application(s) of the proposed innovation and associated products and services relative to NASA needs (infusion into NASA mission needs and projects) (section 9), other Government agencies and commercial markets, (2) identify potential customers, and (3) provide an initial commercialization strategy that addresses key technical, market and business factors for the successful development, demonstration and utilization of the innovation and associated products and services. Commercialization encompasses the transition of technology into products and services for NASA mission programs, other Government agencies, and non-Government markets.

Part 11a: 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. 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. See Part 11b.

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.

A summary of essentially equivalent work information is also required on Form A.

Part 11b: Related Research and Development Proposals and Awards
All federal agencies have a mandate to reduce waste, fraud, and abuse in federally funded programs. The submission of essentially equivalent work and the acceptance of multiple awards for essentially equivalent work in the SBIR/STTR Program have been identified as an area of abuse and possibly fraud. SBIR/STTR funding agencies and the Office of the Inspector General are actively evaluating proposals and awards to eliminate this problem. Related research and development includes proposals and awards that do not meet the definition of "Essentially Equivalent Work" (see: http://sbir.nasa.gov/content/nasa-sbirsttr-program-definitions), but are related to the technology innovation in the proposal being submitted. Related research and development could be interpreted as essentially equivalent work by outside reviewers without additional information. Therefore, if you are submitting closely related proposals or your firm has closely related research and development that is currently or previously funded by NASA or other federal agencies, it is to your advantage to describe the relationships between this proposal and related efforts clearly delineating why this should not be considered an essentially equivalent work effort. These explanations should not be longer than one page, will not be included in the page count, and will not be part of the technical evaluation of the proposal.

3.2.5 Research Agreement (Applicable for STTR proposals only)

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 Research Institution (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. This agreement counts as one page toward the 23-page limit.

3.2.6 Applications to I-Corps

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

3.2.6.1 Step 1: Opt-In Form

Phase I SBIR/STTR offerors interested in participating in I-Corps must complete a short I-Corps Opt-In form as part of their Phase I proposal submission. The form does not count towards the page count of Phase I proposals. Representations in the form will determine an offeror's eligibility to participate in I-Corp. The form also asks 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.

3.2.6.2 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, 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 $35,000 for each SBIR team, and $50,000 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 $15,000 for Entrepreneurial Lead stipend (no stipend for the Principal Investigator or I-Corps Mentor)
        - For STTR teams, maximum of $5,000 for prototyping, only after cohort has finished. SBIR teams are not eligible for prototyping funds.
        - 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 $10,000 for SBIR teams and $20,000 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 Submission 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 Phase I.

3.2.7 Briefing Chart

An electronic form will be provided during the submissions process. The one-page briefing chart is required to assist in the ranking and advocacy of proposals prior to selection. It is not counted against the 23-page limit, and shall not contain any proprietary data or ITAR restricted data.

3.2.8 Firm Level Certifications

Firm level certifications that are applicable across all proposal submissions submitted to this solicitation must be completed via the "Certifications" section of the Proposal Submission 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.

3.2.9 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 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 Forms C 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.

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.

The audit information is not included in the 23-page limit. 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 audit information.

3.2.10 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, date of award, funding agreement number, amount, topic or subtopic title, follow-on agreement amount, source, and date of commitment and current commercialization status 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). The addendum is not included in the 23-page-limit. 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.

3.2.11 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 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 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 is not included in the 23-page limit and content 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 Submission Electronic Handbook

3.2.12 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 Form C, which will help to expedite contract negotiations.

3.3 Phase II Proposal Requirements

3.3.1 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, the commercial aerospace industry, and other potential markets and customers.

False Statements:

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 fines and/or imprisonment of up to five years in prison. The Office of the Inspector General has full access to all proposals submitted to NASA.

3.3.2 Format Requirements

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

Page Limitations and Margins
Any page(s) going over the required page limit will be deleted and omitted from the proposal review. A Phase II proposal shall not exceed a total of 50 standard 8 1/2 x 11 inch (21.6 x 27.9 cm) pages. Forms A, B, and C count as one page each regardless of whether the completed forms print as more than one page. Each page shall be numbered consecutively at the bottom. Margins shall be 1.0 inch (2.5 cm). All required items of information must be covered in the proposal and will be included in the page total. The space allocated to each part of the technical content will depend on the project and the offeror's approach.

Each proposal submitted shall contain the following items in the order presented:

(1) Cover Sheet (Form A), electronically endorsed, counts as 1 page towards the 50-page limit.
(2) Proposal Summary (Form B), counts as 1 page towards the 50-page limit (and must not contain proprietary data).
(3) Budget Summary (Form C), counts as 1 page towards the 50-page limit.
(4) Technical Content (11 Parts in order as specified in section 3.3.4, **not to exceed 47 pages for SBIR and 46 pages for STTR)**, including all graphics, and starting with a table of contents.
(5) R/R&D Agreement between the SBC and RI **(STTR only)**, counts as 1 page towards the 50-page limit.
(6) Briefing Chart (Not included in the 50-page limit and must not contain proprietary data).
(7) NASA Research License Application is not included in the 50-page limit (only if TAV is being proposed).
(8) Capital Commitments Addendum Supporting Phase II and Phase III (optional).
Note: Letters of general endorsement 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:

(9) Firm Level Certifications, are not included in the 50-page limit.
(10) Audit Information, is not included in the 50-page limit.
(11) Prior Awards Addendum, is not included in the 50-page limit.
(12) Commercial Metrics Survey, is not included in the 50-page limit.

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.

Please 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.

3.3.3 Forms

All form submissions shall be done electronically, with each form counting as 1 page towards the 50-page limit and accounting for pages 1-3 of the proposal regardless of the length.

3.3.3.1 Cover Sheet (Form A)

A sample Cover Sheet (Form A) 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. 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. Form A counts as one page towards the 50-page limit.

3.3.3.2 Proposal Summary (Form B)

A sample Proposal Summary (Form B) 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 Form B as required in section 6. Form B counts as one page towards the 50-page limit.

Note: Proposal Summary (Form B), including the Technical Abstract, is public information and may be disclosed. Do not include proprietary information on Form B.

3.3.3.3 Budget Summary (Form C)

A sample of the Budget Summary (Form C) 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. A text box 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. Form C counts as one page towards the 50-page limit.

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

3.3.3.4 Milestone Plan

NASA mandates that SBIR/STIR contracts will be written for a single final deliverable to include a prototype (if applicable), a final report, final summary/briefing chart, and invoice certification. The IT Security Management Plan and the New Technology Reporting (New Technology Summary Report and New Technology Report) requirements remain unchanged. Your firm shall submit a proposed quarterly milestone plan with FORM C. The milestone plan shall be in accordance with your 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 FORM C for each of the proposed quarterly milestones (i.e. each milestone should include the labor, supplies, travel, 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.

3.3.4 Technical Proposal

This part of the submission shall not contain any budget data and must consist of all eleven (11) parts listed below in the given order. All eleven 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 shall 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 and should start on page 4 because Forms A, B, and C account for pages 1-3.

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

Drawing upon Phase I results, succinctly describe:

(1) The proposed innovation.
(2) The relevance and significance of the proposed innovation to an interest, need, or needs, within the subtopic.
(3) The proposed innovation relative to the state of the market, the state of the art, and its feasibility.
(4) The capability of the offeror to conduct the proposed R/R&D and to fulfill the commercialization of the proposed innovation.

Part 3: Technical Objectives

Define the specific objectives of the Phase II research and technical approach.

TAV 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 at the end of the proposal and will not count towards the 50-page limit (See section 1.5).

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 Form C.

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. As an option, the offer may use this section to include bibliographic references.

Please note:

On February 26, 2004, the President issued Executive Order 13329 (69 FR 9181) entitled “Encouraging Innovation in Manufacturing.” In response to this Executive Order, NASA encourages the submission of proposals that deal with some aspect of innovative manufacturing technology. **If a proposal has a connection to manufacturing this should be indicated in the Part 5 (Related R/R&D) of the proposal and a brief explanation of how it is related to manufacturing should be provided.**

Energy Independence and Security Act of 2007, section 1203, stated that federal agencies shall give high priority to small business concerns that participate in or conduct energy efficiency or renewable energy system research and development projects. **If a proposal has a connection to energy efficiency or alternative and renewable energy this should be indicated in Part 5 (Related R/R&D) of the proposal. Provide a brief explanation of how it is related to energy efficiency and alternative and renewable energy.**

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 1.4.3 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 (Phase III) 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. The commercialization plan, at a minimum, shall address the following areas:

(1) **Market Feasibility and Competition:** Describe (a) the target market(s) of the innovation and the associated product or service; (b) the competitive advantage(s) of the product or service; (c) key potential customers, including NASA mission programs and prime contractors; (d) projected market size (NASA, other Government and/or non-Government); (e) the projected time to market and estimated market share within five years from market-entry; and (f) anticipated competition from alternative technologies, products and services and/or competing domestic or foreign entities.

(2) **Commercialization Strategy and Relevance to the Offeror:** Present the commercialization strategy for the innovation and associated product or service and its relationship to the SBC's business plans for the next five years. Infusion into NASA missions and projects is an option for commercialization strategy.

(3) **Key Management, Technical Personnel and Organizational Structure:** Describe: (a) the skills and experiences of key management and technical personnel in technology commercialization; (b) current organizational structure; and (c) plans and timelines for obtaining expertise and personnel necessary for commercialization.

(4) **Production and Operations:** Describe product development to date as well as milestones and plans for reaching production level, including plans for obtaining necessary physical resources.

(5) **Financial Planning:** Delineate private financial resources committed to the development and transition of the innovation into market-ready product or service. Describe the projected financial requirements and the expected or committed capital and funding sources necessary to support the planned commercialization of the innovation. Provide evidence of current financial condition (e.g., standard financial statements including a current cash flow statement).

(6) **Intellectual Property:** Describe plans and current status of efforts to secure intellectual property rights (e.g., patents, copyrights, trade secrets) necessary to obtain investment, attain at least a temporally competitive advantage, and achieve planned commercialization.

Part 8: Facilities/Equipment

General

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 a NASA or another Federal Department or Agency, and such costs shall result in no increase in the price of this contract.

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.

The offeror must execute an SBIR Use Agreement (http://sbir.gsfc.nasa.gov/sbir/firm_library/phase2_proposal.htm) before using any NASA Services, Facilities, or Equipment. The content of the SBIR Use Agreement is limited to the information necessary to ensure efficient administration of the reimbursable work because the terms and conditions for the relationship between the Government and the contractor are contained in any contract awarded pursuant to this solicitation.

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:

a) 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 Form C of their proposal.
b) 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 Form C of their proposal.

Part 9: Subcontracts 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. 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 subcontractor/consultant budget section in Form C and supporting documentation should be uploaded for each (appropriate documentation is specified in Form C). Subcontractors' and consultants' work has the same place of performance restrictions as stated in section 1.4.2.

The following restrictions apply to the use of subcontracts/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.

Part 10: Potential Post Applications (Commercialization)
Building upon section3.3.4, part 7; further specify the potential NASA and commercial applications of the innovation and the associated potential customers; such as NASA mission programs and projects, within target markets. Potential NASA applications include the projected utilization of proposed contract deliverables (e.g., prototypes, test units, software) and resulting products and services by NASA organizations and contractors.

Part 11a: 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. 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. See Part 11b.

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.

A summary of essentially equivalent work information is also required on Form A.

Part 11b: Related Research and Development Proposals and Awards

All federal agencies have a mandate to reduce waste, fraud, and abuse in federally funded programs. The submission of essentially equivalent work and the acceptance of multiple awards for essentially equivalent work in the SBIR/STTR Program have been identified as an area of abuse and possibly fraud. SBIR/STTR funding agencies and the Office of the Inspector General are actively evaluating proposals and awards to eliminate this problem. Related research and development includes proposals and awards that do not meet the definition of "Essentially Equivalent Work", but are related to the technology innovation in the proposal being submitted. Related research and development could be interpreted as essentially equivalent work by outside reviewers without additional information. Therefore, if you are submitting closely related proposals or your firm has closely related research and development that is currently or previously funded by NASA or other Federal agencies, it is to your advantage to describe the relationships between this proposal and related efforts clearly delineating why this should not be considered an essentially equivalent work effort. These explanations should not be longer than one page, will not be included in the page count, and will not be part of the technical evaluation of the proposal.

3.3.5 Research Agreement (Applicable for STTR proposals only)

The Research Agreement (different from the Allocation of Rights Agreement) is a single-page document electronically submitted and endorsed by the SBC and Research Institution (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. This agreement counts as one page toward the 50-page limit.

3.3.6 Capital Commitments Addendum Supporting Phase II and Phase III

Describe and document capital commitments from non-SBIR/STTR sources or from internal SBC funds for pursuit of Phase II and Phase III efforts. Offerors for Phase II contracts are strongly urged to obtain non-SBIR/STTR funding support commitments for follow-on Phase III activities and additional support of the Phase II from parties other than the proposing firm. Funding support commitments must show that a specific and substantial amount will be made available to the firm to pursue the stated Phase II and/or Phase III objectives. They must indicate the source, date, and conditions or contingencies under which the funds will be made available. Alternatively, self-commitments of the same type and magnitude that are required from outside sources can be considered. If a Phase III will be funded internally, offerors should describe their financial position.

Evidence of funding support commitments from outside parties must be provided in writing and should accompany the Phase II proposal. Letters of commitment should specify available funding commitments, other resources to be provided, and any contingent conditions. Expressions of technical interest by such parties in the Phase II research or of potential future financial support are insufficient and will not be accepted as support commitments by NASA. Letters of commitment should be added as an addendum to the Phase II proposal. This addendum will not be counted against the 50-page limitation.

3.3.7 Briefing Chart

A one-page briefing chart is required to assist in the ranking and advocacy of proposals prior to selection. Submission of the briefing chart is not counted against the 50-page limit, and shall not contain any proprietary data or ITAR restricted data. An electronic form will be provided during the submissions process.

3.3.8 Firm Level Certifications

Firm level certifications that are applicable across all proposal submissions submitted to this solicitation must be completed via the "Certifications" section of the Proposal Submission 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.

3.3.9 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 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 Forms C 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.

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.

The audit information is not included in the 50-page limit. 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 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, date of award, funding agreement number, amount, topic or subtopic title, follow-on agreement amount, source, and date of commitment and current commercialization status 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). The addendum is not included in the 50-page limit. 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 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 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 is not included in the 50-page limit and content 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 Submission Electronic Handbook

3.3.12 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.

3.3.13 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 Form C, which will help to expedite contract negotiations.

4. Method of Selection and Evaluation Criteria

4.1 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 B), 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.

4.1.1 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.

4.1.2 Phase I Evaluation Criteria

NASA intends to select for award those proposals that offer the most advantageous research and development to stimulate technical innovation to the Government and the SBIR/STTR Program. 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 3.2.4, 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. The proposed path beyond Phase I 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 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, 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 Form C. NASA will comply with the FAR and NASA FAR Supplement (NFS) to evaluate the proposed price/cost to be fair and reasonable.

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

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 selection for award.

4.1.3 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. The selection decisions will consider the recommendations as well as overall NASA priorities, program balance and available funding. 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 Source Selection Official has the final authority for selecting the specific proposals for award.

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.

4.2 I-Corps

For awardees invited to submit an I-Corps proposal pursuant to section 3.2.6.2, NASA will provide a programmatic assessment of firms and their technologies, assessing:

- 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 required 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 20 SBIR/STTR firms will be selected for participation in I-Corps for Phase I.

4.3 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 B), 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.

4.3.1 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, those proposals with high technical merit 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.

4.3.2 Phase II Evaluation Criteria

NASA intends to select for award those proposals that best meet the Government's interest(s). Note: Past performance will not be a separate evaluation factor but will be evaluated under factors 1 and 4 below. The evaluation of Phase II proposals will apply the following factors described 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.

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 3.3.4, 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 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 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 (Form C). NASA will comply with the FAR and NASA FAR Supplement (NFS) to evaluate the proposed price/cost to be fair and reasonable.

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

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. Proposals receiving acceptable numerical scores will be evaluated and rated for their commercial potential. Factors 1 - 4 will be evaluated and used in the selection of proposals for negotiation. Factor 5 will be evaluated and used in the selection for award.

4.3.3 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. Final selection decisions will consider the recommendations, overall NASA priorities, program balance and available funding, as well as any other evaluations or assessments (particularly pertaining to commercial potential). 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.

4.4 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 e-mail. 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.

4.4.1 Phase I Debriefings

Debriefings will be automatically e-mailed 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. 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.

4.4.2 Phase II Debriefings

For Phase II, offerors must send a debriefing request via e-mail 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 Availability of Funds

All Phase I and 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.

5.1.2 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 contracting officer immediately.
(2) Your firm is registered with System for Award Management (SAM) (section 5.14.2).
(3) Your firm is in compliance with the VETS 100 requirement. 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.

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

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 needs (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. A final NTSR is due at the end of the contract, and an NTR is required if technology is developed, 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 Electronic Handbook (EHB) and NASA requests the submission of report deliverables in PDF or MS Word format. To Access the EHB the NASA network must be accessed. Everyone with access to the NASA network will be required to use 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.

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

5.4 Release of Proposal Information

In submitting a proposal, the offeror agrees to permit the Government to disclose publicly the information contained on the Proposal Summary (Form B). 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 the Freedom of Information Act (FOIA).

5.5 Access to Proprietary Data by Non-NASA Personnel

5.5.1 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.

5.5.2 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.

5.6 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 in the following legend that appears on the Cover Sheet (Form A) of the proposal:

"This data shall not be disclosed outside the Government and shall not be duplicated, used, or disclosed in whole or in part for any purpose other than evaluation of this proposal, provided that a funding agreement is awarded to the offeror as a result of or in connection with the submission of this data, the Government shall have the right to duplicate, use or disclose the data to the extent provided in the funding agreement and pursuant to applicable law. This restriction does not limit the Government's right to use information contained in the data if it is obtained from another source without restriction. The data subject to this restriction are contained in pages ____ of this proposal."

Note: Do not label the entire proposal proprietary. The Proposal Summary (Form B), and the Briefing Chart should not contain proprietary information; and any page numbers that would correspond to these must not be designated proprietary in Form B.

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

5.7 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 grant must remain protected through the protection period of that subsequent SBIR grant. However, effective at the conclusion of the 4-year period, the government shall have unlimited rights in any data delivered under the grant.

5.8 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.

5.9 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. NASA prefers that the awardee use either the electronic or paper version of NASA Form 1679, Disclosure of Invention and New Technology (Including Software), to report inventions. Both the electronic and paper versions of NASA Form 1679 may be accessed at the electronic New Technology Reporting Web site http://ntr.ndc.nasa.gov/.

A New Technology Summary Report (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 also be submitted via the SBIR/STTR EHB at https://ehb8.gsfc.nasa.gov/contracts/public/firmHome.do.

5.10 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.

5.11 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 appended to the proposal. This will not count as part of the 23-page limit for the Phase I proposal.

5.12 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.**

5.13 Additional Information

5.13.1 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.

5.13.2 Evidence of Contractor Responsibility

In addition to the information required to be submitted in section 3.3.12, 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.

5.13.3 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.

5.13.4 Government Furnished and Contractor Acquired Property

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

5.14 Required Registrations and Submissions

5.14.1 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 Program. The SBIR policy directive requires 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 agencies. All SBCs must report and/or update ownership information to SBA prior to each SBIR application submission or if any information changes prior to award.

From the NASA SBIR/STTR Proposal Submission 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 a Firm level form in the Activity Worksheet and is applicable across all proposals submitted by the SBC for that specific solicitation.

5.14.2 System for Award Management (SAM) Registration

Offerors should be aware of the requirement to register in SAM prior to contract award. **To avoid a potential delay in contract award, offerors are required to register prior to submitting a proposal. Additionally, firms shall be registered under the NAICS code of 541712.**

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 DUNS or DUNS+4 number, and a 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 Government and 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 Internet. 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 via the Internet 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:

- 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 Info:
  - 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. In regards to updating SAM Registration please see the following Link:

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

5.14.3 52.204-8 Annual Representations and Certifications

Offerors should be aware of the requirement that the Representation and Certifications required from Government contractors must be completed through SAM website https://www.sam.gov/. FAC 01-26 implements the final rule for this directive and requires that all offerors provide representations and certifications electronically via the BPN website; 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.

5.14.4 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-100 Report) from Federal contractors and subcontractors who receive Federal contracts that meet the threshold amount of $100,000. The VETS-100 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 100 report on file. Please visit the DOL VETS 100 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.

5.14.5 1852.203-17 Contractor Employee Whistleblower Rights

(a) This contract and employees working on this contract will be subject to the whistleblower rights and remedies in the pilot program on Contractor employee whistleblower protections established at 41 U.S.C. 4712 by section 828 of the National Defense Authorization Act for Fiscal Year 2013 (Pub. L. 112-239) and FAR 3.908.

(b) The Contractor shall inform its employees in writing, in the predominant language of the workforce, of employee whistleblower rights and protections under 41 U.S.C. 4712, as described in section 3.908 of the Federal Acquisition Regulation.

(c) The Contractor shall insert the substance of this clause, including this paragraph (c), in all subcontracts over the simplified acquisition threshold.

5.14.6 1852.209-75 Representation by Corporations Regarding an Unpaid Delinquent Tax Liability or a Felony Conviction under any Federal Law. (DEVIATION APRIL 2015)

(a) In accordance with sections 543 and 544 of The Consolidated and Further Continuing Appropriation Act of 2012 (Pub. L. 112-55), sections 540 and 541 of the Consolidated and Further Continuing Appropriations Act of 2013 (Pub. L. 113-6), sections 536 and 537 of the Consolidated Appropriations Act of 2014 (Pub. L. 113-76), and sections 744 and 745 of the Consolidated and Further Continuing Appropriations Act, 2015, (Pub. L. 113-235), none of the funds made available by that Act may be used to enter into a contract with any corporation that –

    (1) Has any unpaid Federal tax liability that has been assessed, for which all judicial and administrative remedies have been exhausted or have lapsed, and that is not being paid in a timely manner pursuant to an agreement with the authority responsible for collecting the tax liability, where the awarding agency is aware of the unpaid tax liability, unless a Federal agency has considered suspension or debarment of the corporation and has made a determination that this further action is not necessary to protect the interests of the Government; or

    (2) Was convicted of a felony criminal violation under any Federal law within the preceding 24 months, where the awarding agency is aware of the conviction, unless a Federal agency has considered suspension or debarment of the corporation and has made a determination that this further action is not necessary to protect the interests of the Government.

(b) The offeror represents that –

    (1) It is [ ] is not [ ] a corporation that has had any unpaid Federal tax liability that has been assessed, for which all judicial and administrative remedies have been exhausted or have lapsed, and that

is not being paid in a timely manner pursuant to an agreement with the authority responsible for collecting the tax liability; and

(2) It is [ ] is not [ ] a corporation that was convicted of a felony criminal violation under a Federal law within the preceding 24 months.

5.14.7 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.

5.14.8 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.

5.14.9 Human and/or Animal Subject

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

5.14.10 HSPD-12

Firms that require access to federally controlled facilities for six consecutive months or more must adhere to the following:

PIV Card Issuance Procedures in accordance with FAR clause 52.204-9 Personal Identity Verification of Contractor Personnel.

Purpose: To establish procedures to ensure that recipients of contracts are subject to essentially the same credentialing requirements as Federal Employees when performance requires physical access to a federally-controlled facility or access to a Federal information system **for six consecutive months or more**. (Federally -controlled facilities and Federal information system are defined in FAR 2.101(b)(2)).

Background: 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" require agencies to establish and implement procedures to create and use a Government-wide secure and reliable form of identification NLT 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 parts 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/.

5.15 False Statements

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 fines and imprisonment of up to five years in prison. The Office of the Inspector General 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

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 e-mail address. Paper submissions are not accepted.

The Electronic Handbook (EHB) for submitting proposals is located at http://sbir.nasa.gov. The Proposal Submission EHB will guide 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 e-mail.

6.2 Submission Process

SBCs must register in the EHB to begin the submission process. 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 3.2.4.

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 including Forms A, B, C, the briefing chart, and other firm level forms 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 e-mail attachments are not acceptable).

(1) Forms A, B, and C are to be completed online.
(2) The technical proposal is uploaded from your computer via the Internet utilizing secure communication protocol.
(3) STTR proposers must submit the Research Agreement between the SBC and RI **(STTR only)**.
(4) Firms must submit a briefing chart online, which is not included in the page count (see section 3.2.7).
(5) NASA Research License Application (only if the use of TAV is proposed).
(6) I Corps Opt-In Form must be completed online (Phase I only).
(7) The firm-level certifications, audit information, prior awards addendum, commercialization metrics survey are required and to be completed online. These are not included in the page count.

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 or MS Word. **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. **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. An e-mail will be sent acknowledging each successful technical proposal upload. Please verify the file name and file size in the confirmation email to ensure the correct proposal was uploaded.

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.

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, January 20, 2017* via the NASA SBIR/STTR website http://sbir.nasa.gov. The EHB will not be available for Internet submissions after this deadline, so firms are also advised to print all forms prior to the deadline since the EHB will not be available. Any proposal received after that date and time shall be considered late and handled according to NASA FAR Supplement 1815.208.

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, 6 months from the effective date of the award for SBIR's and 12 months for STTR's, via the NASA SBIR/STTR website http://sbir.nasa.gov. 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, so firms are also advised to print all forms prior to the deadline since the EHB will not be available. Any proposal received after that date and time shall be considered late and handled according to NASA FAR Supplement 1815.208.

6.5 Acknowledgment of Proposal Receipt

The final proposal submission includes successful completion of Form A (electronically endorsed by the SBC Official and Principal Investigator), Form B, Form C, the uploaded technical proposal, firm-level forms, and the briefing chart. NASA will acknowledge receipt of electronically submitted proposals upon endorsement by the SBC Official to the SBC Official's e-mail address as provided on the proposal cover sheet. If a proposal acknowledgment is not received, the offeror should call NASA SBIR/STTR Program Support Office at 301-937-0888.

6.6 Withdrawal of Proposals

Prior to the close of submissions, proposals may be withdrawn via the Proposal Submission Electronic Handbook hosted on the NASA SBIR/STTR website http://sbir.nasa.gov. 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

Protests, as defined in section 33.101 of the FAR, that are filed directly with an agency and copies of any protests that are filed with the General Accounting Office (GAO) 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 web sites:

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 web sites:

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

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 and Certifications

Please 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.

Firm Certifications

Offerors must complete the "Certifications" section of the Proposal Submission 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 Small Business Innovation Research (SBIR) or Small Business Technology Transfer (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 Policy Directive and also any statutory and regulatory provisions referenced in those authorities.

If the funding agreement 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 verification of any of the information provided as part of a protest. If the funding agreement officer believes, after award, that the business is not meeting certain funding agreement requirements, the agency may request further clarification and supporting documentation in order to assist in the verification of any of the information provided.

Even if correct information has been included in other materials submitted to the Federal government, any action taken with respect to this certification does not affect the Government's right to pursue criminal, civil or administrative remedies for incorrect or incomplete information given in the certification. Each person signing this certification may be prosecuted if they have provided false information.

In submitting the proposals including the certifications, each offeror understands that providing false information is a criminal offense under Title 18 US Code, Section 1001, False Statements, as well as Title 18 US Code, Section 287, False Claims.

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 entire proposal including any supplemental material shall not exceed a total of 23 8.5 x 11 inch pages and follow the format requirements (section 3.2.2).**

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

3. The entire proposal is submitted consistent with the requirements and in the order outlined in section 3.2.

4. The technical proposal contains all eleven parts in order (section 3.2.4).

5. A letter of commitment from the facility manager, if the research or R&D effort requires use of federal facilities (section 3.2.4).

6. Certifications in Form A are completed, and agree with the content of the technical proposal.

7. Proposed funding does not exceed $125,000 (sections 1.3).

8. Proposed project duration does not exceed 6 months (sections 1.3).

9. Entire proposal including Forms A, B, C, I-Corps Opt-In, technical proposal and briefing chart submitted via the Internet.

    a) All firm-level forms most also be submitted, including: 1) all firm-level certifications, 2) audit information, 3) prior awards addendum, and 4) the commercialization metrics survey.

10. Form A electronically endorsed by the SBC Official and the PI.

11. **Proposals must be received no later than 5:00 p.m. EST on January 20, 2017 (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 entire proposal including any supplemental material shall not exceed a total of 23 8.5 x 11 inch pages, including the Research Agreement, and follow the format requirements (sections 3.2.2, 3.2.5).**
2. The proposal and innovation is submitted for one subtopic only (Section 3.1).
3. The entire proposal is submitted consistent with the requirements and in the order outlined in section 3.2.
4. The technical proposal contains all eleven parts in order (section 3.2.4).
5. A letter of commitment from the facility manager, if the research or R&D effort requires use of federal facilities (section 3.2.4).
6. Certifications in Form A are completed, and agree with the content of the technical proposal.
7. Proposed funding does not exceed $125,000 (sections 1.3, 5.1.1).
8. Proposed project duration does not exceed 12 months (sections 1.3).
9. Research Agreement has been electronically endorsed by both the SBC Official and the RI (sections 3.2.5, 6.2).
10. Entire proposal including Forms A, B, C, I-Corps Opt-In, technical proposal, briefing chart, and Research Agreement submitted via the Internet.
    a) All firm-level forms most also be submitted, including: 1) all certifications, 2) audit information, 3) prior awards addendum, and 4) the commercialization metrics survey.
11. Form A electronically endorsed by the SBC Official and the PI.
12. **Proposals must be received no later than 5:00 p.m. EST on January 20, 2017 (section 6.3).**
13. 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 entire proposal including any supplemental material shall not exceed a total of 50 8.5 x 11 inch pages and the format requirements (section 3.3.2).**

2. The proposal and innovation is submitted for one subtopic only.

3. The entire proposal is submitted consistent with the requirements and in the order outlined in section 3.3.

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

5. A letter of commitment from the facility manager, if the research or R&D effort requires use of federal facilities (section 3.3.4).

6. Certifications in Form A are completed, and agree with the content of the technical proposal.

7. Proposed funding does not exceed $750,000, excluding the $5,000 Commercialization Technical Assistance, if requested (sections 1.3, 5.1.1).

8. Proposed project duration does not exceed 24 months (sections 1.3).

9. Entire proposal including Forms A, B, and C, technical proposal, and briefing chart submitted via the Internet.

    a) All firm-level forms most also be submitted, including: 1) all certifications, 2) audit information, 3) prior awards addendum, and 4) the commercialization metrics survey.

10. Form A electronically endorsed by the SBC Official and the PI.

11. **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 entire proposal including any supplemental material shall not exceed a total of 508.5 x 11 inch pages, including the Research Agreement, and follow the format requirements (sections 3.3.2, 3.3.5).**

2. The proposal and innovation is submitted for one subtopic only.

3. The entire proposal is submitted consistent with the requirements and in the order outlined in section 3.3.

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

5. A letter of commitment from the facility manager, if the research or R&D effort requires use of federal facilities (section 3.3.4).

6. Certifications in Form A are completed, and agree with the content of the technical proposal.

7. Proposed funding does not exceed $750,000 excluding the $5,000 Commercialization Technical Assistance, if requested (section 1.3, 5.1.1).

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

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

10. Entire proposal including Forms A, B, C, technical proposal, briefing chart, and Research Agreement submitted via the Internet,

    a) All firm-level forms most also be submitted, including: 1) all certifications, 2) audit information, 3) prior awards addendum, and 4) the commercialization metrics survey.

11. Form A electronically endorsed by the SBC Official and the PI.

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

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

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
H – Human Exploration and Operations Mission Directorate
S – Science Mission Directorate
Z – Space Technology Mission Directorate
T – Small Business Technology Transfer

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.

9.1 SBIR Research Topics

The SBIR Program Solicitation subtopics are developed by the NASA Mission Directorates and Centers in coordination with the NASA SBIR/STTR programs.

Focus Area 1: In-Space Propulsion Technologies

Participating MD(s): SMD, STMD

NASA is interested in technologies for advanced in-space propulsion systems to reduce travel time, reduce acquisition costs, and reduce operational costs 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, and nuclear thermal propulsion systems related to human exploration, sample return missions to Mars, small bodies (like asteroids, comets, and Near-Earth Objects), outer planet moons, and Venus. Propulsion technologies will focus on a number of mission applications included ascent, descent, orbit transfer, rendezvous, station keeping, and proximity operations.

S3.02 Propulsion Systems for Robotic Science Missions
Lead Center: GRC
Participating Center(s): JPL, MSFC

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 (http://solarsystem.nasa.gov/2013decadal/). Future spacecraft and constellations of spacecraft will have high-precision propulsion requirements, usually in volume- and power-limited envelopes. Also recently precise propulsion systems have been incorporated into disturbance reduction systems to demonstrate that a solid body can float freely in space completely undisturbed in order to explore the gravitational universe. However, technology limits to propulsion system life still exist which can ultimately limit mission duration for more ambitious follow-on formation flying applications.

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. Roadmaps for propulsion technologies can be found from the National Research Council (http://www.nap.edu/openbook.php?record_id=13354&page=168) and NASA's Office of the Chief Technologist (http://www.nasa.gov/pdf/501329main_TA02-InSpaceProp-DRAFT-Nov2010-A.pdf).

Proposals should show an understanding of the state of the art, 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 state-of-the-art alternatives.

Advanced Electric Propulsion Components

Towards that end, this solicitation seeks to mature and demonstrate iodine electric propulsion technologies. Iodine propellant has two key advantages over the state-of-the-art (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.

This subtopic seeks proposals that mature iodine propulsion technologies, including:

- Iodine compatible Hall Effect Thruster cathodes with lifetimes greater than 10,000 hours.
- Robust and electrically efficient iodine storage and delivery system architectures (scalable 5 kg to 100 kg iodine):
  - Numerical modeling to guide system design and CONOPS, predicting power consumption, iodine mobility, thermal transport, sublimation rate, condensation, clogging, recovery time post-anomalies, etc.
  - Design and analysis of innovative iodine feed system architectures.
  - Experimental demonstration of promising feed system architectures under conditions of long-term iodine storage and dynamic thermal environments.
- Compact low-power iodine compatible feed system technologies, including high accuracy pressure sensors (<1 atm full scale), propellant flow control valves, latch valves, heaters, etc.
  - Feed system technologies utilizing innovative iodine resistant materials and coating.
  - Experimental and numerical demonstration of component operation in dynamic simulated mission environments.

This subtopic also seeks proposals that explore uses of technologies that will provide superior performance in for high specific impulse/low mass electric propulsion systems at low cost. These technologies include:

- Thruster components including, but not limited to, advanced cathodes, rf devices, advanced grids, lower-cost components enabled by novel manufacturing techniques.
- Any long-life, electric propulsion technology between 1 to 10 kW/thruster that would enable a low-power nuclear electric propulsion system based on a kilopower nuclear reactor.

Secondary Payload Propulsion

The secondary payload market shows significant promise to enable low cost science missions. Launch vehicle providers, like SLS, are considering a large number of secondary payload opportunities. The majority of these satellite missions flown are often selected for concept or component demonstration activities as the primary objectives. Opportunities are anticipated to select future satellite missions based on application goals (i.e., science return). However, several technology limitations prevent high value science from low-cost spacecraft, such as post deployment propulsion capabilities, Additionally, propulsion systems often place constraints on handling, storage, operations, etc. that may limit secondary payload consideration. It is desired to have a wide range of Delta-V capability to provide 100-1000s of m/s.

Specifically, proposals are sought for:

- Chemical and/or electric propulsion systems with green/non-toxic propellants.
- Improved operational life over SOA propulsion systems.

In addressing technology requirements, proposers should identify potential mission applications and quantify the expected advancement over state-of-the-art alternatives.

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 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.

Innovations are sought in the following areas:

- Novel design, packaging, and deployment 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 have been moved to a new STMD subtopic: Z8.01 - Small Spacecraft Propulsion Systems.

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

This subtopic solicits technologies related to cryogenic propellant (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 and In-Situ Resource Utilization in cooperation with Mars Landers in support of the Evolvable Mars Campaign.

Specifically, listed in order of importance:

- Analysis of cryogenic systems for improved modeling of turbulence effects on heat and mass transfer across the liquid/gas interface. Of particular interest are improved models for turbulent heat transfer and mass transfer across the liquid/gas interface that can be applied to Unsteady Reynolds Averaged Navier-Stokes (URANS) simulations using Eulerian-based two-phase models, such as Volume of Fluid. Data to guide modeling efforts such as NASA-TM-2003-212926 or NASA-TM-105411.
- Mars surface cryogenic storage requires a vacuum jacket in order to reduce heat leak and power requirements. A lightweight vacuum jacketed system may be possible, where the vacuum jacket is designed for Mars atmospheric pressure (5-7 torr). The vacuum jacket may be launched purged, evacuated upon reaching orbit, and then sealed prior to Mars entry. The vacuum jacketed system would then have to retain a vacuum for several years while on the surface of Mars.
- 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.
- Analysis of cryogenic systems sometimes requires computational fluid dynamics, especially when significant deformation or breakup of the liquid/gas interface occurs. For many components, or for settled conditions, a simpler fluid and thermal network approach may be sufficient. Of interest is the capability to tightly couple CFD and fluid/thermal network approaches, such as a fluid-thermal network analysis of an active pressure control system coupled to a CFD simulation of the fluid and thermodynamics occurring in a cryogenic storage tank.

Z10.02 Methane In-Space Propulsion
Lead Center: GRC
Participating Center(s): JSC, MSFC

NASA is developing high thrust in-space chemical propulsion capabilities to enable human and robotic missions into the proving ground (Mars and beyond). Successful proposals are sought for focused investments on key technologies and design concepts that may transform the path for future exploration of Mars or beyond, while providing component and system-level cost and mass savings. In-space propulsion is defined as the development and demonstration of technologies for ascent, orbit transfer, pulsing attitude/reaction control (RCS), and descent engines.

Technologies of interest for operation with liquid oxygen and liquid methane specifically are sought:

- Components for integrated RCS (~100-lb class) and Main Propulsion System (MPS) (25,000-lb class) feed systems (utilizing common propulsion tanks), including:
    - Lower power (~100 - 30 W) electric-pump systems (28-100 Vdc) at desired flowrates (~8-10 lbm/s max).
    - Vacuum capable (<10 torr) compact exciters with high spark rates (>200 sps) and 30-50 mJ minimum delivered spark energy.
    - Improved materials/manufacturing capabilities for high temperature (>800 K), high pressure (>1000 psia) applications.
- Technologies to improve throttling in pressure-fed engines (5000-lb class), to minimize performance losses, such as:
    - Improved injector concepts that provide at least 98% c* (c-star) efficiency at full throttle conditions and maintain stability at 20% throttle ratios.
    - Fast-acting (<80 ms response time), low-leakage (<3 SCCS to 0.1 SCCS gaseous propellants) throttle valves, which meet the following performance considerations: maintain consistent mixture ratio (MR) over the throttle range, 50% (minimum) force margin, cold and warm operations, easily chilled in.

Proposers MUST clearly articulate the metrics of their technology, and must show a clear understanding of the current state of the art (SOA), and explicitly describe how their technology advances the state of the art. A clearly defined description of the following, at a minimum, is desired:

- Assessment of SOA with the key performance parameters (KPP) of their choosing (such as performance, mass, response time, etc.), including specifics which may be referenced in backup material - provide SOA for each major technology element in the proposal.
- Address the outstanding technology performance being promised and the degree to which the concept is new, different, and important. Particularly, explicitly define how the technology and/or fabrication technique proposed saves cost, schedule and/or mass. If a new manufacturing technique is proposed, clearly define how the technique provides a unique technology not feasible through other manufacturing methods.
- Provide quantitative rather than qualitative assertions (e.g., x% improvement of y, z kg of mass savings, xx% in cost savings, etc.) to the advancement over the SOA.
- Identify specific deliverables being offered. Clearly and explicitly specify what items are being delivered as part of contract performance, and clearly identify if hardware is being offered. Explicitly identify if any commitment has been made for post-development testing.

Phase I Deliverables - Research to identify and evaluate candidate technology applications to demonstrate the technical feasibility and show a path towards a demonstration. Bench or lab-level demonstrations are desirable. The technology concept at the end of Phase I should be at a TRL of 4 to 5.

Phase II Deliverables - Emphasis should be placed on developing and demonstrating the technology under simulated mission conditions. The proposal shall outline a path showing how the technology could be developed into mission-worthy systems. The contract should deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract. The technology concept at the end of Phase II should be at a TRL of 5 to 6.

Note: Technologies for cryogenic applications must be demonstrated in relevant environment by end of Phase II. Water demonstration is not sufficient for demonstrating TRL 5 capability.

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

Nuclear Thermal Propulsion (NTP)

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. The current NASA Strategic Space Technology Investment Plan states NTP is a high priority technology needed for future human exploration of Mars. 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 ~15,000-35,000 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:

- Reactor fuel element designs with high temperature (> 2600K), high power density (>5 MW/L) to optimize hydrogen propellant heating.
- New additive 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. Fuel can made of Ceramic-metallic (cermet) or composite/carbide 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.
    - Insulator design (one application is for tie tubes) 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. Also needed are radiation shielding technologies that minimize exposure to other stage components and reduce total crew radiation dose. 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.
    - Concept for quick restart of reactor (2-6 hours) after 30-40 minute burns and accounting for Xe135 buildup.
- Radiation shielding concepts that protect the crew and minimize heating of store propellant and the stage. Strategies that minimize radiation shielding system mass, such as utilization of the payload and consumables for shielding (when practical) that may provide an additional bonus of shielding galactic cosmic radiation as well as radiation from the NTP engines.

Ground Test Technologies

Environmental regulations require NTP engine exhaust filtering of radioactive noble gases and particulates to maintain safe environmental levels. NTP engine ground testing will require the development of large scale engine exhaust scrubber technologies and options for integrating it to the NTP engine for ground tests (reference 51st AIAA/SAE/ASEE Joint Propulsion Conference paper AIAA 2015-3773, 'Review of Nuclear Thermal Propulsion Ground Test Options', D. Coote, et al). 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:

- Advanced high-temperature and hydrogen embrittlement resistant materials for use in a hot hydrogen environment (<5500°F) and possibly exposed to neutrons and gamma rays.
- 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.
- Effluent scrubber technologies for efficient filtering and management of high temperature, high flow hydrogen exhausts. Specific interests include:
    - Filtering of radioactive particles and debris from exhaust stream having an efficiency rating greater than 99.5%.
    - Removal of radioactive halogens, noble gases and vapor phase contaminants from a high flow exhaust stream with an efficiency rating greater than 99.5%.
- Applicable Integrated System Health Monitoring and autonomous test operations control systems.
- Modern robotics which can be used to inspect the ground test system exposed to a radiation environment.

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 and Energy Storage

Participating MD(s): SMD, STMD

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. 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, power management, transmission, distribution and control. An overarching objective is to mature technologies from analytical or experimental proof-of-concept (TRL3) to breadboard demonstration in a relevant environment (TRL5). Successful efforts will transition into NASA Projects where the SBIR deliverables will be incorporated into ground testbeds or flight demonstrations.

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

Future NASA science missions will employ Earth orbiting spacecraft, planetary spacecraft, balloons, aircraft, surface assets, and marine craft as observation platforms. Proposals are solicited to develop advanced power-generation and conversion technologies to enable or enhance the capabilities of future science missions. Requirements for these missions are varied and include long life, high reliability, significantly lower mass and volume, higher mass specific power, and improved efficiency over the state of practice for components and systems. Other desired capabilities are high radiation tolerance and the ability to operate in extreme environments (high and low temperatures and over wide temperature ranges).

While power-generation technology affects a wide range of NASA missions and operational environments, technologies that provide substantial benefits for key mission applications/capabilities are being sought in the following areas:

Photovoltaic Energy Conversion

Photovoltaic cell, blanket, and array technologies that lead to significant improvements in overall solar array performance (i.e., conversion efficiency >33%, array mass specific power >300watts/kilogram, decreased stowed volume, reduced initial and recurring cost, long-term operation in high radiation environments, high power arrays, and a wide range of space environmental operating conditions) are solicited. Photovoltaic technologies that provide enhancing and/or enabling capabilities for a wide range of aerospace mission applications will be considered. Technologies that address specific NASA Science mission needs include:

- 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 high intensity, high-temperature environment (i.e., inner planetary and solar probe-type missions).
- Solar arrays to support Extreme Environments Solar Power type missions, including long-lived, radiation tolerant, cell and blanket technologies capable of operating in environments characterized by varying degrees of light intensity and temperature.
- Lightweight solar array technologies applicable to science missions using solar electric propulsion. Current science 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.

Stirling Power Conversion

Advances in, but not limited to, the following:

- Novel Stirling convertor configurations that provide high efficiency (>25%), low mass, long life (>10 yrs), and high reliability for use in 100-500 We Stirling radioisotope generators.
- Advanced Stirling convertor components including hot-end heat exchangers, cold-end heat exchangers, regenerators, linear alternators, engine controllers, and radiators.
- Innovative Stirling generator features that improve the fault tolerance (e.g., heat source backup cooling devices, mechanical balancers) or expand the mission applications (e.g., duplex power and cooling systems).

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 increased use of cubesat/smallsat technology and autonomous remote sensors in support of NASA Science Mission goals has demonstrated the need for low-power, non-solar energy sources. The area of Direct Energy Conversion seeks technology advancements that address, but are not limited to:

- Experimental demonstration of long life (multiyear) alpha-voltaic and beta-voltaic devices with device-level conversion efficiencies in excess of 10%, high reliability, minimal operational performance degradation, 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
Lead Center: GRC
Participating Center(s): ARC, GSFC, JPL, JSC

NASA's science vision (https://smd-prod.s3.amazonaws.com/science-green/s3fs-public/atoms/files/2014_Science_Plan_PDF_Update_508_TAGGED.pdf) is to use the vantage point of space to achieve with the science community and our partners a deep scientific understanding of the Sun and its effects on the solar system, our home planet, other planets and solar system bodies, the interplanetary environment, and the universe beyond. Scientific priorities for future planetary science missions are guided by the recommendations of the decadal surveys published by the National Academies. The goal of the decadal surveys is to articulate the priorities of the scientific community, and the surveys are therefore the starting point for NASA's strategic planning process in science (https://smd-prod.s3.amazonaws.com/science-green/s3fs-public/atoms/files/FY2014_NASA_StrategicPlan_508c.pdf). The most recent planetary science decadal survey, Vision and Voyages for Planetary Science in the Decade 2013 - 2022, was released in 2011. This report recommended a balanced suite of missions to enable a steady stream of new discoveries and capabilities to address challenges such as sample return missions and outer planet exploration. Under this subtopic, proposals are solicited to develop energy storage and power electronics to enable or enhance the capabilities of future NASA science missions. The unique requirements for the power systems for these missions can vary greatly, with advancements in components needed above the current State of the Art (SOA) for high energy density, high power density, long life, high reliability, low mass/volume, and wide temperature operation. Other subtopics which could potentially benefit from these technology developments include S4.04 Extreme Environments Technology, and S4.01 Planetary Entry, Descent and Landing Technology. This subtopic is also directly tied to S3.02 Propulsion Systems for Robotic Science Missions for the development of advanced Power Processing Units and associated components.

Power Electronics and Management

NASAs Planetary Science Division is working to implement a balanced portfolio within the available budget and based on the 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. In addition, studying the Sun, the heliosphere, and other planetary environments as an interconnected system is critical for understanding the implications for Earth and humanity as we venture forth through the solar system. To that end, the NASA heliophysics program seeks to perform innovative space research missions to understand:

- The Sun and its variable activity.
- How solar activity impacts Earth and the solar system.
- Fundamental physical processes that are important at Earth and throughout the universe by using space as a laboratory.

Heliophysics also seeks to enable research based on these missions and other sources to understand the connections among the Sun, Earth, and the solar system for science and to assure human safety and security both on Earth and as we explore beyond it. 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 (PPUs), require advancements in components and systems beyond the state-of-the-art. Of importance are expected improvements in 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, RPS has a need for intelligent, fault-tolerant Power Management and Distribution (PMAD) technologies to efficiently manage the system power for these 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 nano-tubes 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.

Note to Proposers - Cubesat power technologies have been moved to a new STMD subtopic: Z8.03 Small Spacecraft Power and Thermal Control

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, High Voltage Electronics
Lead Center: GSFC
Participating Center(s): GRC JPL, LaRC

NASA is seeking performance improvements to Power Management and Distribution (PMAD) systems through increases to the operating voltages of these electrical components. Specifically, NASA is developing Solar Electric Propulsion systems that use Power Processing Units (PPUs) to convert the 300V solar array output to the 700V-2000V input level of an electric thruster. Although many diodes and transistors exist in the commercial market place that would represent significant improvements over the state of the art space-qualified components, these parts have failed to pass critical tests related to space qualification most importantly in terms of their radiation tolerance. It is believed that the development and integration of high-voltage diodes and transistors that can be space-qualified will lead to increases in system-level performance as they will tend to increase efficiency and decrease mass at the system architecture level.

Proposals are solicited that address the gap for high-power, high-voltage electrical, electronic and electromechanical (EEE) parts suitable for the space environment through design and development of high-voltage, high-power diodes and/or transistors. Proposals must state the initial component state of the art and justify the expected final performance metrics. The proposals must also include plans for validating tolerance to both heavy-ion and total dose radiation. Target radiation performance levels include:

- 300 krad(Si) total ionizing dose tolerance.
- For vertical-field power devices: No heavy-ion induced permanent destructive effects upon irradiation while in blocking configuration (in powered reverse-bias/off state) with ions having a silicon-equivalent surface-

incident linear energy transfer (LET) of 40 MeV-cm^2/mg and sufficient energy to fully penetrate the epitaxial layer(s) prior to the ions reaching their maximum LET (Bragg peak).

- For all other devices: No heavy-ion induced permanent destructive effects upon irradiation while in blocking configuration (in powered reverse-bias/off state) with ions having a silicon-equivalent surface-incident linear energy transfer (LET) of 75 MeV-cm^2/mg and sufficient energy to fully penetrate the active volume prior to the ions reaching their maximum LET (Bragg peak).

Z1.02 Surface Energy Storage
Lead Center: GRC
Participating Center(s): JPL, JSC

NASA is seeking innovative energy storage solutions for surface missions on the moon and Mars. The objective is to develop energy storage systems for landers, construction equipment, crew rovers, and science platforms. Energy requirements for mobile assets are expected to range up to 120 kW-hr with potential for clustering of smaller building blocks to meet the total need. Requirements for energy storage systems used in combination with surface solar arrays range from 500 kW-hr (Mars) to over 14 MW-hr (moon). Applicable technologies such as batteries and regenerative fuel cells should be lightweight, long-lived, and low cost. Of particular interest are technologies that are multi-use (e.g., moon and Mars) or cross-platform (e.g., lander use and rover use). Strong consideration should be given to environmental robustness for surface environments that include day/night thermal cycling, natural radiation, partial gravity, vacuum or very low ambient pressure, reduced solar insolation, dust, and wind. Creative ideas that utilize local materials to store energy would also be considered under this subtopic.

Advanced secondary batteries that go beyond lithium-ion, can safely provide >300-400 watt-hours per kilogram, and have long calendar and shelf lives are highly desired for cross-cutting applications. Secondary batteries that can operate at -60°C with excellent capacity retention as compared to room temperature operation are also highly desired. Additionally, for the Mars Ascent vehicle, secondary batteries that can operate reliably after a 15 year shelf life are highly desired.

Of interest for fuel cells and regenerative fuel cells are technologies that can mature hydrogen-oxygen fuel cells and electrolyzers and can address challenges common to both fuel cells fed by oxygen and methane and electrolyzers fed by carbon dioxide and/or water. Hydrocarbon fuels of interest include, but are not limited to, methane, residual fuel scavenged from lander propulsion tanks, and fuels generated by processing lunar and Mars soils. Components and systems of interest include fuel cells, stack, materials, and system development. For space and Lunar applications, gravity-independent operation should be considered in the design. For Mars applications, cell and stacks capable of Mars atmosphere electrolysis should be considered in the design. High power density for fuel cells, high efficiency for regenerative fuel cells, and designs that are scalable to 1 to 3kW sizes are highly desirable.

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

NASA is seeking novel fission-based power generation technologies for surface missions on the moon and Mars. The objective is to develop power generation systems for landers, crewed habitats, and in-situ resource utilization plants. Power requirements are expected to range up to 40 kW with potential for clustering of smaller building blocks to meet the total need. Applicable thermal energy conversion should be lightweight, long-lived, and low cost. Of particular interest are technologies that are multi-use (e.g., moon and Mars). Strong consideration should be given to environmental robustness for surface environments that include day/night thermal cycling, natural radiation, partial gravity, vacuum or very low ambient pressure, dust, and wind. Recognizing that small businesses are not likely to develop the nuclear fuel core, proposals are solicited for the key non-nuclear components and sub-systems. Specific areas of interest include power conversion technologies that enable system level specific power above 5

W/kg, advanced manufacture of heat exchangers for power conversion, reliable and radiation hard controllers, reactor and power conversion thermal interfaces, neutron reflectors, and radiation shielding.

Focus Area 3: Autonomous Systems for Space Exploration

Participating MD(s): HEOMD

The exploration of space requires the best of the nation's technical community to provide the technologies that will enable human exploration beyond Low Earth Orbit (LEO): to visit asteroids, and to extend our reach to Mars. Autonomous Systems technologies provide the means of migrating mission control from Earth to spacecraft and habitats. This is enhancing for missions in the Earth-Lunar neighborhood and enabling for deep space missions. Long light-time delays, up to 42 minutes round-trip between Earth and Mars, require time-critical control decisions to be closed on-board autonomously through automation and 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 under 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. 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 human research program topic area is very relevant to autonomous systems technologies, and proposers are encouraged to review that subtopic description.

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

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 to support autonomy 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. Within this definition, resilience has two manifestations: engineering and ecological. Engineering resilience is focused on the ability of a system to absorb and recover from adverse events, while ecological resilience is focused on understanding how close a system is to collapse and reorganization. The engineering definition brings resilience principles such as robustness, redundancy, and modularity, while the ecological definition supports principles of flexibility, adaptability, and resourcefulness.

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 designed 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, Assessment, and Recovery (FDIR). FDIR can be realized through hardware or software solutions as well as by intervention of the mission crew or mission control. The detection / assessment / recovery process will involve identification of:

- Small variations in overall system performance that may "coincide and combine" to produce significant risk.
- Dependencies within the system that contribute to unforeseen increased risk.
- The strategies and solutions used by crew and controllers to run mission operations safely.
- Recovery/fallback mechanisms that help the human/technology system cope with foreseen and unforeseen operational conditions and events.
- The adaptability and flexibility needed to handle unpredictable and uncertain situations.
- The different technical, functional, and procedural features that can interact in a positive way to achieve mission success.

Four processes characterize the emergence of resilience as a system property:

- *Sensing* - measuring new information about a system's operating environment with focus on anomalous data. These data can alert system evaluators of overlooked possibilities. This process connects components in the physical domain to the information domain.
- *Anticipation* - imagining multiple future states without reducing improbability to impossibility; this includes incorporating the uncertainty in the future states and including the impact of such uncertainty on system operation. This process connects components in the information domain to the cognitive domain.
- *Adaptation* - reacting to changing conditions or uncertain states to restore critical functionality under altered conditions or operating environments. This process connects the cognitive domain to the physical domain.

- *Learning* - observing external conditions and system responses to improve understanding of relationships and possible futures, identifying needs for system improvement where applicable. This process links the physical, information, and cognitive domains together and can incorporate the social or human crew domain depending on the system studied.

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 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 (i.e., models that assess the resilience of the system over its entire life-cycle) 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 allow bi-directional exchange between a model and the analysis tool.
  - Methods that systemically include desired levels of resilience in the design optimization process.
- 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, while accommodating: uncertainty; incomplete knowledge; sparsity, or high volumes, of data; and humans in the loop.

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.
- 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:

- Resiliency for the computational system should also be addressed.
- In-space applications are preferred, but terrestrial analogues will be considered.

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: http://www.nap.edu/catalog.php?record_id=13457. The National Academies Press. (2012).

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

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 the cognitive software architecture 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://acs.ist.psu.edu/iccm2016/) and CogArch 2016 @ ASPLOS (http://researcher.watson.ibm.com/researcher/view_group.php?id=5848).

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 are 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 simulate 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.

Focus Area 4: Robotic Systems for Space Exploration

Participating MD(s): SMD, STMD

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
Lead Center: JPL
Participating Center(s): AFRC, ARC, GSFC, JSC
Related Subtopic Pointers: 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 planetary and solar system 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. On-orbit manipulation of a Mars sample cache canister is needed from capture to transfer into an Earth Entry Vehicle. 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 Payload Technologies for Free-Flying Robots
Lead Center: ARC
Participating Center(s): JPL, JSC

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

- Supporting deep-space human exploration spacecraft and habitats (operating inside or outside to support critical maintenance and monitoring functions).
- Supporting astronaut extra-vehicular activity (EVA) with scouting, follow-up sensing, and tool/sample delivery.

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 2018. Proposals are sought to create payloads that can be integrated with small-scale free-flying robots, including (but not limited to) the following areas:

- *Sensors* - Compact sensors relevant to the scenarios listed above, including functions such as interior environment monitoring (e.g., air quality), interior/exterior structural inspection, free-flying navigation (obstacle detection and localization), 3D environment modeling, etc.
- *End Effectors* - Small, lightweight mechanisms that can be used for docking/perching, prodding/pushing, tool carrying, and deployment of RFID tags. 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.
- *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.).
- *Novel 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), spacecraft "caretaking" (routine maintenance and emergency response), and other use cases.

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 (e.g., in terms of power) may still target Astrobee, but may require special accommodations (e.g., independent power). 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.

Z5.02 Robotic Systems - Mobility Subsystems
Lead Center: JSC
Participating Center(s): ARC, GRC, KSC

In the coming decades, robots 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. 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. 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.

Proposals are sought to research and develop the following robotic technologies including mobility, manipulation and human robot interaction technologies as described by the 2015 NASA Technology Roadmap for Robotics and Autonomous Systems (Tech Area 4):

- *Extreme Terrain Mobility* - Technology to access and traverse extreme terrain topographies, such as highly-sloped crater walls, gullies, and canyons; soft terrains; or terrains with large rock densities. Key technologies include rappelling and climbing systems and systems that can traverse soft and friable terrains.
- *Below-Surface Mobility* - Technology to access through naturally-occurring terrain cavities, such as lava tubes and deep crevasses; through human-made holes, ice boreholes, or trenches; and through granular or liquid media. Challenges include lack of direct sunlight, or line-of-sight comm. Key technologies include anchoring, burrowing, traction, downhole sensing, and tethering components.
- *Above-Surface Mobility* - Technology to provide longer range and greater coverage of planetary surfaces, independent of the terrain topography. This includes improvements to payload capacity, power, speed, and endurance in terms of time or distance. The type of above-surface mobility used on planetary bodies will be driven by environmental considerations and mission-specific requirements, which would include operation duration, coasting attitude, and the frequency of contacts with the surface.
- *Small-Body and Microgravity Mobility* - Technology to provide surface coverage and in-situ access to designated targets on small bodies with low gravity, as well as in-space mobility inside and around the ISS or other future space assets. Key technologies include human-safe gas propulsion, fan-based propulsion, hopping, flying, anchoring, wheel/track/limb hybrids, and electromagnetic formation flight.
- *Surface Mobility* - Technology to transport payloads, equipment, and other surface assets at much higher traverse speed for both manned and unmanned missions and increase the robustness of their onboard sensing, control, and navigation software. Key technologies include active suspension, traction control, real-time embedding/slip detection, and tractive elements (wheels, tracks, etc.)
- *Robot Navigation* - Technology to provide a highly reliable, well-characterized, and autonomous or semi-autonomous mobility capability to navigate to targets of interest on planetary surfaces. Key technologies include perception algorithms, pose and state estimation algorithms, and on-board autonomy (motion/path planning, target/waypoint selection, etc.).
- *Mobility Components* - Provide critical component technologies, such as compliant long-life wheels, high-torque at low speed actuators, energy-efficient and miniaturized actuators, strong abrasion-resistant tethers, and all-terrain anchors to meet future mobility needs. Provide larger payload and mobility mass fractions. Provide safe movement at speeds that are power-limited, not computation-limited, and yet do not tax human attention.
- *Manipulator Components* - Technologies should address improving kinematic configuration (serial, parallel, hybrids), dynamic performance (variable structural stiffness or compliant actuation), packaging efficiency (stowed and deployed), power density, or payload to mass ratio. This includes actuators tailored for manipulation (in terms of speed and torque range, compliance, size, and mass), lightweight structures (soft mechanisms, tendon systems, etc.), sensors and sensing approaches (both proprioceptive and exteroceptive), and embedded controllers (impedance, compliance, torque, etc.).
- *Dexterous Manipulation* - Technologies to generate smooth, human-like arm trajectories and fine end-effector motions that can flexibly manipulate objects; systems and control approaches capable of interacting with unstructured environments and human arm/hand scale interfaces; and approaches to incorporating or leveraging redundancy for robust manipulation. This includes manipulators and end-effectors, as well as the algorithms that control their motions.
- *Collaborative Manipulation* - Technologies to enable the use of multiple robotic manipulators that are either rigidly connected to a common base or to independent mobile bases. This includes algorithms and software for coordinated and cooperative motion, multi-point contact management (for highly dexterous robots or multi-robot systems), and distributed safety.

- *Grappling* - Technologies to handle large objects in microgravity environments. This includes components to grapple natural and human-made free-flying objects using surface features, and then to berth these objects to the robot's spacecraft through a rigidized interface.
- *Multi-Modal Interaction* - Technology that employs multiple display modalities and multiple communication channels to enhance human situation awareness and enable more efficient interaction. In particular, tools and techniques that combine interactive 3D computer graphics, multi-modal dialogue, haptics, spatialized sound, and other non-visual displays to create an increased sense of presence are of strong interest.
- *Distributed Collaboration and Coordination* - Technology that improves the operational efficiency of a distributed team of humans and robots. This includes performance monitoring systems for real-time evaluation of task execution; summarization and notification systems to help humans understand robot state and trends over time; and physics-based modeling and modeling/simulation of robots and their operational environments.
- *Variable Autonomy Robotic Interaction* - Technology that enables humans, both on Earth and in-mission to more effectively operate and supervise robots that may be remote or proximal. This includes decision support tools to monitor system status, assess task progress, observe the remote environment, and make informed operational decisions; interaction techniques that inspire humans to trust robot team members that are proximal and/or remote; techniques to mitigate the effects of latency on manual control; and methods to reduce dependency on high-bandwidth, high-availability communication links.

Proposals must describe how the technology will make a significant improvement over the current state of the art, rather than just an incremental enhancement. Proposals must also describe how the technology will be employed for a specific application and how performance will be quantitatively assessed.

Focus Area 5: Communications and Navigation

Participating MD(s): HEOMD, 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
Lead Center: JPL
Participating Center(s): GRC, GSFC

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 tranceiver 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 gigabits/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.

H9.02 Intelligent Communication Systems
Lead Center: GRC
Participating Center(s): JPL

NASA's RF and optical systems require increased levels of adaptive, cognitive, and autonomous system technologies to improve mission communication for science and exploration. Goals of this capability are to improve communications efficiency, mitigate impairments (e.g., scintillation, interference), and reduce operations complexity and costs through intelligent and autonomous communications and data handling. Cognition and automation have the potential to improve system performance, increase data volume return, and reduce user spacecraft burden to improve science return from NASA missions. These goals are further described in the TA05 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems Roadmap, Sections 5.2.1, 5.3.1, 5.3.2, 5.3.3, 5.3.4, 5.5.1, 5.5.2, and 5.5.3.

This solicitation seeks advancements in cognitive and automation communication systems, components, and platforms. While there are a number of acceptable definitions of cognitive systems/radio, for simplicity, a cognitive system should sense, detect, adapt, and learn from its environment to optimize the communications capabilities and situational awareness for the network infrastructure and/or the mission. Areas of interest to develop and/or demonstrate are as follows:

- *Flexible and Adaptive Space Hardware Systems* - Signal processing platforms (transceivers) with novel (e.g., low power, small volume, high capacity) processing technology, wideband (e.g., across or among frequency bands of interest), tunable, and adaptive front ends for RF (S-, X-, and Ka-bands) or optical communications, and other intelligent electronics/avionics which advances or enables flexible, cognitive, and intelligent operations.
- *System Wide Intelligence* - while much of the current research often describes negotiations and link improvements between two radio nodes, the subtopic also seeks to understand system wide, architectural aspects and impacts of this new technology. Areas of interest include (but not limited to): cognitive architectures considering mission spacecraft, relay satellites, other user spacecraft, and ground stations. System wide effects to decisions made by one or more communication/navigation elements, handling unexpected or undesired decisions, self-configuring networks, coordination among multiple spacecraft nodes in a multiple access scheme, cooperation and planning among networked space elements to efficiently and securely move data through the system to optimize data throughput and reduce operations costs.
- *Network Operation* - Optimization of the various layers of the Open Systems Interconnection (OSI) model has several aspects applicable to cognitive applications. Knowledge from one layer may be useful to optimize performance at a different layer. As the future space communication architecture progresses towards a more on-demand, ad-hoc, network-based architecture for data delivery among user spacecraft and relay satellite or from user spacecraft direct to ground stations new technologies are needed to securely provide assured data delivery through the network. Areas of interest include intelligent network routing (best route selection) through quality of service metrics and learning, store and forward data protocols over cognitive links, and advanced network management.

- *Node-to-Node Link Adaptation* - New capabilities for communication radios (hardware and software) to sense and adapt to the mission environment (for both RF and optical systems). Areas of interest include interference mitigation, spectrum cooperation, signal identification, maximizing data throughput and efficiency, learned operation between user spacecraft and relay (or ground) or direct to ground station communications.

For all technologies, Phase I will emphasize aspects for technical feasibility, clear and achievable benefits (e.g., 2x-5x increase in throughput, 25-50% reduction in power, improved quality of service or efficiency, reduction in operations staff or costs) and show a path towards Phase II hardware/software development with delivery of specific hardware or software product for NASA. Demonstrate and explain how and where cognitive and automation technologies could be applied to NASA space systems.

Phase I Deliverables - Feasibility study and concept of operations of the research topic, including simulations and measurements, validating the proposed approach to develop a given product (TRL 3-4). Early development and delivery of the simulation and prototype software and platform(s) to NASA. Plan for further development and verification of specific capabilities or products to be performed at the end of Phase II.

Phase II Deliverables - Working engineering model of proposed product/platform or software delivery, along with documentation of development, capabilities, and measurements (showing specific improvement metrics). Proposed prototypes (TRL-5) shall demonstrate a path towards a flight capable platform. User’s guide and other documents and tools as necessary for NASA to recreate, modify, and use the cognitive software capability or hardware component(s). Commercialization plan.

Software applications and platform/infrastructure deliverables for SDR platforms shall be compliant with the NASA standard for software defined radios, the Space Telecommunications Radio System (STRS), NASA-STD-4009 and NASA-HNBK-4009, found at: https://standards.nasa.gov/standard/nasa/nasa-std-4009 and https://standards.nasa.gov/standard/nasa/nasa-hdbk-4009, respectively.

H9.03 Flight Dynamics and Navigation Technology
Lead Center: GSFC
Participating Center(s): MSFC

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.

H9.04 Advanced RF Communications
Lead Center: JPL
Participating Center(s): GRC, GSFC, MSFC

This subtopic is focused on development of innovative Advanced RF Platform technologies, at the physical layer, supporting the needs of space missions in the areas of both communications and RF sensors.

In the future, robotic and human exploration vehicles with increasingly capable instruments producing large quantities of data will be investigating Earth, extraterrestrial moons, planets and asteroids. These vehicles, especially those that visit the surfaces of these myriad destinations, will be tightly constrained in the areas of mass, volume and energy. Our historical method of implementing single function elements such as short and long-range data and voice radios as well as short-range radar sensors does not lend itself to mass, volume or energy efficiencies that can support future resource challenged platforms.

One method of enhancing limited resources is to leverage recent advances in the areas of Reconfigurable Software Defined Radio (SDR) Digital Signal Processing (DSP) technologies as well as RF components, materials and packaging to create advanced multifunction RF platforms. Recent advances in high speed digital electronics, especially where clock speeds exist in the range of several GHz, have blurred the lines between what was traditionally considered “analog” and digital”. Digital signal processing techniques with multi-GHz clock rates can generate arbitrary user-defined analog waveforms at RF frequencies as never before. These waveforms, when coupled with advanced RF electronics focused on S-Band through Ka-Band frequencies, greatly improve the functionality, performance and utility of space-based communications devices. This naturally leads to advanced multi-function RF platforms; platforms that serve more than one user or function and are reconfigurable, on-demand, by the user for arbitrary applications. The commercial cellphone and wireless industries have been highly successful in developing multifunction RF and wireless platforms that serve a broad range of customers. NASA can leverage these techniques, hardware, algorithms and waveforms developed by industry for use in space applications. However, in order to leverage this increased level of configurability, functionality and performance, NASA needs to further invest in technologies for two key areas:

- Advanced waveform development in the digital domain. Specifically: the foundation has been laid through prior NASA investments in the area of generating the infrastructure for software-based algorithms. These investments led to the development and demonstration of the Space Telecommunication Radio System (STRS) architectural standard for software-defined radios. Now that the architecture has been instantiated, the next logical step in NASA's investment portfolio is the development of actual application backend platforms and waveforms that meet this architectural standard. Advanced backend platforms generate (for transmission) or process (from reception) the appropriate waveform at a common Intermediate Frequency (IF) for transmission to, or reception from, an appropriate RF front-end. In addition, the backend processor is reconfigurable, by the user, for a specific application at a given time (radar vs. short range communications link, etc.).
- The development and demonstration of advanced RF Front-Ends that cover NASA RF bands of interest; specifically, S-Band, X-Band and/or Ka-Band. These RF front-ends may support time multiplexed waveforms such as radar or (digitized) half-duplex voice transmissions as well as frequency duplexed waveforms such as full-duplex two-way navigation and data communications. Specifically, these front-ends are expected to leverage state-of-the-art RF materials (e.g., GaN, SiC, CMOS, etc.), packaging (e.g., MIC, SMT, etc.), device (e.g., MMIC, MEMS, etc.) and component techniques to minimize mass, volume and energy resource usage while supporting multi-functionality. In implementing these multifunction RF Front-Ends, we must note that there are three key functions embedded within these front-ends that require further development:
    - *High Efficiency Microwave Power Amplifiers* - Compact, lightweight, space qualifiable Ka-band solid-state power amplifiers (SSPAs) with integrated electronic power conditioner that can deliver an output power on the order of 10 to 20 Watts (CW) with bandwidth on the order of 1% to 2% and mass less than 1 kg is of interest to NASA. In addition, low-noise amplifiers (LNAs) with noise figures on the order of a dB or less is of interest to NASA. Since overall efficiency is of paramount importance for low dc power consumption, efficiency enhancement techniques are of interest. Furthermore, SSPAs with good linearity and capable of functioning in tandem with software defined radios (SDRs) for amplifying spectrally efficient digital modulation format signals are also of interest.
    - *Electronically Steered Antennas* - Electronically steered antennas, especially at Ka-Band, are of interest. Applications include large, high-performance electronicallysteered antennas required for a dedicated communications relay spacecraft with multiple simultaneous connections, advanced multifunction antennas to support science missions that utilize a multifunction antenna to both communicate and conduct science, and small, lightweight antennas for communications only that provide moderate gain without the use of mechanical steering. Antennas that are reconfigurable in frequency, polarization, and radiation pattern that reduce the number of antennas needed to meet the communication requirements of NASA missions are desired.
    - *Ultrawideband (UWB) Antennas and Electronics* - Recent developments in commercial chipsets and antennas that implement UWB modulation techniques are of interest to NASA. Advanced signal processing techniques that can leverage investments made in the commercial communications industry for space applications as well as UWB antennas that function in the standard NASA S/X/Ka-Band frequency ranges are of interest to NASA. This includes modulation and demodulation techniques and algorithms for UWB signal transmission and reception.

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 3-4). 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 development and measurements, including populated verification matrix from Phase I (TRL 5-6). Opportunities and plans should also be identified and summarized for potential commercialization.

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

NASA seeks revolutionary, transformational communications technologies that emphasize not only dramatic reduction in system size, mass, and power but also dramatic implementation and operational cost savings while improving overall communications architecture performance. 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.
- Technologies that address flexible, scalable digital/optical core processing topologies to support both RF and optical communications in a single terminal.
- Nanoelectronics and nanomagnetcis; 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
Lead Center: GSFC
Participating Center(s): ARC, JPL, LaRC, MSFC

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 performance improvements (SWaP-C) 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. Cubesat GN&C technologies have been moved to a new STMD subtopic: Z8.05 Small Spacecraft Avionics and Control.

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

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

Participating MD(s): HEOMD

This Focus Area seeks key capabilities and technologies in areas of Habitation Systems, Environmental Control and Life Support Systems (ECLSS), Environmental Monitoring, Radiation Protection and Extravehicular Activity (EVA) 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, and spacecraft will experience a more challenging radiation environment in deep space than in LEO. Technologies are of interest that enable long-duration, safe and sustainable deep-space human exploration with advanced extra-vehicular capability.

Habitation systems encompass process technologies, equipment and monitoring functions necessary to provide and maintain a livable environment within the pressurized cabin of crewed spacecraft. Vehicle outfitting provides the equipment necessary for the crew to perform mission tasks as well as provide a comfortable and safe habitable volume. Three of the largest logistics consumables in spacecraft include logistical packaging, clothing, and food. 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. Environmental control and life support focus in this solicitation includes aspects of atmosphere revitalization and environmental monitoring for air, water and microbial contaminants.

Advanced radiation shielding technologies are needed to protect humans from the hazards of space radiation. All space radiation environments in which humans may travel in the foreseeable future are considered, including the Moon, Mars, asteroids, geosynchronous orbit (GEO), and low Earth orbit (LEO). Radiation of interest includes galactic cosmic radiation (GCR), solar energetic particles (SEP), and secondary neutrons. Computational tools for the evaluation of the transport of space radiation through highly complex vehicle architectures as represented in detailed computer-aided design (CAD) models are needed. Processing and construction that utilize in situ resources for radiation shielding for habitation systems on Mars are of interest.

Advanced Extra-Vehicular Activity (EVA) needs include innovative, robust, lightweight pressure structures for the hard upper torso of the spacesuit, oxygen-compatible gas flow meters for in-suit operation, and advanced sensors to measure space suit interactions with the human body.

Please review each subtopic for specific details on content of interest within this solicitation.

H3.01 Habitat Outfitting
Lead Center: JSC
Participating Center(s): LaRC, MSFC

Early definition of habitat outfitting for a vehicle is important because it will influence the overall vehicle architecture and layout. Vehicle outfitting provides the equipment necessary for the crew to perform mission tasks as well as provide them a comfortable, safe and livable habitable volume. Effective and efficient human-system interfaces and interactions are critical and should be considered as an integral part of this effort and demonstrated. Integrated outfitting is often a distributed hardware set that operates in unison or independently to perform a habitation function. Outfitting includes secondary structure (e.g., floors and walls), crew structures (e.g., crew quarters, radiation storm shelters) as well as the distribution of outfitting items (e.g., crew personal items) and utilities (e.g., avionics, ventilation, lighting) to sustain the crew during a mission. Habitat features and capabilities that allow autonomous monitoring or robotic interaction of items to enable habitat outfitting (e.g., high accuracy localization systems or mounting approaches) prior to crew arrival or after crew departure are also of interest. Concepts that can reuse launch support structure for outfitting are advantageous if it can be done without significant or with no crew interaction. Concepts should be capable of outfitting habitats with diameters of 3-8 meters and lengths of 4-10 meters. Habitat atmospheric pressure may vary from 0-1 atm for launch and 0.5-1 atm during crew usage. The following habitat outfitting specific habitat outfitting areas are requested.

Interior Structures

Deployable, inflatable, 3D printable from processed launch packaging, reusable secondary structure, and crew structures for outfitting the vehicle habitable volume. Concepts should not be constrained to the ISS rack geometry or attachments. Concepts must be volumetrically and mass efficient, and have a metric less than 25 kg/m^3 for an enclosed volume. Proposed technologies that provide a surface area (e.g., floor) or utility (e.g., plumbing) should define a normalized metric (e.g., kg/ m^2 or kg/m/plumbing run). The selection of non-metallic materials is very important in a spacecraft and will need to meet off-gassing and flammability requirements. Concepts should also have surfaces that either resist the accumulation of dust and dander or are readily cleanable. Structures should include appropriate factors of safety and assumptions should be included in the proposal. Concepts should be capable of sustaining launch loads (which can be in a stowed configuration) of 6g axial and 2g lateral. Crew structures must be capable of withstanding crew kick loads of 125 lbs when fully deployed. Concepts that are also applicable to habitat and life support equipment mounting are desirable.

Autonomous Outfitting Capabilities

Development of features and systems are required that can enable habitat structures, crew equipment, logistics, and trash to be interacted with autonomously with no direct crew involvement. Requested capabilities are rapid identification, localization in 3D space (including pose or orientation), and interaction with items. The intent is to allow robotic interaction with items prior to crew arrival and after crew departure. This may include deployment of interior structures, maintenance of the habitat, or monitoring of the habitat including health and status of items. Systems may also enable or facilitate human-machine interactions by providing greater situational awareness. Development of the robotic elements themselves are excluded from this subtopic. Mechanisms, electro-mechanical, and software applications and algorithms that enable autonomous outfitting and maintenance capability are requested. Dependencies on batteries are highly undesirable. Concepts that provide significant automated vehicle health monitoring should consider submission to the 'Autonomous Systems' topic.

Additional information on NASA needs can be found in 2015 NASA Technology Roadmaps including but not limited to sections TA06 6.1.4.2 and TA07 7.2.1.3, 7.2.1.7, 7.2.1.9, 7.4.1.1, and 7.4.1.3. These roadmaps are available at the following link: (http://www.nasa.gov/offices/oct/home/roadmaps/index.html). An example of an inflatable habitat can be found at (http://www.nasa.gov/content/bigelow-expandable-activity-module). Examples of conference papers on habitat outfitting and crew structures (TransHab, ISS Crew Quarters, Waste and Hygiene Compartments, Multipurpose Cargo Bags) can be found at the Internal Conference on Environmental Systems and the AIAA Space Conference websites. Human Research Program (HRP)-related research on Habitable Volume and Habitat Design can be found at the following link: https://humanresearchroadmap.nasa.gov/risks/risk.aspx?i=162. Other related risks can be found at the following link: https://humanresearchroadmap.nasa.gov/explore/.

Phase I Deliverables - Detailed analysis, proof of concept test data, and predicted performance (mass, volume, positioning accuracy). Deliverables should clearly describe and predict how performance of targeted habitat vehicles are enhanced, improved, or integrated. Evaluation of concepts for human-system performance should be predicted.

Phase II Deliverables - Delivery of technologically mature components/subsystems that demonstrate deployments and/or automated features are required. Prototypes must be full scale unless physical verification in 1-g is not possible. Consideration of recovery from deployment failures should be included. Ability to sustain launch loads and on-orbit crew loads needs to be demonstrated. Evaluation of concepts for human-system performance should be validated with modeling as a minimum and demonstrated where possible.

H3.02 Environmental Monitoring for Spacecraft Cabins
Lead Center: JPL
Participating Center(s): ARC, JSC, MSFC

Environmental Monitoring is comprised of the following four monitoring disciplines: air, water, microbial and acoustics. ISS has employed a wide variety of analytical instruments to deal with critical items. These functional needs are required to address identified risks to crew health during Exploration-class missions. The current approach onboard ISS, if any, will serve as the logical starting point to meeting the functional needs. However, the following limitations were found common to all the current approaches on-board ISS for any missions beyond low-Earth orbit (LEO): reliance on return sample and ground analysis, require too much crew time, constraints on size, mass, and power, lack of portability, and insufficient calibration life. Hence a concerted effort is underway to address these gaps and mature those solutions to ground and flight technology demonstrations. Technologies that show improvements in miniaturization, reliability, life-time, self-calibration, and reduction of expendables are of interest.

In-Line Silver Monitoring Technologies

NASA is interested in sensing technologies for the in-line measurement of ionic silver in spacecraft potable water systems. Overall, the sensing technology should offer small, robust, lightweight, low-power, compatible design solutions capable of stable, continuous, and autonomous measurements of silver for extended periods of time. Sensors of particular interest would provide: Continuous in-line measurement of ionic silver at concentrations between 0 and, at least, 1000 parts per billion (ppb); A minimum detection limit of 10 ppb or less; Measurement accuracies of at least 2.5% full scale (1000 ppb); Stable measurements in flows up to 0.5 L/min and pipe diameters up to ¾ inch; High sampling frequency, e.g., up to 1 measurement per minute; Stable calibration, greater than 3 years preferred; Minimal and/or no maintenance requirements; Operation at ambient temperature, system pressures up to 30 PSIG, and a solution pH between 4.5 - 9.0; A volumetric footprint less than 2000 cubic centimeters; Input/output signal(s) capable of interfacing with small embedded controllers, e.g., 4-20 mA or 0 – 5 V. In addition, the sensing technology should have a little to no impact on the overall volume, portability and concentration of silver being maintained within the spacecraft water system.

Sample Processing Module for the ISS Microbial Monitors

NASA continues to invest in the near- and mid-term development of highly-desirable systems and technologies that provide innovative ways to monitor microbial burden and enable to meet required cleanliness level of the closed habitat. To date, developing sample collection module and sample detection PCR systems such as RAZOR, Wet-lab 2 systems are planned for surface, water, and air. The sample collection and sample concentration modules are being developed but biomolecule (DNA, protein, etc.) processing and subsequent sample transfer modules that could deliver biological materials to the sample detection systems (PCR, microarray, sequencers, etc.) are not matured. More importantly, the future sample processing/transfer module should be compatible with existing NASA sample detection PCR systems. NASA is interested in an integrated sample collection/concentration/extraction system that could feed samples to conventional or molecular microbial monitoring techniques.

The scope of this solicitation is the sample processing and sample transfer systems. Furthermore, integration of sample collection, concentration steps and a sample delivery to the molecular instruments (such as PCR) as a single module is solicited.

Required technology characteristics include: 2-year shelf-life and functionality in microgravity and low pressure environment (~8 psi). Technologies that show improvements in miniaturization, reliability, life-time, self-calibration, and reduction of expendables are also of interest. The proposed integrated sample collection/concentration/extraction delivery system for molecular microbial monitoring detection should be capable of collecting all kinds of microorganisms as well as identifying "problematic" microbial species on-board ISS (ISS MORD: SSP 50260; http://emits.sso.esa.int/emits-doc/ESTEC/AO6216-SoW-RD9.pdf). Existing PCR systems are: Biofire's Razor (http://biofiredefense.com/razorex/) and Cephied's Smart Cycler (http://www.cepheid.com/us/cepheid-solutions/systems/smartcycler).

Hydrazine Measurement Technology

NASA currently has hydrazine measurement technology that is sensitive, selective, and reliable – but the time to make the measurement is relatively slow. It takes 15 minutes to collect and analyze a sample. This is operationally acceptable for the current operational environment, but future missions will likely need a hydrazine measurement capability that responds more quickly. The primary use of the Hydrazine Monitor is for measurements of spacecraft cabin atmosphere. NASA is especially interested in systems with the following performance parameters:

- Hydrazine lower detection limit of 1 ppm when measured in STP conditions.
- Ammonia / hydrazine selectivity ratio of 25:1 or better (e.g., background concentrations of 50ppm ammonia will measure as no more than 2 ppm hydrazine).
- Response time (T90) or 30 seconds or faster.
- Measurement range of 1 ppm to 1000 ppm.
- Instrument size smaller than 2500 cubic centimeters.

H3.03 Environmental Control and Life Support
Lead Center: JSC
Participating Center(s): ARC, GRC, MSFC

Spacecraft Cabin Carbon Dioxide Removal

NASA currently has CO_2 removal and capture systems that are compact and effective, but future missions may require CO_2 capture technology that control to lower levels, and operate with greater power efficiency. NASA is especially interested in systems with the following performance parameters:

- Removal rate of 4 kg/day.
- Operate in an environment with 1.5 mmHg $ppCO_2$.
- System size 0.3 cubic meters.
- System power use 500 watts of power.
- Effectively separate out water vapor (less than 100 ppm water vapor in the CO_2 product is desired).

Oxygen Separation from Air

NASA mission planners envision future mission scenarios that require oxygen separation from spacecraft cabin air. New technology developments show promise for reliable, low power performance. System safety, and the ability to easily verify oxygen product purity are especially important. Reliable operation without service or repair is key, but many R&D designs cannot report Mean Time Between Failure. If MTBF data is not available, an assessment of reliability should be provided. Although pressurization of product oxygen is not the intent of this call, future requirements for oxygen delivery pressure are variable, depending on mission scenario: some scenarios use ambient pressure (<5psig) oxygen, while other scenarios intend to store oxygen at pressures as high as 3600 psig. NASA is interested in systems with the following performance parameters:

- Production rate: 15 slpm.
- Power use: ≤450 W (30 Watts/liter).
- Sound level: <45 dB.
- System size: 0.03 cubic meters (200 cc/liter).

Carbon Repurposing

Several oxygen recovery technologies currently under consideration for future long-duration missions involve production of solid carbon. For technologies whose goal is to maximize oxygen recovery by producing this carbon, approximately 1 kg of solid carbon must be disposed of or repurposed daily for a crew of four. Repurposing this carbon will reduce logistical challenges associated with disposal and will ultimately result in materials or processes advantageous to long-duration missions.

The carbon product includes nanofibers, microfibers, and amorphous carbon. It may contain quantities of metals including, but not limited to iron, nickel, and cobalt. Venting or disposal of this carbon to space will present considerable logistical challenges and will result in large volumes of space debris. Disposal of this carbon on a planetary surface may result in concerns for Planetary Protection or science. NASA is seeking technology and/or processes that repurpose solid carbon and its contaminants and that result in useful products for transit, deep space, or planetary surface missions.

Filtration of Particulate Carbon and Hydrocarbons from Process Gas Streams

Oxygen recovery technology options almost universally result in particulates in the form of solid carbon or solid hydrocarbons. Mitigation for these particulates will be essential to the success and maintainability of these systems during long duration missions.

Techniques and methods leading to compact, regenerable methods for removing residual particulate matter generated from Environmental Control and Life Support (ECLS) system process equipment such as carbon formation reactors and methane plasma pyrolysis reactors is desirable for long-duration manned life support. Filtration performance approaching HEPA rating is desired for ultrafine particulate matter with minimal pressure drop. The gas filter should be capable of operating for hours at high particle loading rates and then employ techniques and methods to restore its capacity back to nearly 100% of its original clean state through in-place and autonomous regeneration or self-cleaning operation. The device must minimize crew exposure to accumulated particulate matter and enable easy particulate matter disposal or chemical repurposing.

Solid State Microwave Generator for Environmental Control and Life Support

Many possible future technologies for human spaceflight may utilize microwave energy, including plasma pyrolysis of methane, incineration and solid waste drying, and ovens for food heating. Traditional microwave generating systems have significant inefficiencies resulting in a high mass, high volume power system. Solid state microwave generators have the potential to limit the total mass and volume of a microwave power system. However, limited advancement has been achieved at power levels of 1kW and higher.

NASA is seeking solid state microwave generators with the following capabilities:

- Microwaves generated and controlled at 2.38-2.54GHz (nominally 2.45GHz).
- Maximum output power level capability of 1-5kW.
- Variable power output over entire range (0-max kW).
- Input power of 120VDC.
- Efficiency greater than or equal to 50%.
- Method of measuring/monitoring output power.
- Method of measuring/monitoring reflected power.
- Method of dispersing/absorbing reflected power up to maximum output power.
- Utilizes non-air cooling method (e.g., liquid cooling).

H3.04 Logistics Reduction
Lead Center: JSC
Participating Center(s): ARC, LaRC

All human space missions, regardless of destination, require significant logistical mass and volume that is directly proportional to mission duration. As our exploration missions increase in distance and duration, logistics reduction becomes even more important since they may need to be pre-deployed 2-5 years before a crew arrives. Reducing the initial mass and volume of supplies, or reusing items that have been launched, will be very valuable. Logistics unique to a spacecraft system (i.e., life support and propulsion) are not addressed by this subtopic and are not requested. Three of the largest logistics consumables are the logistical packaging (e.g., cargo bags, foam, retention straps, and cargo support pallets), clothing, and food. Approximately 1,000 cargo bags (0.053 m3 each) may be required for a Mars mission's logistics. Cargo is typically packed in foam, placed in a bag, and strapped to the vehicle or a cargo pallet/structure in the vehicle. Clothing is currently disposed of on the Space Station when it becomes too dirty to wear because there is no way to clean it. Food nutritional content and quality decreases over time and depends on the specific nutrients, food matrix, food packaging, and storage environment. Food may need to be stored up to five years before consumption, and maintaining stable nutrition is a significant challenge. Reductions in food mass, nutrient studies, and nutrient generation are not requested as part of this subtopic. All proposals should consider maintainability as well as dormancy periods without crew.

Vehicle Level Cold/Alternate Atmosphere Food Storage

Innovative use of materials, insulation, and heat removal systems are requested. Standalone systems as well as innovative approaches integrated into portions of the vehicle structure and thermal loops are acceptable. One method of increasing food nutrient shelf-life is with cold stowage and/or alternate atmospheres (i.e., low oxygen composition). Stored food volumes of 2-8 m^3, with average packaged food density of 250-500 kg/m^3, may be required at temperature ranges of -80° to +20°C. Oxygen levels <21% and food compartment pressures less than one atmosphere are being studied for their effects. Ability to control the atmosphere and pressure in the cold stowage volume is beneficial but is not required of a submitted technology, nor is the full temperature range listed above required. Systems must be capable of surviving launch loads (6g axial and 2g lateral) when fully loaded and be capable of autonomous operation for up to five years in microgravity. Concepts must be volumetrically efficient, mass efficient, and highly reliable since loss of food quality can result in loss of crew performance. The advantages of proposed concepts compared to the ISS Refrigerator/Freezer Rack (RFR) and terrestrial high efficiency freezers must be described. The ISS RFR, which never flew but achieved temperatures of -22°C and +4°C in freezer and refrigerator modes, had a secondary mass penalty of 1.36 kg for every 1 kg of food due to cabinet, drawers, insulation, cooling system and rack masses. (NASA/TP-2015–218570) The goal is to lower this secondary mass penalty for cold stowage below 0.2 kg per 1 kg of food. For long term storage of food, drawers are not required. At the same time, the refrigeration and insulation systems should be efficient enough to run (at steady state) on less than 0.15 Watts per kg of food frozen at -22°C in a 23°C ambient.

Alternative Launch Packaging of Logistics and Cargo

Alternatives to the existing ISS use of Cargo Transfer Bags (CTBs), foam, straps, and cargo pallets is required. Cargo densities of 510 kg/m3 (single CTB capability) must be supported during launch acceleration of 6g axial and 2g lateral. Total packaging mass efficiencies of all required materials between the cargo and the vehicle pressure shell structure should be less than 0.3 kg packaging/kg of cargo. Concepts should be capable of scaling between logistics vehicles with diameters of 3-8 meters and lengths of 4-10 meters. Logistics vehicle atmospheric pressure may vary from 0-1 atm for launch and 0.5-1 atm during crew use.

Innovative Crew Clothing Systems to Extend Duration of Wear

Innovative systems that refresh crew clothing to extend the duration of wear are requested. Crew exercise clothing, for example, is currently discarded into the trash after 2-3 uses because there are no space laundry systems. The goal is to extend the duration of wear by 2-3 times or more for several types of garments. Systems must be capable of sanitizing/refreshing a small set of crew clothing that includes exercise t-shirts, exercise socks, exercise shorts, male and female undergarments, and male and female daily wear, such as crew polo shirts. The system should provide odor control while preserving the appearance, color and brightness, and the physical and mechanical properties of the fabrics, which include cotton, wool and modacrylic. Odor control can be through absorption, adsorption, denaturation, or neutralization of pH and odorous compounds, etc. Innovative use of technologies, such as ultraviolet light, microwaves, vacuum, ozone, steam, CO_2, charcoal filtration, minimal water, or other technologies will be considered. The crew clothing sanitizing/refreshing system must be capable of operating for a minimum of 3 years in microgravity with minimal consumables, crew time requirement and electrical power. Cleaning/washing agent should be limited to less than 10 grams of consumables per kg of crew clothing for each refresh. No water or extremely low water usage systems are preferred, but if water is used, water usage should be less than 200 grams per kg of clothing washed. No hazardous gases or particles can be released into the crew atmosphere during or after operation. Concepts must be volumetrically efficient, mass efficient, not adversely impact the closed loop life support systems, and be highly reliable. Cleaning/washing systems may be used during outbound transit to Mars, then be dormant for up to 18 months prior to the return trip to Earth. Controlling microbial activity and odor during this dormancy is important to habitat and crew health.

Additional information on NASA needs can be found in NASA Technology Roadmaps including but not limited to sections TA06 6.1.4.11 and TA07 7.2.1.9. These roadmaps are available at the following link: (http://www.nasa.gov/offices/oct/home/roadmaps/index.html). Examples of conference papers on refrigeration technologies such as Merlin, and the ISS Refrigerator Freezer Rack can be found at the Internal Conference on Environmental Systems, and food storage issues are described in the Human Research Program Investigators Workshop. Specific references include: Winter, J., Zell, M., Hummelsberger, B., Hess, M. et al., "The Crew Refrigerator/Freezer Rack for the International Space Station," SAE Technical Paper 2001-01-2223 and http://www.nasa.gov/mission_pages/station/research/experiments/MERLIN.html

Phase I Deliverables - Detailed analysis, proof of concept test data, and predicted performance (mass, volume, thermal performance). Deliverables should clearly describe and predict performance over the state of the art.

Phase II Deliverables - Delivery of technologically mature components/subsystems that demonstrate deployments and/or automated features are required. Prototypes should be full scale unless physical verification in 1-g is not possible. Ability to sustain launch loads and on-orbit crew loads needs to be demonstrated. A minimum of 2 months of cold stowage/alternate atmosphere performance should be demonstrated if relevant.

H4.01 Damage Tolerant Lightweight Pressure Structures
Lead Center: JSC

Damage to and the resultant leakage of the suit structure is a criticality 1 failure that could result in loss of mission or life. NASA is striving to build a robust suit structure that can withstand the wear and tear related to exploration of a planetary surface. A highly mobile exploration spacesuit must have lightweight and robust hard upper torso. Hard upper torsos are used on the current Extravehicular Mobility Unit systems and desirable for the future because they are robust structures that require little maintenance, they provide simple and robust interfaces with the portable life support system, and they create a consistent and well sized structure for the mobility joints.

On recent development of the Z-2 space suit, NASA evaluated the use of carbon fibers, fiberglass, and kevlar composite structures to push the state of the art for a complex geometry, lightweight, and damage tolerant hard upper torso structure. Development included evaluation of various lay-ups, material combinations, and polymer systems. The end product was a hybrid composite structure of carbon and fiber glass composite. The hybrid structure was able to withstand impact energies around 100J.

NASA is interested in developing an innovative, new structure that is even more robust to impact and can maintain a low leakage level or re-seal the pressure structure after impact or damage. Hybrid laminates, materials, and construction methods should be considered to optimize toughness and damage tolerance (strength and durability). Special consideration should be given to select materials and configurations which lend themselves to manufacturability to complex shapes and repair-ability. NASA has also investigated the use of thin films on pressure vessels to make a composite structure more robust to damage and leakage. Mechanical strength of the selected materials should be characterized in both the "pristine" and "damaged" (after impact) condition, including Tension, Compression, and Interlaminar shear.

Performance targets:

- No leakage after Low Velocity Impact (LVI) of 300J of energy using ASTM D-7136 impact test with 2" diameter steel impactor and impact velocities of less than 15 ft/s.
- Structure density of less than 1.7 g/cm3.
- Primary structure and sample thickness of 0.125" or less.

Reference:

Ross, A., Rhodes, R., Graziosi, D., Jones, B., Lee, R., Haque, B., and Gillespie Jr., J., "Z-2 Prototype Space Suit Development", ICES-2014-091, 44th International Conference on Environmental Systems, Tucson, AZ, July 2014.

H4.02 Small, Accurate Oxygen Compatible Gas Flow Meter for Suit Operations
Lead Center: JSC

The current state of the art for flow measurement on the current ISS Extravehicular Mobility Unit (EMU) space suit is a flapper valve tied to a microswitch. The current EMU flapper valve technology only supports microgravity EVAs (single flow rate requirement) with a sufficient versus non-sufficient flow measurement capability. With the multi-mission goals of the advanced space suit, variable flow rates are required. Therefore, the goals for the required flow meter include accurate measurement of 2-8 acfm ± 1% with a pressure drop requirement of less than 0.68 in-H_20 in a pure oxygen (O_2) environment. This flow meter needs to also fit within a volume/shape factor of approximately 2.5 in x 1.5in x 3in or less. An innovation is required since currently available flow meters do not meet these specifications.

The Portable Life Support System (PLSS) capable of supporting planned exploration missions is capable of adapting between varied Space Suit Assembly (SSA) architectures that are optimized for micro-gravity Extra-Vehicular Activities (EVAs) from vehicles such as the International Space Station (ISS) to rear-entry walking suits suitable for operation on the lunar and Martian surfaces. The varied suit designs and associated crewmember exertion within the suits under micro-gravity to partial gravity require the ability to vary the suit ventilation flow rate and also to vary the monitoring/alarming for the selected ventilation flow rates. This limits the application of existing flapper-microswitch style low pressure drop flow switches and requires application of technologies such as flow/pressure drop measurements or thermal mass flow measurements. One of the most constraining requirements is the low permissible pressure drop as the flow measurement has been integrated as a measured pressure drop across the ventilation loop heat exchanger 0.68 +/- 0.07 in-H_2O with ventilation gas flow at 6 acfm (170 lpm) and suit pressure of 4.3 psia and 60°F and 100% O_2 (traces of NH_3, H_2O, CO_2); the allocation of differential pressure (DP) will be ~0.5 in-H_2O should the measurement not be acquired across an existing pressure drop in the system. Evaluation of commercial off-the-shelf (COTS) DP sensors has yielded units that are either too large or orientation/vibration sensitive as this hardware needs to operate and tolerate up to 2 grms Grms vibration during operation and >9 grms Grms while stowed.

Volume/shape factor is approximately 2.5 in x 1.5 in x 3 in or less including fluid ports and electrical connectors; if added as an in-line flow, 1 in inlet/outlet porting will be necessary. The absolute pressure range with 100% oxygen is up to 25 psia; the optimal choices would include materials not considered flammable in this environment to reduce compatibility issues with things such as kindling chain ignitions of human generated debris. A thermal mass flow measurement would also seek to minimize the energy input and operating temperature above the core stream temperature to further improve oxygen compatibility. The measurement range for the sensor is 2-8 acfm +/- 1% with 100% O_2, suit pressure from 3.5-25 psia, temperature from 50-90°F, RH 0-50%, and CO_2 from 0-15mmHg. The sensor must also tolerate low dose rate to 30 krad as well as high energy particles to 75 MeV-cm^2/mg without destructive Single Event Effects (SEE) such as latchup, gate rupture, burnout, etc. The ambient operating environment will range from sea level conditions to vacuum with ambient thermal sink ~50°F. Operating life will need to be 8 years without calibration and 5000 hrs of powered operation.

H4.03 Sensors to Measure Space Suit Interactions with the Human Body
Lead Center: JSC
Participating Center(s): JSC

Space suits can be tested unmanned for range of motion and joint torque in an attempt to quantify and compare space suit joint designs and overall suit architecture. However, this data is irrelevant if humans using the suits aren't effective. Characterizing human suited performance has continued to be a challenge, partly due to limitations in sensor technology. One concept is to use sensors placed at/on the human body, underneath the pressure garment to obtain knowledge of the human bodies movements. This data could then be compared against the suit motion. Various sensors, sensor technologies, and sensor implementations have been attempted over two decades of efforts, but each has had issues. Previous efforts have used Force Sensitive Resistors (FSR), TouchSense shear sensors, pressure-sensing arrays (Tek scan etc.), piezo-electric sensors, among others but have not met all requirements. Most issues have centered around accuracy when placed on the pliant surface of the skin, and accuracy when placed over curved surfaces of the skin. Accuracy has been sufficient to delineate low, medium or high levels of force but not a reliable quantitative value. This, combined with aberrant readings when the sensor is bent has led to these sensors only providing a rough idea of the interaction between the suit and the skin: while in a controlled environment the sensors are accurate to within 10% or so, the accuracy falls significantly when measuring the skin and being bent or pressed in inconsistent ways; on the order of 50% accuracy or worse. The sensors also are prone to drift (falling out of calibration) quickly during use. Lastly, the sensors, while pliant, are still relatively thick and as such translates to discomfort and loss of tactility. This is typical during all previous testing but most notable when sensors are bent along an axis (or worse, along two axis such as required to follow a complex anatomical contour). As such, the effect on the suit/skin interface that is being measured is changed, which adds an additional complication to interpreting data output from these sensors. Much of the work within JSC has improved the integration, comfort, and calibration of these sensors, but the accuracy performance characteristics when in use have not been sufficient to meet requirements. A new sensor technology is warranted for use in our application.

Current critical needs that this technology would enable include the ability to optimize suit design for ergonomics, comfort and fit without the sole reliance on subjective feedback. While subjective feedback is important, developing a method to quantify the amount of force or pressure on a particular anatomical or suit landmark will aid in providing a richer definition of the suit/human interface that can be leveraged to make space suits more comfortable while reducing risk of injury. Taken together, these improvements will enhance EVA performance, reduce overhead and reduce personnel and programmatic risk. This technology implementation would require relatively accurate pressure or force readings in the medium to high range.

In the future, alternative space suit architectures such as mechanical counter pressure may be feasible, and a critical ancillary to such an architecture is to verify that necessary physiological pressure requirements are being met to ensure the health and safety of the crew. To this end, the technology should be able to accurately measure mechanical pressure on the human skin in the low pressure (< 10 psi) range.

Performance targets vary upon application, but the sensing technology should have the following characteristics:

- Measures force and/or mechanical pressure.
- Accurate to within 10%.
- Resistant to aberrant readings when under moderate bending, shear or torsion.

- Either sufficiently pliant, or high enough spatial resolution, to follow anatomical curves on the human skin without discomfort or lack of mobility.
- Thin profile (~mm).
- Packaged at high spatial resolution (~cm) or sufficiently small to facilitate a custom packaging/substrate solution with a high spatial resolution.
- Free of rigid or sharp points that would cause discomfort.
- Low power (~5V, ~mA).
- Capable of integration to the inside of the pressurized suit surface as well as the human skin (or integrated to conformal garment).
- At this early stage, a simple digital readout capability to evaluate sensor performance.

For this SBIR opportunity specifically, we are looking for a single sensor technology that targets the above requirements including readout capability. They should either be packaged into a component level prototype (shoulder or arm segment with multiple sensors) or a flexible packaging option (multiple sensors that could be integrated ad-hoc into a component level prototype through placement of said sensors on the skin or comfort garment).

The most attention should be paid to maximizing spatial resolution, accuracy and thinness for this prototype. Lastly, as previous work has demonstrated a relatively high failure rate of these sensor types over time, the individual sensor elements should be replaceable and/or spares should be provided.

H6.01 Integrated System Health Management for Sustainable Habitats
Lead Center: ARC
Participating Center(s): JSC, MSFC
Related Subtopic Pointers: T6.01, T6.03

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 photo-voltaic 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.

Proposals that address lower TRL research on the foundational principles of sustainable technologies and systems involving academic partnerships should consider responding to STTR subtopic T6.01 - Closed-Loop Living System for Deep Space ECLSS with Immediate Applications for Sustainable Planet. Proposals that address bio-manufacturing research may also consider the STTR subtopic T7.01 - Advanced Bioreactor Development for in-situ Microbial Manufacturing. For integrated system health management and monitoring capabilities that support these systems, respondents are encouraged to consider the currently listed subtopic - H6.01 - Integrated System Health Management for Sustainable Habitats.

H11.01 Radiation Shielding Technologies for Human Protection
Lead Center: LaRC
Participating Center(s): JSC, MSFC

Advanced radiation shielding technologies are needed to protect humans from the hazards of space radiation during future NASA missions. All space radiation environments in which humans may travel in the foreseeable future are considered, including the Moon, Mars, asteroids, geosynchronous orbit (GEO), and low Earth orbit (LEO). All particulate radiations are considered, particularly galactic cosmic radiation (GCR), solar energetic particles (SEP), and secondary neutrons.

For this 2017 solicitation, technologies of specific interest include, but are not limited to, the following:

- Computational tools that enable the evaluation of the transport of space radiation through highly complex vehicle architectures as represented in detailed computer-aided design (CAD) models are needed. The needed tools are the following:
    - An easy way to manipulate metadata for CAD or CAD-derived geometries, such as materials and densities for input into radiation transport codes;

  - A general method of scoring/tallying that can be equated across multiple radiation transport codes and validating these equivalencies;
  - A general method/interface of radiation transport problem setup that can be used for many different radiation transport codes. This would include (1) and (2) above, as well as allow for radiation source selection for various spectral and special distributions common to space radiation problems, provide this setup data to create input files for many different radiation transport codes (HZETRN, PHITS, FLUKA, GEANT4, etc.), and provide error checking for incompatible user inputs;
  - Provide a tool for visualizing vast numbers of complex radiation transport data sets allowing the user to evaluate quickly scored/tallied parameters in the context of the three-dimensional geometry used in the problem setup. The tool should also be able to move quickly through any or all parameters that were scored/tallied in the problem setup. Phase I deliverables are alpha-tested computer codes. Phase II deliverables are beta-tested computer codes.
- Processing/manufacturing/construction technologies for habitation that utilize in-situ resources (atmosphere, water, regolith, etc.) for radiation shielding on Mars are also of interest. Phase I deliverables are detailed conceptual designs. Phase II deliverables are initial prototypes.
- Credible "out-of-the-box" solutions for space radiation shielding. This could include passive or active radiation shielding solutions. Phase I deliverables are detailed conceptual designs. Phase II deliverables are initial prototypes.

Focus Area 7: Human Research and Health Maintenance

Participating MD(s): 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, technologies, and tools 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 IRP illustrates the program's research plan through the timescale of early lunar missions of extended duration. 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.
- Behavioral Health & Performance.
- Exploration Medical Capability.
- Space Human Factors and Habitability.
- Space Radiation and 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. With the exception of Space Radiation, 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
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 and cataracts (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.

This subtopic will consider:

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

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.

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 cancer, 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.

H12.02 Advanced Model-based Adaptive Interfaces and Augmented Reality
Lead Center: JSC
Participating Center(s): ARC, JPL, KSC, MSFC
Related Subtopic Pointers: A3.01

NASA is seeking innovative solutions for the design of adaptive interfaces for complex information systems that will be used on autonomous missions by crewmembers in various states of workload, stress, and fatigue.

Adaptive user interfaces, also called intelligent user interfaces, can decrease workload in cases of high attentional loads by presenting the information needed in simpler forms or in different formats. For example, to decrease attentional load, the interface may be modified from text to icons, or the interaction may change from written procedures to voice commands. There is evidence that workload can be reduced if some of the visual information is presented in a different modality or format in high attentional demand situations. Adaptive user interfaces can also provide displays that offer improved and optimized navigation tailored for the current state of the user. Interfaces can be augmented with visual and auditory elements that, again, adapt based on the needs of the user. Thus, the adaptability of the interface is increased in a different dimension. The augmented reality (AR) technology holds the promise to improve crew performance to execute complex procedures in a deep-space human spaceflight missions where communication back to the Earth-based mission control is limited and delayed.

In Phase I, a proof-of-concept prototype for an adaptive interface system with augmented reality should be developed and tested for a high workload (e.g., fault management or critical time constraints) scenario. The work should include a literature review on the effects of modality (visual, auditory, tactile, and combination of these) and format (e. g., text, icons, graphs) on workload. A model should be developed based on these principles, as well as an adaptive interface framework for a selected system used for spaceflight. Example scenarios and displays will be provided by NASA for this purpose. Model inputs can be simulated or emulated with hardware. The key technology areas are image registration, new software approaches to integrate augmented reality content from multimedia and multiple modalities, fusion of vision, human tracking, and integration of digital data with live sensor data and models.

In Phase II, the prototype adaptive interface system with augmented reality should be designed and validated for the selected high workload use case, as well as a procedure-based task. Display components should dynamically change as a function of the cognitive state and the level of expertise of the operator. The cognitive states (stress, fatigue, and workload) do not need to be measured or prototype; they can be simulated with various levels and treated as input parameters to the prototype. The usability of the prototype should be tested, including trigger events and timing of adaptation.

The team should include expertise on augmented reality, interface design, task analysis, and workload.

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 including source code for NASA testing.

This technology will support NASA's Human Spaceflight Architecture Team List of Critical Technologies, including HAT 4.7.a-E Crew Autonomy Beyond LEO (systems and tools to provide the crew with independence from Earth-based ground support) and HAT 6.3.e-E Deep Space Mission Human Factors and Habitability (human factors technology in design).

For proposers who may be interested in applying these concepts to Aeronautics systems, please see Subtopic A3.01 - Advanced Air Traffic Management Systems Concepts.

Focus Area 8: In-Situ Resource Utilization

Participating MD(s): HEOMD

As terrestrial explorers and settlers learned to use local resources for provisions, shelter, and fuel to stay alive and prosper, so too must future human explorers learn to live off the land and use the resources found in space. Known as In Situ Resource Utilization (ISRU), this approach to exploration 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. By using and converting local resources into products, less material needs to be launched from Earth. The ability to make life support consumables (oxygen, nitrogen, and water), propellants for ascent and space transportation vehicles, and fuel cell reactants for energy generation and storage have the biggest influence on launch mass, crew and mission risk, and cost in current human exploration mission plans. These products 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 and providing increased self-sufficiency, and reduce costs by needing less launch vehicles to complete the mission and/or through the reuse of hardware and lander/space transportation vehicles.

The ISRU Focus Area in this year’s solicitation will concentrate on how to acquire carbon dioxide and water from the Mars atmosphere and soil resources. Because understanding resource characteristics is extremely important to designing larger scale systems to extract and process these resources, the ISRU Focus Area will also emphasize the need for small payloads to perform this task on future lunar missions.

H1.01 Mars Atmosphere Acquisition, Separation, and Conditioning for ISRU

Lead Center: JSC

Participating Center(s): ARC, GRC, JPL, KSC, LaRC, MSFC

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. Proposals must consider and address operating life issues for Mars surface applications that can last for up to 480 days of continuous (day/night) operation. All proposals need to identify the State of the Art of applicable technologies and processes. Hardware to be delivered at the conclusion of Phase II will be required to operate under Mars surface pressure, atmosphere constituent, and temperature conditions. Therefore, thermal management during operation of the proposed technology will also need to be specified in the Phase I proposal. Requirements and specifications for Mars surface conditions and soil properties can be found in the ISRU Topic Description. Phase I proposals for innovative technologies and processes must include the design and test of critical attributes or high risk areas associated with the proposed technology or process. Proposals will be evaluated on mass, power, complexity, and the ability to achieve hardware specifications below.

Technologies are sought for collection and compression of Mars atmosphere gases for subsequent processing into oxygen and possibly fuel. Based on redundancy and production margin assumptions (40% of total production rate), carbon dioxide in the Mars atmosphere must be acquired and compressed to a minimum of 103.4 KPa (15 psi) pressure and up to a desired 517.1 KPa (75 psi) at a rate of 0.6 kg/hr for oxygen and fuel production and 2.7 kg/hr for oxygen production alone. Multiple units are allowed, but should be justified based on overall mass, power, thermal, and/or operation duration requirements. Understanding the change in mass, power, volume, and complexity as a function of outlet pressure is also an important factor in selection. Since carbon dioxide is the main gas of interest, techniques and technologies that separate the carbon dioxide from the other gases in the Mars atmosphere before, during, or after compression are considered beneficial in the selection process. Proposers should consider but not be limited to past work on Mars atmosphere collection, separation, and compression technologies such as carbon dioxide freezing, rapid cycle adsorption pumps, and mechanical compressors. For concepts that separate carbon dioxide from other Mars gases at Mars atmosphere pressures, proposers must include an active flow device to ensure the remaining gases do not prevent further separation and collection of the carbon dioxide. Proposals should consider the impact on atmosphere flow to overcome flow resistance due to filtration devices that will need to be placed at the inlet. 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. Since downstream carbon dioxide processing technologies are performed at a minimum of 400°C, cooling of the compressed gas to below this temperature is not required for downstream operations.

Technologies are sought for separation of nitrogen and argon from the Mars atmosphere during or after Mars carbon dioxide separation and compression. Mars atmosphere gas flow rates, pressures, and temperatures are as specified above for Mars atmosphere/carbon dioxide compression. 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. All proposals need to identify the State of the Art of applicable technologies and processes. At this time, it is not known whether the nitrogen and argon will be stored as a pressurized gas or a cryogenic liquid, so it should be noted which storage option is more beneficial for the proposed technology.

H1.02 Mars Soil Acquisition and Processing for In-Situ Water
Lead Center: JSC
Participating Center(s): ARC, GRC, JPL, KSC, LaRC, MSFC

Innovative technologies and approaches are sought related to ISRU processes associated with excavating and processing soils on Mars to remove, collect, and clean in-situ water for subsequent use in oxygen and fuel production or delivery to the habitat for life support and radiation shielding usage. Proposals must consider and address operating life issues for Mars surface applications that can last for up to 480 days of continuous (day/night) operation. All proposals need to identify the State of the Art of applicable technologies and processes. Hardware to be delivered at the conclusion of Phase II will be required to operate under Mars surface pressure, atmosphere constituent, and temperature conditions. Therefore, thermal management during operation of the proposed technology will also need to be specified in the Phase I proposal. Requirements and specifications for Mars surface conditions and soil properties can be found in the ISRU Topic Description. Phase I proposals for innovative technologies and processes must include the design and test of critical attributes or high risk areas associated with the proposed technology or process. Proposals will be evaluated on mass, power, complexity, and the ability to achieve hardware specifications below.

Technologies are sought for excavation and transfer of hydrated and icy Mars soils. For hydrated soils, the excavated soil can be delivered to a centralized soil processing plant or processed on the excavation rover itself. The amount of water content in the hydrated Mars soil can vary from as low as between 1.5 and 2% on the surface at almost all locations on Mars to above 10% depending on the location and mineral. The concentration of water may also increase below a desiccated layer of soil at the surface, so technologies for excavation and transfer need to consider soil properties and water content as a function of depth and minerals and should be applicable to a range of landing sites where icy soils do not exist. The need to excavate down to at least 0.5 meters should be considered. The amount of water content in icy Mars soil can vary greatly as a function of depth and latitude. Based on analysis of Mars orbital data, proposers should assume a minimum of 10% by weight of water/ice up to 90%. Due to human landing and ascent considerations, Mars water based resources should be constrained between +/1 50 deg. latitude. Based on the potential high water content by mass in icy soils, it is expected that icy soil excavated will be either processed in-situ or on the excavation rover itself. Proposers should also assume that up to 0.5 m of soil may exist above icy soils and that excavation down to at least 1 meter is required. Proposers should note the impact on concept mass, power, and complexity for excavation down to 3 meters. Proposals should consider water loss due to hardware temperature, material agitation, and duration of soil exposure to the environment before transfer to soil processing systems. Note requirements for the mobility platform associated with hydrated soil excavation and transfer will be included in the H8 Robotic Systems Topic.

Technologies are sought for processing of hydrated and icy Mars soils to extract water. Soil processing for water extraction needs to consider the range of water content in Mars soils and water extraction rates defined below. Proposals for soil processing also need to define potential water loss due to valve/enclosure sealing for closed soil reactors or losses due to exposure to the surrounding environment or soil for open soil reactors. Proposals need to consider what other volatiles and contaminants are released due to soil processing/heating. Proposed solutions that perform in a non-continuous fashion are acceptable, as long as they achieve the same total production quantities on a daily or weekly basis. Understanding the change in mass, power, volume, complexity, and contaminant release as a function of water content in the soil, heating temperature, and heating method are important factors in selection. 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.

Based on past and recent human Mars exploration mission studies, to meet ascent propellant production rates with margin, approximately 1.6 kg/hr of water must be collected and cleaned for subsequent processing. At this time, 3 soil processing units for extraction of water from Mars soils is baselined for human Mars missions. Multiple excavation and processing units are allowed, but should be justified based on overall mass, power, thermal, and/or operation duration requirements. Proposers can submit combined excavation and soil processing technologies.

Technologies are sought for the separation, collection, and cleaning of water released from soil processing of hydrated and icy Mars soils. Separation of contaminants from water can be performed in the vapor phase during release or after collection, but technologies need to be regenerative. Separate and multiple technologies for collection, separation, and cleanup can be proposed for any one or all of the functions (separation, collection, and cleaning) All must operate in conjunction with the soil processing reactors for the soil/water production rates, contaminants, and mission durations specified above. It is encouraged that proposers for soil processing of Mars soils also consider including technologies requested below for water separation, collection, and cleanup since the two technology needs can be highly interconnected. Multiple units are allowed, but should be justified based on overall mass, power, thermal, and/or operation duration requirements. Water will need to be clean enough to be fed to a proton exchange membrane (PEM) water electrolysis unit.

H2.01 Lunar Resources
Lead Center: KSC
Participating Center(s): ARC, GRC, GSFC, JPL, JSC, LaRC, MSFC

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 of this 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.

An ancillary benefit is that the 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.

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.

Small payloads up to 2 kg in mass are needed to characterize and map the lunar volatiles resources so that they can be included in a future lunar ISRU strategy. This payload may be delivered to 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. Impactors and other devices that are used or released in lunar orbit are not within the scope of this solicitation.

The entire surface of the Moon is covered with fragmental and unconsolidated crushed rock material known as regolith, which was formed over billions of years of high-energy impacts by meteorites, comets and other solar system debris. Estimates are that this regolith covers the top 8-10 meters of the Moon's surface. Regolith represents a significant resource due to the bound oxygen that is present in some minerals; metals such as aluminum, iron and magnesium that can be extracted to make parts; and its use as a bulk construction aggregate material for civil engineering structures or radiation shielding. In addition, other engineering parameters such as trafficability must be known before effective exploration can take place.

Silicate minerals, composed dominantly of silicon and oxygen, are the most abundant constituents, making up over 90% by volume of most lunar rocks. The most common silicate minerals are pyroxene, $(Ca,Fe,Mg)2Si_2O_6$; plagioclase feldspar, (Ca,Na)(Al,Si)408; and olivine, $(Mg,Fe)2SiO_4$. Oxide minerals, composed chiefly of metals and oxygen, are next in abundance after silicate minerals. They are particularly concentrated in the mare basalts, and they may make up as much as 20% by volume of these rocks. The most abundant oxide mineral is ilmenite, $(Fe,Mg)TiO_3$, a black, opaque mineral that reflects the high TiO_2 contents of many mare basalts. The second most abundant oxide mineral, spinel, has a widely varying composition and actually consists of a complex series of solid solutions. Members of this series include: chromite, $FeCr_2O_4$; ulvöspinel, Fe_2TiO_4; hercynite, $FeAl_2O_4$; and spinel (sensu stricto), $MgAl_2O_4$. Another oxide phase, which is only abundant in titanium-rich lunar basalts, is armalcolite, $(Fe,Mg)Ti_2O_5$.

Small payloads up to 2 kg in mass are needed to characterize and map the mineral resources so that they can be included in a future lunar ISRU strategy. This payload may be delivered to 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. Impactors and other devices that are used or released in lunar orbit are not within the scope of this solicitation.

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 NEA-Mars. Relevant to 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), H2-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.
I-G. Lunar ISRU production efficiency
Measure the actual efficiency of ISRU processes in the lunar environment. Highly dependent on location & and nature of the input material. Process at high temperature to test techniques for extracting metals (e.g., Fe, Al) from regolith. This is enhancing long duration activity on the Moon and potentially beyond LEO.
III-C-2 Lunar surface trafficability – in-situ measurements
Characterization of geotechnical properties and hardware performance during regolith interactions on lunar surface.
III-D-1 Lunar dust remediation
Test conceptual mitigation strategies for hardware interactions with lunar fines, such as hardware encapsulation and microwave sintering of lunar regolith to reduce dust prevalence.
III-D-2 Regolith adhesion to human systems and associated mechanical degradation
In-situ grain charging and attractive forces, and cohesive forces under appropriate plasma conditions to account for electrical dissipation. Analysis of wear on joints and bearings, especially on space suits.
III-D-4 Descent / ascent engine blast ejecta velocity, departure angle and entrainment mechanism
Measurement of actual landing conditions on the lunar surface and in-situ measurements of witness plates and other instrumentation.
III-G Test radiation shielding technologies
Protecting human crews beyond the magnetic fields of the Earth from space radiation is a critical. In addition to Earth-based testing, could be further accomplished during lunar robotic missions.

All proposals need to identify the state-of-the-art of applicable technologies and processes. Hardware to be delivered at the conclusion of Phase II will be required to operate under lunar equivalent vacuum and temperature conditions, so thermal management during operation of the proposed technology will need to be specified in the Phase I proposal. Phase I 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 the Phase II delivered payload hardware. Proposals will be evaluated on mass, power, volume, and complexity. At the end of Phase II, the payload hardware should be capable of being ready to be flown in space within one year, with additional testing taking place during that year.

Focus Area 9: Sensors, Detectors and Instruments

Participating MD(s): SMD

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 2017 program year, we are restructuring the Sensors, Detectors and Instruments Topic, adding new, rotating out, splitting and retiring some of the subtopics. Please read each subtopic of interest carefully. There are two new subtopics for this year. The first 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. The second seeks instruments and component technologies that will enable unambiguous determination of whether extant life is present in target environments on other solar system bodies. The microwave technologies subtopic has been split this 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
Lead Center: GSFC
Participating Center(s): JPL, LaRC

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 NASA's 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 beam's 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 2017 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 2.05 micrometer wavelengths suitable for Lidar. Specific wavelengths of interest to match absorption lines or atmospheric transmission: 0.29 – 0.32 micrometer (ozone absorption), 0.45 – 0.049 micrometer (ocean sensing), 0.532 micrometer, 0.815 micrometer (water line), 1.0 micrometer, 1.57 micrometer (CO_2 line), 1.65 micrometer (methane line), and 2.05 micrometer (CO_2 line). Architectures involving new developments in diode laser, quantum cascade laser, and fiber laser technology are especially encouraged. 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 0.28 micrometer to 2.05 micrometer. Specific wavelengths of interest are listed in the above bullet. 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 1.6 micrometer wavelength, consisting of the detection device, complete Dewar/cooling systems, and associated amplifiers. General requirements are: large single-element active detection diameter (>200 micrometer), high quantum efficiency (>85%), noise equivalent power of the order of 10-14 W/sqrt(Hz), and bandwidth greater than 10 MHz.
- Novel, highly efficient approaches for High Spectral Resolution Lidar (HSRL) receivers. New approaches for high-efficiency measurement of HSRL aerosol properties at 1064, 532 and/or 355 nm. New or improved approaches are sought that substantially increase detection efficiency over current state of the art. Ideally, complete receiver subsystems will be proposed that can be evaluated and/or implemented in instrument concept designs.
- New space lidar technologies that use small and high-efficiency diode or fiber lasers to measure range and surface reflectance of asteroids and comets from >100 km altitude during mapping to <1 m during landing and sample return with a size, weight, and power substantially less than 28x28x26 cm^3, 7.4 kg, and 17 W

respectively. Technologies that can significantly extend the receiver dynamic range of the current space lidar without movable attenuators, providing sufficient link margin for the longest range but not saturating during landing. The output power of the laser transmitters should be continuously adjusted according to the spacecraft altitude. The receiver should have single photon sensitivity to achieve a near-quantum limited performance for long distance measurement. The receiver integration time can be continuously adjusted to allow trade-off between the maximum range and measurement rate. The lidar should have multiple beams so that it can measure not only the range but also surface slope and orientation.

- Fast laser beam steering mechanism to increase the sampling density, coverage, and signal to noise ratio of pulsed space-based Lidar. The mechanism needs to steer a 1064 nm pulsed laser beam through a set of at least 8 discrete and repeatable angles spanning a range of 10 mrad or greater along one dimension. The scan repetition rate needs to be 8 kHz or higher. Desired specifications include a pointing accuracy of 0.1 mrad or better, a settling time of <15 microseconds to switch between two angles apart, and a usable aperture of 10 mm (can be achieved using a beam expander as long as the outgoing beam meets all requirements).

S1.02 Technologies for Active Microwave Remote Sensing
Lead Center: JPL
Participating Center(s): GSFC
Related Subtopic Pointers: S1.03

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, Nano Sats 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.

Efficient X-band High Power Amplifiers

Amplifiers for high power X-band radar remote sensing instruments are sought that push the state of art in efficiency, size and RF power. Solid state technologies, such as GaN are expected, but new developments in tube-based amplifiers (TWT, Pentode, etc.) are welcome. Technologies requiring high voltage power supplies (>>50V), should include challenges in power supply development.

Efficiency: >40% PAE
Output Power: >400W peak
Pulsed: ~30% duty cycle
Bandwidth: >50MHz

Deployable Cylindrical Parabolic Antenna including feed support structure

A singly-curved, offset fed parabolic antenna with feed structure to support a linear array feed (along the non-curved dimension) will be used to demonstrate advanced scanning cloud and precipitation radar operating at Ka- and W-band. Frequency Range: 35 GHz, 94 GHz. Minimum Aperture Size: 1m x 2m (larger desirable)
Stowed Volume: 20cm x 20cm x 100 cm

Compact and modular backend radar subsystems for Cube/Small-Sats

Up/down converters: Ka, Ku, X, L to baseband
Receiver/ADCs: multichannel, >2GS/s, 12-bits or greater
Digital Processors: FPGA or GPU technologies on with performance on order of Xilinx V5, with significantly lower DC power consumption.
Synthesizers/AWGs: Stable signal sources, arbitrary waveform generators, required to generate standard radar waveforms.

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.

Reconfigurable Radar Processors

Radar processor capable of simultaneous or rapidly reconfigurable precipitation reflectivity and SAR measurements for multi-mode, multi-beam radars. Processor should be capable of high-altitude airborne operation with a path for spaceflight.

S1.03 Technologies for Passive Microwave Remote Sensing
Lead Center: GSFC
Participating Center(s): JPL
Related Subtopic Pointers: S1.02

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). While other concepts will be entertained, specific technology innovations of interest are listed below.

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 (X, K, Ka) with dual-polarization inputs. Interfaces include waveguide input, power, control, and digital data output. Design features allowing subsystems of multiple (tens of) integrated units to be effectively realized.

A low-power, radiation tolerant, spectrometer back end capable of sampling a 4 GHz bandwidth with up to 16k channels desired.

Microwave integrated photonic components to demonstrate feasibility and utility for future microwave instruments. Components used in spectometers, beam forming arrays, correlation arrays and other active or passive microwave instruments are sought.

Microwave to mm wave blackbody calibration target with a 65 dB return loss, an aperture of 8 cm, and performance from 50 GHz to 1 THz.

A focal plane array antenna design to enable large aperture microwave radiometers conical scanning reflector antennas fed by focal plane arrays are needed. Designs are desired for 4-to-12-meter apertures operating at K and Ka band are needed.

Development of microwave-on-wafer probe station for cryogenic circuit characterization. Proposed capability should support test and validation of normal metals and superconductors. Device under test temperature <2.2K desired, with control over the radiant environment and parasitic heat paths through probes. Demonstration from 0-50 GHz with a 2.4 mm compatible interface desired; however, proposed thermal design should define path forward or enable extension to application at millimeter wavelengths

Components for addressing gain instability in LNA based radiometers from 100 and 600 GHz.

Low power RFI mitigating receiver back ends for broad band microwave radiometers.

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.

Laser-based THz local-oscillator (LO) ultra-broadband heterodyne mixers for remote sensing.

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

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/).

1k x 1k or larger format MCT detector arrays with cutoff wavelength extended to 12 microns for use in missions to NEOs, comets and the outer planets.

Compact, low power, readout electronics for Kinetic Inductance Detector arrays with >10bit ADC at >1GHz sampling rate with >2000 bands, ~5kHz bandwidth each with an operating power <300mW and operation at both room temperature and cryogenic temperatures.

New or improved technologies leading to measurement of 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 un-cooled or cooled Infrared detectors (hybridized or designed to be hybridized to an appropriate read-out integrated circuit) with NEΔT<20mK, QE>30% and dark currents <1.5x10-6 A/cm^2 in the 5-14 µm infrared wavelength region. Array formats may be variable, 640 x 512 typical, with a goal to meet or exceed 2k X 2k pixel arrays. Evolve new technologies such as InAs/GaSb type-II strained layer super-lattices to meet these specifications.

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.

New or improved, lightweight spectrometer operating over the spectral range 350 – 2300 nm with 4 nm spectral sampling and that is capable of making irradiance measurements of both the sun and the moon.

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 upto >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.

S1.05 Detector Technologies for UV, X-Ray, Gamma-Ray and Cosmic-Ray Instruments
Lead Center: GSFC

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 - (http://nasascience.nasa.gov/planetary-science/mission_list).
- Earth Science Decadal missions - (http://www.nap.edu/catalog/11820.html).

- Helio Probes - (http://nasascience.nasa.gov/heliophysics/mission_list).
    - 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 µm) 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 µm) 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 um, 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
Lead Center: GSFC
Participating Center(s): ARC, JPL, JSC, MSFC

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, 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, and associated support electronics and materials. Specific areas of interest include:

- High efficiency reliable cold ionizers to ionize neutral gas as an alternative to thermionic emitters.
    - Science Traceability: Decadal survey missions: DRIVE Initiative, EXPLORERs DISCOVERY, CubeSats / Smallsats, Sounding Rockets.
    - Need Horizon: 1 to 3 years, 3 to 5 years.
    - Reliable and efficient cold ionizers are desires as an alternative to commonly used thermionic emitters. Possible use of nanotechnology. Efficiency >1%.
    - Importance: Very High – Critical need for next generation low energy neutral particle spectrometers.
- Strong, compactly stowed magnetically clean magnetic field booms possibly using composite materials that deploy mag sensors (including internal harness) to distances up to 10 meters, for Cubesats;
    - Science Traceability: Explorer missions, DRIVE Initiative, CubeSat/Smallsat missions.
    - Need Horizon: 1 to 3 years.
    - State of the Art: Such a boom up to 10 meters long will high quality electric filed measurements from small platforms.
    - Importance: Very High for future Cubesat and SmallSat stand alone and constellation missions.
- Control Element for High Voltage Power Supplies.
    - Science Traceability: Decadal survey missions: IMAP, MEDICI, DRIVE Initiative, EXPLORERs DISCOVERY, CubeSats / Smallsats, Sounding Rockets.
    - Need Horizon: 1 to 3 years, 3 to 5 years.
    - State of art high voltage controller device with the following basic characteristic. Control from standard voltage of 3.3V to 5V, HV switch of up to 20KV, HV isolation up to 25KV, low leakage currents, slew rates of 100V/us on 10pf loads, mil spec temperature range, radiation tolerance up to 300 krads.

S1.07 In-Situ Instruments/Technologies for Planetary Science
Lead Center: JPL
Participating Center(s): ARC, GRC, GSFC, JSC, KSC, MSFC
Related Subtopic Pointers: S1.12

This subtopic solicits development of advanced instrument technologies and components suitable for deployment on in-situ planetary and lunar 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://science.hq.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* - Advancements in the areas of compact, light-weight, low power instruments geared towards in-situ lunar surface measurements, geophysical measurements, lunar atmosphere and dust environment measurements & regolith particle analysis, lunar resource identification, and/or quantification of potential lunar resources (e.g., oxygen, nitrogen, and other volatiles, fuels, metals, etc.). Specifically, advancements geared towards instruments that enable elemental or mineralogy analysis (such as high-sensitivity X-ray and Raman spectrometers, UV/fluorescence systems, scanning electron microscopy with chemical analysis capability, mass spectrometry, gas chromatography and tunable diode laser sensors, calorimetry, laser-Raman spectroscopy, imaging spectroscopy, and LIBS) are sought. These developments should be geared towards sample interrogation, prior to possible sample return. Systems and subsystems for seismometers and heat flow sensors capable of long-term continuous operation over multiple lunar day/night cycles with improved sensitivity at lower mass and reduced power consumption are sought. Also of interest are portable surface ground penetrating radars to characterize the thickness of the lunar regolith, as well as low mass, thermally stable hollow cubes and retro-reflector array assemblies for lunar surface laser ranging. Of secondary importance are instruments that measure the micrometeoroid and lunar secondary ejecta environment, plasma environment, surface electric field, secondary radiation at the lunar surface, and dust concentrations and its diurnal dynamics. Further, lunar regolith particle analysis techniques are desired (e.g., optical interrogation or software development that would automate integration of suites of multiple back scatter electron images acquired at different operating conditions, as well as permit integration of other data such as cathodoluminescence and energy-dispersive x-ray analysis.).

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 Surface & Sub-surface Measurement Systems
Lead Center: ARC
Participating Center(s): GSFC, JPL, LaRC, MSFC, SSC

Surface & Sub-surface Measurement Systems are sought with relevance to future space missions such as Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS), Orbiting Carbon Observatory 2 (OCO-2), Global Precipitation Measurement (GPM), Geostationary Coastal and Air Pollution Events (GEO-CAPE), Hyperspectral InfraRed Imager (HyspIRI), Aerosol, Cloud, and Ecosystems (ACE, including Pre-ACE/PACE). Early adoption for alternative uses by NASA, other agencies, or industry is desirable and recognized as a viable path towards full maturity. Sensor system innovations with significant near-term commercial potential that may be suitable for NASA's research after full development are of interest:

- Precipitation (e.g., motion stabilized disdrometer for shipboard deployments).
- Aquatic suspended particle concentrations and spectra of mineral and biogenic (phytoplankton and detritus) components.
- Miniaturized, stable, pH sensors for ocean applications to support validation of OCO-2 that can be used in the ARGO network.
- Miniaturized gas sensors or small instruments for carbon dioxide, methane, etc., only where the sensing technology solution will clearly exceed current state of the art for its targeted application.
- Miniaturized air-dropped sensors, for ocean surface and subsurface measurements such as conductivity, temperature, and depth.
- Multi-wavelength, LIDAR-based, atmospheric ozone and aerosol profilers for continuous, simultaneous observations from multiple locations. Examples include three-band ozone measurement systems operating in the UV spectrum (e.g., 280-316 nm, possibly tunable), or visible/infrared systems with depolarization sensitivity for aerosols and clouds.
- Portable, robust, ground based LIDAR system for 3D scanning of winds, temperature, density, and humidity with ability to scan horizontally and vertically with a range of up to 10 km.
- Miniaturized, novel instrumentation for measuring inherent and apparent optical properties (specifically to support vicarious calibration and validation of ocean color satellites, i.e., reflectance, absorption, scattering), in-situ biogeochemical measurements of marine and aquatic components and rates including but not limited to nutrients, phytoplankton and their functional groups, and floating and submerged aquatic plants.
- Novel geophysical and diagnostic instruments suitable for ecosystem monitoring. Fielding for NASA's Applications and Earth Science Research activities is a primary goal.

S1.09 Cryogenic Systems for Sensors and Detectors
Lead Center: GSFC
Participating Center(s): ARC, JPL, MSFC

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 WFirst (http://wfirst.gsfc.nasa.gov/), 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, 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 cm3.
- 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
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 $<1\times10^{-9}$ 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 ≤ ~ 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: 5×10^{-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 offerers 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 for Ocean Worlds Life Detection
Lead Center: JPL
Participating Center(s): ARC, GRC, GSFC, JSC, KSC, MSFC

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. 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={5C43865B-0C93-6ECA-BCD2-A3783CB1AAC8}&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 miscroscope, 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).
- *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.
- *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 (95K) environments; sample extraction from liquid methane/ethane, sampling from organic 'dunes' at 95K 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 (95K).
- 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.

S1.12 Sample Processing For Life Detection Investigations for Ocean Worlds
Lead Center: GSFC
Participating Center(s): ARC, JPL
Related Subtopic Pointers: S1.07

This solicitation is for 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 support minimal biological and analytical contamination of the full technological component and sample stream in order to meet planetary protection requirements and maintain sample integrity for mission-science investigations as well as those that 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={5C43865B-0C93-6ECA-BCD2-A3783CB1AAC8}&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, and other Ocean Worlds with liquid water and ice* - 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).
- *Titan* – 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 (95K) and hydrocarbon-rich environments; sample extraction from liquid methane/ethane and/or hydrogen cyanide, sampling from organic 'dunes' at 95K and robust sample preparation and handling mechanisms that feed into spectral and mass analyzers, as well as X-ray detection devices are solicited.

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.

Development of these technologies may support environmental, laboratory, military and medical fields that require low mass, power and volume sample processing.

The Technologies for Detection of Extant Life subtopic seeks instruments and component technologies that will enable unambiguous determination of whether extant life is present in target environments on other solar system bodies. Because there is no single measureable signature of life, this will require advances in a variety of areas, from those involving sample processing to the detailed components of chemical and optical instruments. Searches for extant life can take place in a variety of environments, including ocean depths, ice sheets, dry deserts, seasonal flows, or even dense atmospheres; technologies are required for handling samples obtained from any or all of these environments. Preprocessing technologies required for those samples may include separation, concentration, dilution, drying, staining, mixing, and many other common processes for laboratory analysis, but which must be done in a remote, autonomous environment. Tests of whether a given sample contains or indicates the presence of extant life include the full range of microbiological and chemical techniques, but those that do not require the addition of potential biomarkers (e.g., complex organics) as part of the test are preferred. Technologies that support or enable the use of multiple techniques to investigate a single sample are of particular interest, both because of small sample sizes in planetary missions and the need to apply multiple independent tests to identify extant life. Proposed technologies should support miniaturization and design for low power and use in harsh environments.

S4.06 Sample Collection for Life Detection in Outer Solar System Ocean World Plumes
Lead Center: ARC
Participating Center(s): GSFC, JPL
Related Subtopic Pointers: S4.02

This subtopic solicits development of in-situ instrument technologies and components to advance the maturity of instruments focused on the collection of samples for life detection from plumes 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 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={5C43865B-0C93-6ECA-BCD2-A3783CB1AAC8}&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.

Focus Area 10: Advanced Telescope Technologies

Participating MD(s): SMD

The NASA Science Missions 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 Coronagraphy
Lead Center: JPL
Participating Center(s): ARC, GSFC

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
Lead Center: JPL
Participating Center(s): GSFC, LaRC

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 scaleable 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
Lead Center: MSFC
Participating Center(s): JPL, GSFC

This subtopic matures technologies needed to affordably manufacture, test or operate complete mirror systems or telescope assemblies. Solutions are solicited in the following areas:

- Components and Systems for potential EUV, UV/O or Far-IR mission telescopes.
- Technology to fabricate, test and control potential UUV, UV/O or Far-IR telescopes.

Specific needs are listed in the Technical Challenges Section. New for 2017 are two areas using additive manufacturing technology:

- Lightweight mirror substrates for Far-IR with < 100 nm rms cryo-deformation at 10K.
- Ultra-stable support structures for potential telescope assemblies: 0.5 meter LISA, 4-m monolithic HabEx, or 12-m segmented LUVOIR.

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 NASA's 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.

Exoplanet Balloon Mission Telescope

A potential exoplanet mission seeks a 1-m class wide-field telescope with diffraction-limited performance in the visible and a field of view > 0.5 degree. The telescope will operate over a temperature range of +10 to -70 C at an altitude of 35 km. It must survive temperatures as low as -80 C during ascent. The telescope should weigh less than 250 kg and is required to maintain diffraction-limited performance over:

- The entire temperature range.
- Pitch range from 25 to 55 degrees elevation.
- Azimuth range of 0 to 360 degrees.
- Roll range of –10 to +10 degrees.

The telescope will be used in conjunction with an existing high-performance pointing stabilization system.

Planetary Science Balloon Mission Telescope

A potential planetary balloon mission requires an optical telescope system with at least 1-meter aperture for UV, visible, near- and mid-IR imaging and multi/hyperspectral imaging, with the following optical, mechanical and operational requirements:

Optical Requirements:

- ≥ 1-meter clear aperture.
- Diffraction-limited performance at wavelengths ≥ 0.5 µm over entire FOV.
- System focal length: 14.052-meters.
- Wavelength range: 0.3 – 1.0 µm and 2.5 – 5.0 µm.
- Field of view: 60 arc-sec in 0.3 – 1.0 µm band, 180 arc-sec in 2.5 – 5.0 µm band.
- Straylight rejection ratio ≥ 1e-9.

Mechanical/Operational Requirements:

- Overall length: ≤ 2.75 meters.
- Overall diameter: ≤ 1.25 meters.
- Mass: ≤ 250 kg.
- Temperature: -80 to +50°C.
- Humidity: ≤ 95% RH (non-condensing).
- Pressure: sea level to 1 micron Hg.
- Shock: 10G without damage.
- Elevation angle range: 0° to 70° operating, -90° to + 90° non-operating.

Other Requirements:

- Must allow field disassembly with standard hand tools.
- Maximum mass of any sub-assembly < 90 kg.
- Largest sub-assembly must pass through rectangular opening 56 by 50 inches (1.42 by 1.27 meters).

2. 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. Fabrication, Test and Control of Advanced Optical Systems

While Sections 1 and 2 detail the capabilities need to enable potential future UVO and IR missions, it is important to note that this capability is made possible by the technology to fabricate, test, and control optical systems. Therefore, this subtopic also encourages proposals to develop such technology which will make a significant advance of a measurable metric.

S2.04 X-Ray Mirror Systems Technology, Coating Technology for X-Ray-UV-OIR, and Free-Form Optics
Lead Center: GSFC
Participating Center(s): JPL, MSFC

This subtopic solicits proposals in the following areas:

- Components, Systems, and Technologies of potential X-Ray missions.
- Coating technologies for X-Ray, EUV (extreme ultraviolet), LUV (Lyman ultraviolet), VUV (vacuum ultraviolet), Visible, and IR (infrared) telescopes.
- Free-form Optics surfaces design, fabrication, and metrology.

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, LUV, VUV, Visible, and IR).
- 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.

Technical Challenges:

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. It's desirable to achieve 35° Kelvin 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 from1/2 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 un-obscured 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

Participating MD(s): SMD, 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: http://nasascience.nasa.gov/about-us/science-strategy.
- 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 and Planetary Balloons
Lead Center: GSFC
Participating Center(s): JPL

Terrestrial Balloons

NASA's Scientific Balloons provide practical and cost effective platforms for conducting discovery science, development and testing for future space instruments, as well as training opportunities for future scientists and engineers. Balloons can reach altitudes above 36 kilometers, with suspended masses up to 3600 kilograms, and can stay afloat for several weeks. Currently, the Balloon Program is on the verge of introducing an advanced balloon system that will enable 100 day missions at mid-latitudes and thus resemble the performance of a small spacecraft at a fraction of the cost. In support of this development, NASA is seeking innovative technologies in power storage and satellite communications bitrates as described below:

- *Power Storage* - Improved and innovative devices to store electrical energy onboard balloon payloads are needed. Long duration balloon flights can experience 12 hours or more of darkness, and excess electrical power generated during the day from solar panels needs to be stored and used. Improvements are needed over the current state of the art in power density, energy density, overall size, overall mass and/or cost. Typical parameters for balloon are 28 VDC and 100 to 1000 watts power consumption. Rechargeable batteries are presently used for balloon payload applications. Lithium Ion rechargeable batteries with energy densities of 60 watt-hours per kilogram are the current state of the art. Higher power storage energy densities, and power generation capabilities of up to 2000 watts are needed for future support.
- *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 under development, but the operational cost is prohibitive.

Planetary Balloons

Innovations in materials, structures, and systems concepts have enabled buoyant vehicles to play an expanding role in planning NASA's future Solar System Exploration Program. Balloons are expected to carry scientific payloads at Venus that will perform in-situ investigations of the atmosphere. Venus features extreme environments that significantly impact the design of balloons. Proposals are sought in the following areas:

- *Floating Platforms for Venus* - NASA is interested in conducting long term monitoring of the Venus atmosphere and the signatures of seismic and volcanic events from the planetary surface using floating platforms at altitudes of between 50 and 60 km for periods in excess of 100 days. The temperature at 50 km is roughly 75°C; at 60 km it is about -10°C. Sulfuric acid aerosols are known to exist in this altitude range on Venus. A target payload mass of 100 kg shall be used for system sizing purposes. The primary focus should be on the design of the floating platform system and the materials for achieving long duration operation. Concepts may include fixed altitude and/or variable altitude (controlled) floating vehicles. Systems that use alternative lift gases such as ammonia, or phase change fluids should be considered. Traditional lift gases such as helium or hydrogen are acceptable. Additional areas of interest for developing floating platforms include:
  - Analytical tools for predicting vehicle dynamic behavior in the atmosphere.
  - Packaging and storage methods for inflatable components.
  - Methods for deployment, inflation, and component separation during descent in the atmosphere.

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.

S3.07 Slow and Fast Light
Lead Center: MSFC

Steep dispersions in engineered media of a wide variety have opened up a new direction of research in optics. A positive dispersion can be used to slow the propagation of optical pulses to extremely small velocities. Similarly, a negative dispersion can lead to conditions where pulses propagate superluminally. These effects have now moved beyond the stage of intellectual curiosity, and have ushered in studies of a set of exciting applications of interest to NASA, ranging from ultraprecise superluminal gyroscopes to spectral interferometers having enhanced resolving power.

This research subtopic seeks slow-light and/or fast-light enhanced sensors for space applications of interest to NASA including:

- Superluminal gyroscopes and accelerometers (both passive and active)
- Enhanced strain and displacement sensors for non-destructive evaluation and integrated vehicle health management applications.
- Slow-light-enhanced spectrally-resolved interferometers for astrophysical and Earth science observations, as well as for exploration goals.
- Other applications of slow and fast light related to NASAs mission areas.

Superluminal Gyroscopes

In conventional ring laser gyroscopes, sensitivity increases with cavity size. Fast light, however, can be used to increase gyro sensitivity without having to increase size, for spacecraft navigation systems which are constrained by weight and volume. The increased sensitivity also opens up new science possibilities such as detection of subsurface geological features, tests of Lorentz invariance, improving the bandwidth sensitivity product for gravity wave detection, and tests of general relativity. This research subtopic seeks:

- Prototype fast light gyroscopes, active or passive, that unambiguously demonstrate a scale factor enhancement of at least 10 with the potential for 1000. The minimum or quantum-noise limited angular random walk (ARW) should also decrease.
- Designs for fast light gyros that do not require frequency locking, are not limited to operation at specific frequencies such as atomic or material resonances, and permit operation at any wavelength.
- Fast light gyroscope designs that are rugged, compact, monolithic, rad-hard, and tolerant to variations in temperature and varying G-conditions.

Slow-Light Enhanced Spectral Interferometers

Slow light has the potential to increase the resolving power of spectral interferometers such as Fourier transform spectrometers (FTS) for astrophysical applications without increasing their size. Mariner, Voyager, and Cassini all used FTS instruments for applications such as mapping atmospheres and examining ring compositions. The niche for FTS is usually thought to be for large wavelength (IR and beyond), wide-field, moderate spectral resolution instruments. Slow light, however, could help boost FTS spectral resolution making FTS instruments more competitive with grating-based instruments, and opening up application areas not previously thought to be accessible to FTS instruments, such as exoplanet detection. A slow-light FTS could also be hyper-spectral, providing imaging capability. FTS instruments have been employed for remote sensing on NASA Earth Science missions, such as the Atmospheric

Trace Molecule Spectroscopy (ATMOS), Cross-track Infrared Sounder (CrIS), and Tropospheric Emission Spectrometer (TES) experiments, and have long been considered for geostationary imaging of atmospheric greenhouse gases. This research subtopic seeks research and development of slow-light-enhanced spectral interferometers that are not restricted by material resonances and can operate at any wavelength. An inherent advantage of FTS systems are their wide bandwidth. It will therefore of importance to develop slow light FTS systems that can maintain a large operating bandwidth.

S3.08 Command, Data Handling, and Electronics
Lead Center: GSFC
Participating Center(s): JPL, LaRC

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 2017 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:

- *System-In-Package Integrated Assemblies* - Technologies enabling highly integrated System-In-Package (SIP) assemblies integrating multiple die from different processes and foundries, enabling implementation of miniaturized, highly-reliable embedded processing or sensor readout modules.
- *Printed Wiring Board Miniaturization* - Technologies enabling miniaturization of highly reliable printed wiring board assemblies and interconnect.
- *COTS Micropower/Ultra-Low Power Computing* - Technologies enabling the use of COTS micropower/ultra-low power computing devices in highly reliable spacecraft avionics systems.

- *Radiation Shielding* - Innovative additive manufacturing and/or deposition technologies starting at TRL 3 are sought to create integral one-piece surface claddings of graded atomic number (Z) materials for use as radiation shielding for electronics. Shielding thicknesses must be able to achieve up to 3 g/cm^2 for initial shielding applications. At the end of Phase I, delivery of layered slabs and/or half sphere samples is expected with areal densities from 1 -3 g/cm^2; samples must be able to show a strong interface property to avoid delamination and consistent density and thickness (areal density) uniformity.

S4.03 Spacecraft Technology for Sample Return Missions
Lead Center: JPL
Participating Center(s): GRC

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
Lead Center: JPL
Participating Center(s): ARC, GRC, GSFC, LaRC, MSFC

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 Venusians 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-powerwide-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.

S4.05 Contamination Control and Planetary Protection
Lead Center: JPL

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 being 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.

Z6.01 High Performance Space Computing Technology
Lead Center: JPL
Participating Center(s): GSFC, JSC

The NASA state-of-the-art in space computing is currently lagging commercial capabilities in both the hardware and software capabilities. Presently, NASA is investing in the development of a radiation-hardened multi-core General Purpose Processor (GPP) that is scalable for a variety of space computing application.

The GPP will require additional support components and software to enable it to function as a multi-application device. Also, the GPP may not be the best approach to specific specialized applications that require niche-processing approaches. This subtopic is seeking flight-computing enhancements in the following areas:

- GPP parallel processing support libraries such as: real-time and fault-tolerant Message Passing Interface (MPI), the Vector, Signal, and Image Processing Library (VSIPL), the Fastest Fourier Transform in the West (FFTW), and other parallel I/O and math libraries.
- Computing accelerators/co-processors that will connect to the HPSC processor via the Serial Rapid I/O (SRIO) ports for supporting specific applications such as cyber-physical/robotics and autonomous systems.
- Generic I/O expander chips for a GPP that provide typical serial data communications support suitable for use in subsystems and instruments such as TIA/EIA-422, SpaceWire, SpaceFiber, MIL-STD-1553, wireless RFID-based device interfaces, and Time Triggered Ethernet (TTE)/Time-Triggered Gigabit Ethernet (TTGbE).
- Interconnect switches and end points for SRIO with integral micro-controllers, suitable for use in subsystems and instruments including components, IP for FPGA and SOC implementation and associated software.

- Low-power Graphics Processor Units and related display technologies.
- General purpose SIMD engines.
- Neuromorphic processors, especially those using >2D topologies.
- Board-support technologies, such as fault tolerant, multiple voltage, high efficiency, Point-of-Load converters, that reduce the SWaP burden of the overall computing board to permit higher system power efficiency and smaller computing system form factors.
- High Performance, low power/power manageable, fault tolerant, memory components, both volatile and non-volatile, especially those using >2D topologies and high speed, low power interfaces such as SRIO.
- Middleware that provides machine configuration management and resource allocation for GPP and extended GPP (incorporating co-processors, accelerators and expanded I/O).

Focus Area 12: Entry, Descent and Landing Systems

Participating MD(s): HEOMD, SMD, STMD

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.

- Supersonic parachute materials, testing and instrumentation.
- 3-dimensional woven thermal protection materials.
- Hot structures control surface technologies.
- EDL and small body proximity operations sensors. The specific needs and metrics of each of these specific technology developments are described in the subtopic descriptions.

H5.02 Hot Structure Entry Control Surface Technology
Lead Center: LaRC
Participating Center(s): AFRC, JSC, MSFC

The focus of this subtopic is the development of hot structure technology for entry vehicle control surfaces. A hot structure is a type of multifunctional structure that can reduce or eliminate the need for a separate thermal protection system (TPS) to protect the structure. The potential advantages of using a hot structure in place of a cool structure with a separate TPS are: reduced mass, increased mission capability such as reusability, improved aerodynamics, improved structural efficiency, and increased ability to inspect the structure. Hot structures is an enabling technology for reusability between missions or mission phases, such as aerocapture followed by entry, and have been used in many prior NASA programs: Space Shuttle (nosecap and leading edges), HyperX (nose and all-moving control surfaces), X-37 (flaperon and ruddervator control surfaces), and many Department of Defense programs.

This subtopic seeks to develop innovative low-cost, damage tolerant, reusable and lightweight 1450°C to 2200°C hot structure technology applicable to control surfaces for atmospheric entry vehicles such as body flaps, ailerons, and trim tabs. Proposals should address one or more of the following technical challenges:

- Fabrication technologies for stiffened structures that can be scaled to components as large as 3 meters in span and/or chord.
- Material/structural architectures providing significant improvements of in-plane and interlaminar mechanical properties, compared to current high-temperature laminated composites.
- Concepts for reliable integration of control surface deflection functionality (such as hinges and point attachment for actuators) which can integrate with a cool primary structure.
- Remote monitoring capability for high temperature structures and associated enviro-mechanical models to quantitatively diagnose the state of the structure between missions or mission phases.

For all above technologies, research, testing, and analysis should be conducted to demonstrate technical feasibility during Phase I and show a path towards Phase II hardware demonstration. Emphasis should be on the delivery of a manufacturing demonstration unit for NASA testing at the completion of the Phase II contract. Opportunities and plans should also be identified and summarized for potential commercialization.

Reference:

Glass, D. E. "Ceramic Matrix Composites (CMC) Thermal Protection Systems (TPS) and Hot Structures for Hypersonic Vehicles," 15th AIAA International Space Planes and Hypersonic Systems and Technologies Conference, Dayton, Ohio, AIAA-2008-2682, April 2008. (http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20080017096.pdf).

S4.01 Planetary Entry, Descent and Landing and Small Body Proximity Operation Technology
Lead Center: JPL
Participating Center(s): ARC, JSC, LaRC

NASA seeks innovative sensor technologies to enhance success for entry, descent and landing (EDL) operations on missions to other planetary bodies, including Earth's Moon, Mars, Venus, Titan, Europa, and proximity operations (including sampling and landing) on small bodies such as asteroids and comets.

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 point cloud (for hazard detection, absolute state estimation, landing/sampling site selection, and/or body shape characterization).
- Atmosphere-relative measurements (velocimetry, pressure, temperature, flow-relative orientation).

NASA also seeks to use measurements made during EDL to better characterize the atmosphere of planetary bodies, providing data for improving atmospheric modeling for future landers or ascent vehicles.

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 accomodation 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.

For all the aforementioned technologies, 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, and planetary protection requirements.

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.

Submitted proposals should show an understanding of the current state of the art of the proposed technology and present a feasible plan to improve and infuse it into a NASA flight mission.

Z7.01 Supersonic Parachute Inflation Materials Testing, And Instrumentation
Lead Center: JPL
Participating Center(s): LaRC

Mars landed missions have traditionally relied on large (nominal diameter between 11.5 and 21.5 m) disk-gap-band (DGB) parachutes that must be inflated between Mach 1.2 and 2.2 at dynamic pressures between 300 and 850 Pa to ensure that the terminal landing phase occurs before hitting the ground. For robotic payloads larger than the Curiosity rover, larger parachutes will be required. These parachutes need to be tested under the low-density supersonic conditions that match Mars conditions. However understanding the shape history, dynamics, and induced stresses in the parachute structure and broadcloth during the inflation event is needed to ensure that minimum strength margin requirements are met. Further understanding the strength capability of materials under bi-axial and shear stress is essential. The measured material capabilities and stress conditions during inflation will be matched with computer models that will eventually be used as predictive tools in the parachute design process. This SBIR asks for help inventing and utilizing techniques for measuring parachute materials strength capabilities under flight-like loading conditions, and measuring, or inferring, parachute material stress and shape histories found during the inflation process during supersonic parachute inflation testing planned for the 2018 timeframe.

Parachute Materials Testing

Low mass, high strength parachute fabrics typically are constructed using various woven low mass Dacron or nylon broadcloth (e.g., 1.2 oz./yd2) that are sewn as gores onto Kevlar (or other high strength) webbing that forms a circumferential and radial skeleton primary structure. These materials as well as associated seams and joints are typically strength tested uni-axially. In some cases bi-axial testing has occurred however test fixtures and test facilities that attempt to reproduce the bi-axial and shear-induced stresses and strain associated with the dynamic inflation event do not appear to exist.

Proposers to this subtopic should suggest ideas and provide the capability for determining the strength of these classes of materials including joints and seams under various bi-axial stress and shear conditions (materials, sample joints and seams will be provided) that are representative of the manner in which the materials are loading during and after inflation.

Phase I will be expected to deliver: Measurement detailed design (and design review), Details of material test requirements (to be worked with the lead center in this phase), Implementation and cost plan, and Test facility and calibration plan

Phase II will be expected to deliver: Tested and calibrated material test instrumentation and/or facility, Material testing (using samples provided by parachute manufacturers), Test data analysis and results.

In-situ Instrumentation

Ultimately, to prove that sufficient strength margin exists in the parachute design we need to determine the stresses or strains of the materials, seams and joints during the supersonic inflation event(s). Computer models that attempt to predict these stresses have not been validated due to an absence of data to ground the simulation results. NASA may execute supersonic, high-altitude inflation testing using various sized DGB parachutes in the 2018 timeframe. Plans include the use of high-speed stereo machine vision cameras that will allow shape history reconstruction of the very fast (< 1 sec) inflation event. Load cells on the riser(s) will provide estimates of the integrated tension during the event. After the test, the parachute and its instrumentation will be recovered and data extracted to gain understanding of the event. Some strain might be observable. What is missing are means to more directly measure or infer the peak stresses in the skeleton and broadcloth during the inflation event. Creative solutions have been proposed in the past, to instrument the parachute directly but these suffer from immaturity, use unproven integration techniques, and/or have questionable accuracies. These past solutions include: stress paint, strain threads that act as peak strain telltales, ultra-low-mass miniature self-contained strain gauges, and passive peak stress detection sewn into the circumferential and radial skeleton webbing (ball-strain yielding). These and other ideas are encouraged.

Proposers should suggest and have the ability to deliver various types of in-situ or remote instrumentation. Care should be taken to ensure that the incorporation of these devices do not excessively interfere with the operation of the parachute during the mortar-launched parachute inflation.

Phase I will be expected to deliver: Detailed design concepts, Implementation and cost plan, Details of accommodation (to be worked with the lead NASA center), and Instrument test and calibration plan.

Phase II will be expected to deliver: Tested and calibrated instrumentation, System test support (use of instrument in a ground or flight test), and Instrument data analysis.

Z7.02 Deployable 3D Woven Thermal Protection Materials
Lead Center: ARC

Large scale mechanically deployed decelerator skirts are expected to experience 50-100 W/cm^2 in various planetary oxidizing environments and are currently designed using flat panels of 3-D woven carbon fibers with sacrificial ablating outer layers over structural layers. The flat panels currently require cutting and joining at each structural rib.

Technologies Sought Include:

- Advancements are sought in weaving carbon fabric-based decelerator skirts that minimize stitched joints (maximum of 1 stitched joint) through the use of polar weaving or spider weave based designs. The weave thickness should be ~0.1 inches with a finished skirt diameter in the 1-3 meter range.
- Development of alternate 3D weave architectures that utilize multiple fiber types, including but not limited to non-ablating fibers on the outer mold line side that transition to structural and/or insulating fiber types. Development of such a capability could provide significant mass savings and performance benefits over pure carbon fiber-based fabric designs.
- Fabric joint development. Improvements are sought in the design of high temperature capable, stitched structural joints to improve post heated failure loads while minimizing conductive heat transfer into underlying deployable structure elements.
- Advancements in integrating 3D features into woven carbon fabrics to reduce manufacture and integration complexity. Examples include incorporation of rounded trailing edge radii into acreage material such that a trailing edge radius is 2-4x the acreage thickness without requiring multiple piece parts and stitching.

For all above technologies, research should be conducted to demonstrate technical feasibility and design during Phase I and show a path towards Phase II demonstration with delivery of a ~1-m diameter demonstration unit for NASA evaluation at the completion of the Phase II contract.

Z7.03 Deployable Aerodynamic Decelerator Technology
Lead Center: LaRC
Participating Center(s): GRC, ARC, JSC, MSFC

Background: NASA is developing deployable aerodynamic decelerators to enhance, and enable, robotic and scientific missions to destinations with atmospheres such as Mars, Venus, and Titan, as well as returning payloads to Earth from Low Earth Orbit (LEO). The benefit to deployable decelerators is that relatively large atmospheric entry vehicles can be designed to fit within a comparatively small vehicle launch fairing. Deployable decelerator technology will enable delivery of an estimated 20 metric tons of payload required to support human exploration of Mars, and will also enable return of large payloads from Low Earth Orbit as well as launch asset recovery for reduced cost of space access. For Mars human exploration it is estimated that a deployable may have a diameter of 18 meters which, for an inflatable system, will require over 100 cubic meters of hydrogen gas at a weight of nearly 700 kilograms.

This subtopic area solicits innovative technology solutions applicable to deployable entry vehicles. Specific technology areas included in the subtopic can include the development of gas generator technologies used as inflation systems that result in improved mass efficiency and system complexity over current pressurized cold gas systems. Inflation gas technologies can include warm or hot gas generators, sublimating powder systems, or hybrid systems. Proposed approaches should clearly demonstrate that the inflation technology can be scaled to inflated aero-shells at a size relevant to human scale Mars exploration missions. These lightweight, high efficiency gas inflation technologies should be capable of delivering gas at 10,000 standard liters per minute.

Another research area included in the subtopic advancements in woven and non-woven textile technologies that can be used in the design and production of mass efficient flexible thermal protection systems such as durable high temperature fibrous insulators capable of operating above 1200°C that efficiently suppress both radiation and convective heat transfer. Thermal protection systems can be passive systems that do not rely on decomposition to manage heat loads, or more active systems where phase changes or material decomposition enhances thermal management capability.

Proposals in this area must clearly demonstrate large scale manufacturing capability together with durability against multiple packing and deployment cycles without loss of expected performance. Phase I products should include gas generator design and integration concepts, with Phase II delivering a prototype system at a scale capable of inflating a 3-6 m demonstration article.

Focus Area 13: Information Technologies for Science Data

Participating MD(s): 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

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).

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. Thus 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 and software, accessibility, and workforce development.).

S5.02 Earth Science Applied Research and Decision Support
Lead Center: GSFC
Participating Center(s): JPL

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, land surface modeling, air quality and health.

This subtopic aims to connect and demonstrate the integration of NASA Earth science data and models into societal benefit areas with clear operational partners. 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/), NASA Earth Exchange – NEX (https://nex.nasa.gov/nex/), and SERVIR (http://www.nasa.gov/mission_pages/servir/). 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. 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/stakeholder organization 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 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.

S5.03 Enabling NASA Science through Large-Scale Data Processing and Analysis
Lead Center: GSFC
Participating Center(s): ARC, JPL, LaRC, MSFC, SSC

The size of NASA's observational data sets is growing dramatically as new mission data become available. In addition, NASA scientists continue to generate new models that regularly produce data sets of hundreds of terabytes or more. It is growing increasingly difficult for NASA to effectively analyze such large data sets for use within their science projects.

The following lists show representative examples of both observational and model generated data sets that are relevant to NASA science projects. This list is not meant to be all-inclusive, but rather to provide examples of data sets and to show the extent of the “Big Data” problems encountered by NASA. Some remote observation examples are the following:

- The HyspIRI mission is expected to produce an average science data rate of 800 million bits per second (Mbps).
- JPSS-1 will be 300 Mbps and NPP is already producing 300 Mbps, compared to 150 Mbps for the EOS-Terra, Aqua and Aura missions.
- SDO with a rate of 150 Mbps and 16.4 Gigabits for a single image from the HiRise camera on the Mars Reconnaissance Orbiter (MRO).
- Landsat and MODIS data sets continue to grow at extremely high rates.
- National Geospatial Agency (NGA) high-resolution imagery data of the Earth.

From the NASA climate models, some examples include:

- Reanalysis data sets such as MERRA (200 TB) MERRA2 (400 TB), and emerging reanalysis data sets with chemistry componets.
- Several high-resolution nudged and free running climate simulations have generated Petabytes of data (all publically releasable).

This subtopic area seeks innovative, unique, forward-looking, and replicable approaches for using “Big Data” for NASA science programs. The emphasis of this subtopic is on the creation of novel analytics, tools, infrastructure, and/or algorithms to enable high performance analytics across large observational and model data sets.

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 in the following areas (note that this list is not inclusive and is included to provide guidance for the proposers):

- New services, methods, and/or algorithms for high performance analytics that scale to extremely large data sets – of specific interest are the following:
    - Preference to employ machine and deep learning methods
    - Other techniques to be considered could cover data mining, searching, fusion, subsetting, discovery, and visualization
    - Automated derivation of analysis products in large data sets, that can then be utilized into Science models – the following are two representative examples
        - Extraction of features (e.g., volcanic thermal measurement, plume measurement, automated flood mapping, disturbance mapping, change detection, etc.).
        - Geospatial and temporal correlation of climate events (e.g., hurricanes, mesoscale convective systems, atmospheric rivers, etc.).
- New services, methods, and/or algorithms to enable in-situ, data proximal, parallel data analytics that will accelerate the access, analysis, and distribution of large Science datasets.
    - Use of open source data analytic tools to accelerate analytics is desired.
    - Application of these tools to structured, binary, scientific data sets.
    - Performing analytics across both physically collocated and geographically distributed data.
    - High performance file systems and abstractions, such as the use of object storage file systems.

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 software that is 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
Lead Center: JPL
Participating Center(s): GSFC, JSC, KSC

NASA seeks innovative systems modeling methods and tools to:

- Define, design, develop and execute future science missions, by developing and utilizing advanced methods and tools that empower more comprehensive, broader, and deeper system and subsystem modeling, while enabling these models to be developed earlier in the lifecycle. The capabilities should also allow for easier integration of disparate model types and be compatible with current agile design processes.
- Enable disciplined system analysis for the design of future missions, including modeling of decision support for those missions and integrated models of technical and programmatic aspects of future missions. Such models might also be made useful to evaluate technology alternatives and impacts, science valuation methods, and programmatic and/or architectural trades.

Specific areas of interest are listed below. Proposers are encouraged to address more than one of these areas with an approach that emphasizes integration with others on the list:

- Conceptual phase modeling and tools that assist design teams to develop, populate, and visualize very broad, multidimensional trade spaces; methods for characterizing and selecting optimum candidates from those trade spaces, particularly at the architectural level. There is specific interest in models that are able to easily compare architectural variants of systems.
- Capabilities to rapidly and collaboratively generate models of function or behavior of complex systems, at either the system or subsystem level. Such models should be capable of eliciting robust estimates of system performance given appropriate environments and activity timelines, and should be tailored:
    - To support design efforts at the conceptual and preliminary design phases, while being compatible with transition to later phases.
    - To operate within highly distributed, collaborative design environments, where models and/or infrastructure that support/encourage designers are geographically separated (including Open Innovation environments). This includes considerations associated with near-real-time (concurrent?) collaboration processes and associated model integration and configuration management practices.
    - To be capable of execution at variable levels of fidelity/uncertainty. Ideally, models should have the ability to quickly adjust fidelity to match the requirements of the simulation (e.g., from broad-and-shallow to in-depth).
- Processes, tools, and infrastructure to support modeling-as-design paradigms enabled by emerging model-based engineering (MBE) capabilities. MBE approaches allow a paradigm shift whereby integrated modeling becomes the inherent and explicit act of design, rather than a post hoc effort to represent designs converged using traditional methods. Modeling-as-design processes will first instantiate changes and/or refinements to models at all relevant levels, accompanied by frequent simulations that drive the integrated models to elicit performance of the system being designed.
- Target models (e.g., phenomenological or geophysical models) that represent planetary surfaces, interiors, atmospheres, etc. and associated tools and methods that allow them to be integrated into system design models and processes such that instrument responses can be simulated and used to influence design. These models may be algorithmic or numeric, but they should be useful to designers wishing to optimize systems remote sensing of those planets.

Focus Area 14: In-Space and Advanced Manufacturing

Participating MD(s): HEOMD, STMD

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 In-Space Manufacturing of Electronics and Avionics
Lead Center: MSFC
Participating Center(s): ARC

The purpose of this subtopic is to encourage highly collaborative research and development in the area of In-Space Printable Electronics capabilities geared towards laying the foundation and infrastructure for the next generation of in-space advanced electronics manufacturing technologies.

Hardware

3D Electronics Manufacturing Hardware Miniaturization and Adaptation for Microgravity Environment including but not limited to:

- Repackaging and modularization of commercially available state-of-the-art electronics printer platforms such as: aerosol jet, ink-jet, poly-jet, and fluidic dispensing systems.
- Addition of in-line 3D scanning metrology processes to existing printer platforms.
- Implementation of in-line laser and photonic sintering processes into existing electronics manufacturing platforms.
- Integration of advanced robotic and automation processes into printing processes to facilitate hybrid electronic manufacturing and assembly.
- Introduction of advance automated multi-material handling and delivery into electronics manufacturing processes.
- Incorporation of open source flexible hardware architectures into existing printer platforms to promote highly specialized and advance electronics manufacturing solutions.

Software

Advanced Software Development for Ultimate Portability and Autonomy for use in Microgravity based 3D Electronics Printers and Manufacturing Systems:

- Development of open-source flexible intuitive software environments and applications that integrate multiple electronic printing methodologies including but not limited to: aerosol jet, ink-jet, plasma-jet, FDM, fluidic and laser assisted dispensing.
- Improving existing open-source software platforms to support advanced open electronics printer hardware configurations and architectures to support the addition of cutting-edge metrology and digital manufacturing solutions.
- Introduction of advanced integrated design and manufacturing graphical user environments that support autonomous and tele-operation of 3D electronics printers and manufacturing systems.
- Implementation of Graphical user-friendly utilization cataloging and database software to support organization, classification, and utilization of in-space manufactured avionics.
- Development of new versatile algorithms and software processes geared towards 3D electronics printer robotic tool-path planning and routine development from inside electrical and mechanical design environment.

- Advance the state-of-the-art in portable mechanical and electrical design packages for in-space manufacturing through the development of integrated electrical and mechanical design software and tools that include support for in-space multi-material avionics parts production.

Phase I Objectives - Near term performance targets consist of electronics printer prototypes aimed at the in-space production of novel avionics products that are commonly based on passive electronic elements such as: resistors, capacitors, inductors, transformers, and diodes to supply on-orbit non-critical avionics parts production. Near term software targets will focus primarily on increasing portability and reliability of existing open software architectures for 3D printing to include support for in-space 3D electronics printing and multi-material advanced manufacturing processes. *Ending TRL 4 for Hardware and Software Prototypes.

Phase II Objectives - Mid-term objectives will seek to improve existing in-space electronics manufacturing capabilities to include higher complexity active electronic elements such as semiconductor based avionics products. *Ending TRL 5-6.

Phase III Objectives - Far-term objectives will include continued development of advanced in-space electronics manufacturing infrastructure and seek to introduce feasible concepts for deployable self-replicating and self-supporting avionics manufacturing architectures and systems. *Ending TRL 6-9.

H7.02 In-Space Manufacturing of Precision Parts
Lead Center: MSFC
Participating Center(s): GRC, LaRC

Currently, both 3D Printers onboard the International Space Station (ISS) use Fused Deposition Modeling (FDM), an additive manufacturing extrusion based process that builds up a plastic part layer by layer. Since this process is not dependent on buoyancy driven convection to achieve material consolidation, it is highly functional in the microgravity environment and no microgravity effects on material outcomes have been observed to date. To expand material capabilities and impart an ability to produce high-strength, precision components on-orbit, candidate metal manufacturing technologies are currently being investigated for adaptation to microgravity.

This part of the subtopic seeks to develop concepts for innovative manufacturing technologies for on-demand production of precision parts in the microgravity environment. For example, an innovative manufacturing solution could be a hybrid system that consists of an additive manufacturing process that can produce near-net shape parts and a traditional subtractive process that finishes the parts to the desired net shape. The quality of fabricated parts (dimensional accuracy, surface finish, etc.) should be comparable to what is achievable by a commercial off the shelf CNC machine.

This subtopic seeks innovative technologies in the following areas for in-space use:

- Innovative on-demand manufacturing technologies and techniques adaptable for use in the microgravity environment (such as hybrid additive and subtractive systems or other novel manufacturing techniques).
- Systems that address microgravity considerations such as debris / cutting fluid management and control of feedstock are of special interest.
- Preferred feedstock materials are aerospace metal alloys, however other materials such as high strength polymers, composites, and ceramics are also of interest.
- Easily scalable manufacturing technologies that can function using minimal power, mass, and volume due to operational constraints on space missions.

Phase I Deliverables - Feasibility study with proposed path forward to develop a full scale engineering unit in Phase II. Study should address operational constraints for system deployment on ISS such as system mass, volume, and power, as well as initial safety considerations such as material flammability, toxicity, and handling. It is desirable to have a bench top proof-of-concept/laboratory demonstration, including samples and test data, proving the proposed approach to develop an engineering unit in Phase II (TRL 3-5).

Phase II Deliverables - Functional Engineering Unit of proposed product. Full report of development and test data, including relevant material test data for samples produced by the Engineering Unit (TRL 5-6). Report should also address how the design will meet flight certification and safety requirements

Phase III Deliverables - Flight Unit for International Space Station Technology Demonstration Payload. Phase III deliverable includes all supporting documentation for flight certification, safety requirements, and operations.

Z3.01 In-Situ Sensing of Additive Manufacturing Processes for Safety-Critical Aerospace Applications
Lead Center: MSFC
Participating Center(s): ARC, GRC, LaRC

NASA programs are embracing Additive Manufacturing (AM) technologies for their potential to increase the affordability of propulsion parts and components by offering significant schedule and cost savings over traditional manufacturing methods. Many NASA programs baseline AM components in their design, however qualification efforts are complicated by the absence of industry-accepted standards and process controls. The near-term methodology for part quality assurance is to use pre-process and post-process measurements to show that a part design and as-built hardware meet the established requirements to safely and reliably complete the intended mission. This method relies heavily on the ability to non-destructively evaluate parts to identify process escapes resulting in flaws in the AM parts. For parts of complex geometry, which is often the motivation toward AM, post-build inspections can be limited. The long-term goal of part qualification is to "qualify as you go." This concept uses pre-process, in-process, and post-process measurements to demonstrate that a part will perform to requirements. Successful technology demonstration has the potential to reduce scrap rates, and the cost and quantity of post-build NDE required for part qualification.

The principal desired outcome of this subtopic is to develop reliable in-process sensing and monitoring technologies for powder bed fusion (PBF) AM processes to aid in the quality of processes used to produce critical components for aerospace applications. Current AM PBF technologies run with limited or no process feedback; therefore, the ability to rely on process control alone is limited and the ability to non-destructively inspect AM parts is critical to the flight rationale for fracture critical components. The ability to augment AM process controls with verifiable feedback regarding process stability and part quality will significantly reduce the risk associated with complex AM parts that cannot be readily inspected with available non-destructive evaluation methods. The objective of the subtopic is to support activities that provide a foundation for practical application of AM sensing and monitoring technology in the aerospace sector, and also enable and stimulate development and innovation within the topic area. Supported activities will be based on long-term vision and the immediate needs of NASA programs and projects.

Specific research objectives include:

- Sensing technologies for layer-by-layer quality confirmation.
- In-process monitoring and sensing to detect off-nominal process conditions or defects.
- In-process monitoring and sensing for melt pool characterization.
- Predictive modeling of system response to sensing-related process changes.
- Multi-physics modeling of AM process as related to monitored quantities.

Z3.02 Advanced Metallic Materials and Processes Innovation
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 boron nitride nanotube (BNNT) reinforced metal matrix composites (MMCs). Topic areas for solid state welding revolve around joining high melting point metallic materials including combinations of these higher melting point metals—preferably using solid state welding processes such as friction stir, thermal stir, and ultrasonic stir welding. Higher melting point materials include the nickel based superalloys such as Inconel 718, Inconel 625, titanium alloys such as Ti-6Al-4V, GRCop, and Mondaloy. The technology needs for solid state welding should be focused on process improvement, structural efficiency, quality, and reliability for higher temperature propulsion and propulsion-related components and hardware.

The primary objectives of this technology area include:

- 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.

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 certification and the use of AM hardware. The metallic AM topic area needs are concentrated on advancing the state of the art for powder bed fusion and/or directed energy wire deposition processes.

The primary objectives are focused on process improvements and include:

- 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.
- Linking process parameters to mechanical properties, microstructure, grain texture and grain size through empirical observations, real time process monitoring, or modeling.
- In-situ assessment or process monitoring of grain size, defect detection, build anomalies, and defect repair.
- Improved thermal monitoring and control hardware and methods to minimize build-to-build variations and microstructural anomalies.
- 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 for certification.

The goal of work supporting this area is to help build the knowledge needed to support certification of AM hardware. In the specialty materials processing area, the focus for this solicitation is on bulk metallic glasses (BMG) and BNNT reinforced MMCs. Specific areas of interest relate to optimized processing to fabricate these materials while retaining their unique microstructures and properties.

Of specific interest for BNNT MMCs are innovative processing methods that:

- Achieve uniform distribution and alignment of BNNTs within the metal matrix.
- Minimize the formation of brittle phases at the “reinforcing agent / metal” interface.

Product forms of interest include continuously- or discontinuously- reinforced nano-composites, and hybrid laminate materials. Improved processing may involve modifying incumbent methods such as powder metallurgy, melting/solidification, thermal spray, and electrochemical deposition or introduction of new method. The success of proposed processing improvements will be measured by increases in tensile strength achieved over existing alloys. Consequently, proposals must include characterization and testing of the fabricated materials.

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 and structures of high dimensional accuracy and precision (from nm to cm scales). 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.

Focus Area 15: Lightweight Materials, Structures, Assembly, and Construction

Participating MD(s): HEOMD, STMD

As NASA strives to explore deeper into space than ever before lightweight structures and advanced materials have been identified as a critical need for NASA space missions. The Lightweight Materials, Structures and 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. Improvement in all of these areas is critical to future missions. Applications include structures and materials for launch, in-space, deployable nondestructive evaluation, integrated structural health monitoring (SHM) and surface systems. 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.

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
Lead Center: LaRC
Participating Center(s): GRC

Initial manned missions to the Mars surface may use large photovoltaic (PV) solar arrays to generate power for habitats, ISRU, science investigations, and battery charging. Nominal overall size of the solar array "farm" is 2500 m^2. Because of the critical nature of electrical power, this equipment may be prepositioned and validated prior to human landings. Modular solar array designs could be based on individual deployable structures with 50-150 m^2 of area each. Another approach could be a single monolithic structure. Regardless of the configuration, autonomous deployment/assembly is assumed to be required.

This subtopic seeks innovations in lightweight structures, robust deployment/retraction mechanisms, and autonomous assembly focusing on the process of post-landing deployment and erection of a large solar power system on the surface of Mars. Each lander might have its own modular power system that could be relocated closer to the loads to reduce cabling lengths and grow available power as the human Mars base grows.

Design guidelines for these autonomously deployed Mars solar array structures are:

- 2500 m^2 total solar cell area; < 5000 kg total mass including all mechanical and electrical components; and < 20 m^3 total launch volume.
- Loads: 5 g axial, 2 g lateral, 145 dB OASPL for launch and 50 m/s Mars surface winds. Ideally > 1 g deployed strength to allow unconstrained Earth deployment qualification.
- Capable of being optionally deployed on lander, offloaded and transported to another site, and then optionally interfaced with other power units.
- Deployable/retractable at -50° C on terrain with up to 0.5 m obstacles and 15 deg slopes. Operating height > 1 m to avoid wind-blown sand collection.
- Integrated dust mitigation and abatement methods. Dust accumulation is the #1 design risk issue for sustained PV power production on Mars.
- Tolerant of daily thermal cycling from -100° C to 25° C over a lifetime of 10 years.
- Concept of operations (ConOps) including transportation and robotic assembly aids and all design assumptions must be clearly defined.

This subtopic seeks innovations in the following areas for Mars solar array structures:

- Novel packaging, deployment, retraction, dust-abatement, or in-situ manufacturing concepts.
- Lightweight, compact components including booms, ribs, substrates, and mechanisms.
- 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 mechanical design innovations, not PV, 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 modular designs that are self-supporting in 1 g and can be autonomously deployed, retracted, relocated, and optionally interfaced with other power sources at least twice after months of operation on the Mars surface. Sharing of conceptual CAD models and analyses with NASA for mission studies, and delivery of prototype hardware to NASA at the end of Phase II for independent testing, are highly encouraged.

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:

- Tom Kerslake, "Solar Electric Power System Analyses for Mars Surface Missions," 1999, http://ntrs.nasa.gov/search.jsp?R=19990063893.
- Robert Cataldo, "Power Requirements for NASA Mars Design Reference Architecture 5.0," 2009, http://ntrs.nasa.gov/search.jsp?R=20120012929.
- Mars landing site concept animation, "Mars Exploration Zones," 2015, https://www.youtube.com/watch?v=94bIW7e1Otg&sns=em.

Z4.01 In-Space Structural Assembly and Construction
Lead Center: LaRC
Participating Center(s): GSFC, MSFC

Spacecraft that use modularity can be adaptable to changing needs particularly when open architectures with common interfaces are employed in the design. The ability to join spacecraft components autonomously in-space allows for the assembly of vehicles (perhaps aggregated from multiple launches) and for re-use of vehicle subsystems. Modular "plug and play" interfaces permit rapid assembly, upgrade and reconfiguration of spacecraft subsystems and instruments. The joining technology used for module interfaces should be reversible for maximum flexibility and utilize simple approaches (electro-mechanical or other) amenable to robotic assembly and disassembly. In addition, the joining technology must provide for mechanical, electrical and optionally thermal load transfer.

This subtopic seeks innovative spacecraft open architectures enabled by modularity and common interfaces that can be joined using autonomous robotic operations. Innovative joining technologies and capabilities are sought for in-space assembly, disassembly, and re-use of space exploration vehicles. Additionally, joint designs that support modular "plug and play" interfaces for upgrade and reconfiguration of spacecraft subsystems are sought. In-space joining of structural trusses that support multiple solar arrays for solar electric propulsion is one class of needed joint technology. The assembled truss must provide power connections either integral to the structural joint or as a non-mechanical load bearing harness with connectors. The second class of in-space joining is for modular subsystems nominally three-dimensional platforms (square or rectangular) with power, data, and mechanical load carrying connections. While these modules could represent orbital replacement units (ORUs), the modules could serve to construct an entire space vehicle.

Specific Research Objectives include:

- Innovative connection approaches/architectures that enable on-orbit geometry adaptation. Areas of interest include structural connections, electrical connections, fluid connections, thermal connections or combinations of these.
- Methods for in-situ connection verification (smart joints).
- Innovative reversible joining systems for robotic operations that minimize mass, energy and complexity while maximizing assembled stiffness, strength, stability, heat transfer, power density, etc.

Application orbits include LEO/GEO/Lunar. Nominal mechanical joining requirements are:

- Class 1: Structural Truss Joints.
  - Strength: 100N to 500N axial target
- Class 2: Module Joints.

- Strength: > 0.4 g (Mars Extensible) with 0.25 meter cubic module connected on one face with uniform density of 640 Kg/m3.
- Current from milliamp to amps per contact.
    - Voltage 28 to 100V DC
- Assembly/Disassembly: 20-50 times.

References:

- Barnhart, David; Will, Peter; Sullivan, Brook; Hunter, Roger; and Hill, Lisa: "Creating a Sustainable Assembly Architecture for Next-Gen Space: The Phoenix Effect," 30th Space Symposium, May 2014, Colorado Springs CO.
- Erkorkmaz, Catherine; Nimelman, Menachem; and Ogilvie, Andrew: "Spacecraft Payload Modularization for Operationally Responsive Space," 6th Responsive Space Conference, April 28-May 1, 2008, Los Angeles, CA.
- Troutman, Patrick A.; Krizan, Shawn A; Mazanek, Daniel D.; Stillwagen, Frederic H.; Antol, Jeffrey; Sarver-Verhey Timothy R.; Chato, David J.; Saucillo, Rudolf J.; Blue, Douglas R.; and Carey, David: "Orbital Aggregation and Space Infrastructure Systems (OASIS)", IAC-02-IAA.13.2.06, 53rd International Astronautical Congress, 10-19 Oct. 2002, Houston Texas.

Z11.01 NDE Sensors
Lead Center: LaRC
Participating Center(s): ARC, GRC, GSFC, JPL, JSC, KSC, LaRC, MSFC
Related Subtopic Pointers: A1.01, Z11.02

Technologies sought under this SBIR program can be defined as advanced sensors, sensor systems, sensor techniques or software that enhance or expand NASA's 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 I's 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 interested in the simulation and analysis of NDE data, please see Subtopic Z11.02 - NDE Simulation and Analysis.

For proposers with an interest in airframes, please see Subtopic A1.01 - Structural Efficiency - Tailored Airframes and Structures.

Z11.02 NDE Simulation and Analysis
Lead Center: LaRC
Participating Center(s): ARC, JSC
Related Subtopic Pointers: Z11.01

Technologies sought under this subtopic include near real-time large scale nondestructive evaluation (NDE) and structural health monitoring (SHM) simulations and automated data reduction/analysis methods for large data sets. Simulations techniques will seek to expand NASA's use of physics based models to predict inspection coverage for complex aerospace components and structures. Analysis techniques should include optimized automated reduction of NDE/SHM data for enhanced interpretation appropriate for detection/characterization of critical flaws in space flight structures and components. Space flight structures will include light weight structural materials such as composites and thin metals. Future purposes will include application to long duration space vehicles, as well as validation of SHM systems. It is also considered highly desirable to develop tools for automating detection of material Foreign Object Debris (FOD) and/or defects and evaluation of bondline and in-depth integrity for light-weight rigid and/or flexible ablative materials are sought. Typical internal void volume detection requirements for ablative materials are on the order of less than 6mm and bondline defect detection requirements are less than 25mm.

Techniques sought include advanced material-energy interaction (i.e., NDE) simulations for high-strength lightweight material systems and include energy interaction with realistic damage types in complex 3D component geometries (such as bonded/built-up structures). Primary material systems can include metals but it is highly desirable to target composite structures and/or thermal protection systems. NDE/SHM techniques for simulation can include ultrasonic, laser, Micro-wave, Terahertz, Infra-red, X-ray, X-ray Computed Tomography, Fiber Optic, backscatter X-Ray and eddy current. It is assumed that any data analysis methods will be focused on NDE techniques with high resolution high volume data. Modeling efforts should be physics based and it is desired they can account for material aging characteristics and induced damage, such as micrometeoroid impact. Examples of damage states of interest include delamination, microcracking, porosity, fiber breakage. Techniques sought for data reduction/interpretation will yield automated and accurate results to improve quantitative data interpretation to reduce large amounts of NDE/SHM data into a meaningful characterization of the structure. Realistic computational methods for validating SHM systems are also desirable. It is advantageous to use co-processor configurations for simulation and data reduction. Co-Processor configurations can include graphics processing units (GPU), system on a chip (SOC), field-programmable gate array (FPGA) and Intel's Many Integrated Core (MIC) Architecture. Combined simulation and data reduction/interpretation techniques should demonstrate ability to guide the development of optimized NDE/SHM techniques, lead to improved inspection coverage predictions, and yield quantitative data interpretation for damage characterization.

Phase I Deliverables - Feasibility study, including demonstration simulations and data interpretation algorithms, proving the proposed approach to develop a given product (TRL 2-4). Plan for Phase II including proposed verification methods.

Phase II Deliverables - Software of proposed product, along with full report of development and test results, including verification methods (TRL 5-6). Opportunities and plans should also be identified and summarized for potential commercialization.

Potential NASA Customers include:

- Space exploration missions such as missions to Asteroids, Mars or various Earth-Moon Liberation Waypoints.
- International Space Station.

For proposers with an interest in the sensors used in NDE, please see Subtopic Z11.01 - NDE Sensors.

Focus Area 16: Ground and Launch Processing
Participating MD(s): 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 focus area 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.

H10.01 Advanced Propulsion Systems Ground Test Technology
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 the 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 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 project 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.

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 efficiency 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 Improved Operations via Interface Design
Lead Center: KSC
Participating Center(s): AFRC, SSC

This subtopic seeks to simplify prelaunch and surface operations through improved interface design concepts. Development and adoption of improved, standardized interfaces holds the potential of reducing the cost and complexity of future space systems and their related design and implementation, which can increase the funding available for additional flight hardware.

NASA is interested in areas of interface technology that lower launch vehicle operations costs and provide evolution paths for in-space exploration. This includes interfaces between systems normally present within a launch system. For the purpose of this subtopic a launch system includes a vehicle ready for flight with payload, and includes all related support systems and infrastructure.

A substantial portion of pre-launch processing involves the integration of spacecraft assemblies to each other or to the ground/surface systems that supply the commodities, power or data. Each assembly requires a reliable interface that connects it to the adjacent hardware which includes flight critical seals or connectors and other components.

The benefits of standardized, simplified interfaces are particularly strong for small launch vehicles. Due to a lack of common specifications and standards, each launch vehicle system may impose different interface requirements thereby resulting in unique components/subsystems tailored for each vehicle. This complicates recent efforts to establish a multi-user capability within the existing launch infrastructure. For the launch provider, unique interface requirements result in higher recurring cost per launch vehicle and reduced ability to incorporate newer subsystems as the vehicle matures.

Future activities at exploration destinations in space and on other surfaces will rely on a combination of structures and systems working together with a high degree of reliability. The impact of these interface-dependent tasks are of particular concern for surface systems where the additional work must be accomplished by crew performing Extra-Vehicular Activities (EVAs) or by purpose-built robotic systems. Areas of interface technology development relevant for surface operations may include (but are not limited to) cryogenics, modular systems, dust tolerance, standardized disconnects, and embedded intelligence.

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 to identify and evaluate candidate technology applications, 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. 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.

Phase II Deliverables - Emphasis should be placed on developing and demonstrating the technology under simulated operational conditions with analog earth-based systems including dynamic events such as commodity loading, disconnect or engine testing. The proposal shall outline a path showing how the technology could be developed into or applied to mission-worthy systems. The contract should deliver demonstration hardware for functional and environmental testing at the completion of the Phase II contract. The technology concept at the end of Phase II should be at a TRL of 5 or higher.

H10.03 Cryogenic Purge Gas Recovery and Reclamation
Lead Center: SSC
Participating Center(s): GRC, KSC

Helium is becoming a major issue for NASA and the country. Helium is used as a purge gas to reduce the concentration of hydrogen below the flammable threshold at test and launch complexes. Most of the Nation's helium comes from the National Helium Reserve operated by the Bureau of Land Management (BLM). The statutory authority for BLM to operate is expiring and responsibility is being transferred to the commercial sector. Helium is a non-renewable gas that is in limited supply. There are already helium supply constrictions and prices are going up. Conservation and/or reuse of this non-renewable resource would substantially reduce the cost of operating NASA's test and launch facilities.

Specific areas of interest include the following technologies:

- Development of non-proton exchange helium/hydrogen gas separation technologies.
- Technologies for the rapid capture and safe storage of high volumes of mixed helium/hydrogen gas mixtures.
- Development of zero trapped gas system technologies to improve purge effectiveness.
- Development of sensor technologies that can validate that recycled gases meet stringent cleanliness levels of Table 2 of MSFC-STD-3535.

Focus Area 17: Thermal Management Systems

Participating MD(s): SMD, STMD

All spacecraft, regardless of size or power consumption, must be able to manage the flow of heat and energy. Temperatures must be maintained within design limits, whether those be cryogenic systems for science instruments, or comfortable shirt sleeve operations temperatures for crew missions. NASA seeks components for both active and passive thermal systems that collect heat, transport heat, and reject heat, or insulate components to prevent the flow of heat. These components may be designed to operate in challenging temperature ranges, and must survive mission environments such as launch, space vacuum, or planetary surfaces. They also must be highly efficient and lightweight to minimize use of launch mass and power allocations.

S3.06 Thermal Control Systems

Lead Center: GSFC
Participating Center(s): ARC, JPL, JSC, LaRC, MSFC

Future Spacecraft and instruments for NASA's Science Mission Directorate will require increasingly sophisticated thermal control technology. Innovative proposals for the cross-cutting thermal control discipline are sought in the following areas:

- Advanced thermal devices capable of maintaining components within their specified temperature ranges are needed for future advanced spacecraft. Some examples are:
    - Phase change systems with high thermal capacity and minimal structural mass.
    - High performance, low cost insulation systems for diverse environments.
    - High flux heat acquisition and transport devices.
    - Thermal coatings with low absorptance, high emittance, and good electrical conductivity.
    - Radiator heat rejection turndown devices (e.g., mini heat switches, mini louvers).
    - Miniature pumped fluid loop systems with passive valve for radiator heat rejection turndown, and consumes minimal power.
- Current capillary heat transfer devices require tedious processes to insert the porous wick into the evaporator and to seal the wick ends for liquid and vapor separation. Advanced technology such as additive manufacturing is needed to simplify the processes and ensure good sealing at both ends of the wick. Additive manufacturing technology can also be used to produce integrated heat exchangers for pumped fluid loops in order to increase heat transfer performance while significantly reducing mass, labor and cost.
- Science missions are more dependent on optically sensitive instruments and systems, and effects of thermal distortion on the performance of the system are critical. Current Structural-Thermal-Optical (STOP) analysis has several codes that do some form of integrated analysis, but none that have the capability to analyze any optical system and do a full end-to-end analysis. An improvement of existing code is needed in order to yield software that can integrate with all commonly used programs at NASA for mechanical, structural, thermal and optical analysis. The software should be user-friendly, and allow full STOP analysis for performance predictions based on mechanical design, and structural/thermal material properties.
- Thermoelectric converts (TEC) have advantages of small size, long life, solid state design, and no moving parts or fluid operation, and have been used on many science instruments requiring dedicated/localized cooling to meet their stringent requirements. However, they have historically exhibited poor efficiency and have not been able to provide the cold temperatures needed by certain types of space science instruments. Research and development in areas of advanced materials, processes, and designs are needed in order to improve its efficiency, and extend its low temperature (<90K) capability for space science application.
- Water has been used in two-phase thermal control devices such as heat pipes due to its high heat transport capability. However, water has two main drawbacks that limit its use in many aerospace applications. Its expansion upon freezing creates a concern about rupture of the heat pipe and the concern for reliable startup from an initially frozen state. Water-containing azeotropes, which behave as a single-component working

fluid, can offer substantial benefits as alternatives to use of pure water for applications where freeze/thaw and frozen startup concerns exist. High-performance water azeotropes which can lower the freezing point of water below -40°C while providing improved reliability for aerospace thermal control systems are needed.

- Three-dimensional (3D) integrated circuits (ICs) offer unprecedented functionality and efficiency in small form factors, but their operation is constrained by the current remote cooling paradigm that relies on conduction and heat spreading across multiple interfaces. An embedded approach, which facilitates in-situ cooling of the chip stack is needed. Such a cooling device must also accommodate high heat fluxes and minimize the thermal resistance between the heat source and sink.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration. Phase II should deliver a demonstration unit for NASA testing at the completion of the Phase II contract.

Note to Proposers - Cubesat thermal technologies have been moved to a new STMD subtopic: Z8.03 Small Spacecraft Power and Thermal Control

Z2.01 Thermal Management
Lead Center: JSC
Participating Center(s): GRC, GSFC, JPL, MSFC

Exploration Vehicle Thermal Systems

Variable Heat Rejection Technologies

Exploration vehicles require variable heat rejection due to the potential to operate in environments ranging from full sun on one side to a cold deep space environment, while rejecting a range of waste heat loads. NASA Technology Roadmap Area 14 identifies a turn down goal of 6 to 1 for a thermal control system. Room temperature thermal control systems are sought that are sized for nominal operation in full sun exposure, yet are able to maintain set point control and stable operation at one-sixth of their design heat load when in a deep space (0°K) environment. Solutions for variable heat rejection may include novel architectures, novel thermal control fluids, advanced radiator technologies, and/or variable working fluid/radiator conductance. Radiator-based technologies should have an areal mass no greater than 5.8 kg/m^2.

Advanced-Closed Loop Extravehicular Activity Thermal Control

NASA continues to evolve space suit technology for exploration missions; however, the portable life support system (PLSS) includes a water evaporator to reject waste energy produced by the suit. Closed-loop, non-venting thermal heat rejection systems that are capable of rejecting heat in the Martian atmosphere are needed to create a PLSS that minimizes consumable use and does not impact the Mars environment. NASA seeks novel approaches to close the thermal control system of the space suit, targeting 80% or greater reductions in evaporated water mass for the same heat rejection. However, the mass and volume of the system must be limited as it must be carried on the crewmember's back. Approaches may include novel radiative approaches and/or desiccant systems to reclaim evaporants, as well as other novel solutions. Examples of such technologies and goals are outlined in NASA's Technology Roadmap Area 06, but more innovative concepts are also sought.

Advanced Heat Exchangers and Coldplates

Air/liquid heat exchangers (HXs), liquid/liquid HXs, and coldplates are at the core of any active thermal control system for a space vehicle. While these individual components are small, they are found throughout spacecraft vehicles and their cumulative mass and volume is significant. Advances in materials or manufacturing may yield a considerable mass savings over the current state of the art heat exchangers. NASA's Technology Roadmap Area 14 details various points of interest for these heat exchangers, and key goals are listed below:

- Corrosion resistant coldplates with less than the state of the art 8.8 kg/m^2 mass per area.
- Heat exchangers with minimal structural mass and good thermal performance to reduce mass below 2 kg/kW of heat transfer, assuming delta-T on the order of 5°C.
- Condensing heat exchangers (air/liquid heat exchangers) for closed loop life support, achieving highly reliable 3-year minimum lifetime, not contaminated by microbial growth, and whose coatings do not impact the life support system's water recovery system.

High Lift Heat Pumping Devices

Heat pumps are needed to reject spacecraft waste heat to a higher temperature sink. At lunar equatorial locations, lunar surface temperatures can climb to 400°K, making it difficult to reject waste heat at nominal temperatures. A more severe application involves rejecting waste heat for a Venus lander where environmental sink temperatures can exceed 700°K. Ground-based designs that do not rely on gravity for elements of heat pump operation, such as lubricant management, contaminant control, or phase separation, are a reasonable starting point for a high lift heat pump device for extreme environment applications. However, these designs must be adapted or proven to work in space applications. Intermittent operation in microgravity, low gravity, and/or in severe environments, such as hard vacuum, radiation, and extreme temperatures, are significant challenges to viable space-based heat pumps. NASA seeks targeted improvements for space-based heat pump technology, which may include exceptionally long life, low mass, and operation with high temperature lifts (50°C or more) and a coefficient of performance at least at 30% of Carnot efficiency.

Thermal Insulation for Pressurized Environments

To enable longer duration missions to the surface of Venus, advanced insulation systems are required. External insulation on a Venus lander pressure vessel allows the system to take advantage of the thermal mass of the pressure vessel and reduce the heat transfer rate into the pressure vessel. The goal is to extend mission lifetime to collect and transmit more science data by allowing multiple communication passes with an orbiter. In addition to Venus in-situ explorers, this insulation can be used for future deep atmospheric probes for gas giant planets, or even in high temperature and pressure chemical processes in other systems. The current state-of-the-art in insulation systems considered for the Venus atmosphere are heavy, fragile and difficult to implement on the exterior of a pressure vessel. NASA seeks a lightweight, flexible insulation system that can be accommodated on the exterior of a pressure vessel. The insulation thermal conductivity should be less than 0.1 W/m-K at 470°C and 90 bar pressure in a carbon dioxide environment.

Focus Area 18: Air Vehicle Technology

Participating MD(s): ARMD

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 (2015).

A1.01 Structural Efficiency-Tailored Airframe & Structures
Lead Center: LaRC
Participating Center(s): AFRC

A primary goal of structural efficiency is to reduce structural mass. Reduced mass has the direct benefit of fuel burn savings, and it also influences noise and emissions by enabling advances in airframe configurations and in propulsion. The state of the art for lightweight airframe structures are carbon fiber reinforced polymeric composite structures which make up approximately 50% of the weight of Boeing's 787. Further improvements in structural efficiency above the state of the art are possible with tailored materials and structures. Tailored materials can improve the mechanical properties that directly affect structural mass, can provide functional properties that eliminate systems that add parasitic mass (e.g., to accommodate thermal, electrical, acoustic loads), or both. Tailored structures can improve the structural efficiency of existing airframe configurations and can enable new, non-traditional airframes. The tailoring covered for this subtopic solicitation is intended to apply to fuselage structures, and is further focused on one or more of the following:

- Tailoring mechanical properties beyond the state of the art by taking advantage of newly available product forms and precision robotic fabrication such as to control composite ply thicknesses and orientations
- Tailoring mechanical and functional properties through “designer microstructures” such as alloys that enhance fatigue, polymer composites with advanced fibers and/or nanostructured constituents, or hybrid metal-composite laminates, where the additional functional capability eliminates a parasitic mass (e.g., lightning protection, cooling systems, acoustic dampening)
- Design and analysis codes that enable development of structural concepts that utilize the aforementioned tailored properties, product forms, and fabrication processes to developed fuselage structures for traditional tube-wing and for advanced configurations.

For this subtopic, the Phase I proposal should identify an airframe component/application that would be the target of the tailored material and/or structural approach, should describe how the proposed approach would provide a significant improvement in structural efficiency over the state of the art, and should describe how the feasibility of the innovation to achieve this improvement will be demonstrated in a Phase I effort. 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 identified in Phase I.

Note: This subtopic is distinctly addressing materials (including product forms and processing), structures and design technologies as they relate to tailored airframe structures. If you are interested in proposing technologies addressing sensors, simulation, and analysis for NDE (and specifically how they relate to space technology) you should NOT propose to this subtopic but instead view subtopics ID# 130 and 131.

A1.02 Quiet Performance - Airframe Noise Reduction
Lead Center: LaRC
Participating Center(s): GRC

Innovative technologies and methods are necessary for the design and development of efficient, environmentally acceptable aircraft. In support of the Advanced Air Vehicles, Integrated Aviation Systems and Transformative Aero Concepts Programs, improvements in noise prediction, acoustic and relevant flow field measurement methods, noise propagation and noise control are needed for subsonic, transonic and supersonic vehicles targeted specifically at airframe noise sources and the noise sources due to the aerodynamic and acoustic interaction of airframe and engines. Innovations in the following specific areas are solicited:

- Fundamental and applied computational fluid dynamics techniques for aeroacoustic analysis, which can be adapted for design purposes.

- Prediction of aerodynamic noise sources including those from the airframe and those that arise from significant interactions between airframe and propulsion systems including those relating to sonic boom.
- Prediction of sound propagation from the aircraft through a complex atmosphere to the ground. This should include interaction between noise sources and the airframe and its flow field.
- Propagation of sonic boom through realistic atmospheres, especially turbulence effects.
- Innovative source identification techniques for airframe (e.g., landing gear, high lift systems) noise sources, including turbulence details related to flow-induced noise typical of separated flow regions, vortices, shear layers, etc.
- Concepts for active and passive control of aeroacoustic noise sources for conventional and advanced aircraft configurations, including adaptive flow control technologies, and noise control technology and methods that are enabled by advanced aircraft configurations, including integrated airframe-propulsion control methodologies. Innovative acoustic liner and porous surface concepts for the reduction of airframe noise sources and/or propulsion/airframe interaction are solicited but engine nacelle liner applications are specifically excluded.
- Concepts for novel acoustic calibration sources for both open- and closed-wall wind tunnel testing. Such sources should provide well-defined acoustic characteristics both without and with flow for typical frequency ranges of interest in scale-model wind tunnel testing, for the purposes of magnitude and phase calibration for both single microphones and microphone phased arrays.
- Development of synthesis and auditory display technologies for subjective assessments of aircraft community noise, including sonic boom.

A1.03 Low Emissions Propulsion and Power-Turboelectric and Hybrid Electric Aircraft Propulsion
Lead Center: GRC
Participating Center(s): AFRC, LaRC

Proposals are sought for the development of enabling power systems, electric machines, power converters, and related materials that will be required for future small (9 + pax) to large (500 + pax) commercial transport vehicles which use turboelectric or hybrid electric power generation as part of the propulsion system. Turboelectric and hybrid electric power generation as well as distributed propulsive power have been identified as candidate transformative aircraft configurations with reduced fuel burn 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 transport-class aircraft. Novel developments are sought in:

Power Systems:

- Aircraft power systems operating above 1000V.
- Novel power system topologies that minimize the weight and electrical losses.

Power Components:

- Electric machines (motors/generators) with efficiency >98% and specific power>13 kW/kg, power >200kW.
- Converters (inverters/rectifiers) with efficiency>99% and specific power>19kW/kg, power >200kW.
- Circuit protection devices significantly lighter and with lower losses than the state of the art.
- Aircraft Energy Storage:
    - Rechargeable energy storage with usable specific energy at the integrated level (packaging and power management system included) >500 W-hr / kg.
    - Rechargeable energy storage with usable specific energy at the integrated level (packaging and power management system included) >250 W-hr / kg, >5C charge rate and full discharge cycle life>10,000 cycles.

Materials:

- Soft magnetic material with magnetic saturation >2.5 T.
- Hard magnetic materials with an energy product greater than neodymium iron boron.
- Conductors with a specific resistivity less than copper.
- Cable insulation materials with significantly higher dielectric strength and thermal conductivity than the state of the art.

Individual components should target the 50kW-3MW size range and would be combined into power systems in the range of 500kW-10MW total power.

A1.04 Aerodynamic Efficiency-Active Flow Control Actuators and Design Tools
Lead Center: LaRC
Participating Center(s): AFRC

NASA's Aeronautical Research Mission Directorate (ARMD) has developed the Strategic Implementation Plan (SIP) that describes its research plan for advancing aeronautics research to meet the aviation industry's demands over the next 25 years and beyond. One element of the plan focuses on developing ultra-efficient commercial vehicles. Improved vehicle efficiency will be achieved by reducing fuel burn and emissions. Active flow control (AFC) is a technology that has the potential to aid in achieving the efficiency goals of the next two generations of commercial vehicles. Active flow control is the on-demand addition of energy into a boundary layer for maintaining, recovering, or improving vehicle performance. AFC actuation methods have included steady mass transfer via suction or blowing, and unsteady perturbations created by zero net mass flux actuators, pulsed jets, and fluidic oscillators. Previous wind tunnel and flight tests demonstrated that this technology is capable of improving vehicle performance by reducing and/or eliminating separation and increasing circulation. When integrated into a transport aircraft, therefore, AFC would result in smaller control surfaces creating less drag and thereby less fuel consumption during flight. Widespread application of the technology on commercial transports, however, requires that AFC actuation systems be energy-efficient, reliant, and robust. Another challenging aspect of the design of the actuation system involves understanding how and where to integrate the actuator into the vehicle. Computational tool development is needed, in parallel with actuator development, to enable a more synergistic approach to active flow control system design thus maximizing the potential benefits of an AFC system.

This solicitation is for innovative AFC actuator concepts and design tools, applicable to subsonic transports and/or civil aircraft that incorporate vertical lift capability, that take advantage of reduced order models to develop AFC actuators and AFC actuation systems that will aid in advancing AFC technology.

Areas of specific interest where research is solicited include but are not limited to the following:

- Development of simple, low-cost, and efficient tools for modeling AFC actuator performance.
- Development of design tools for optimizing AFC actuator system integration.
- Development of actuator concepts capable of controlling separation due to large adverse pressure gradients or shock/boundary layer interactions.
- Development of novel, energy-efficient, and robust actuation systems.
- Development of closed-loop active flow control systems with demonstrated improvements in AFC efficiency measured by the energy consumed by the AFC actuator.
- Experimental or computational studies that demonstrate the efficiency of a proposed actuation system.

A1.05 Computational Methods & Tools - High Fidelity Mesh and Geometry Tools
Lead Center: LaRC
Participating Center(s): AFRC, GRC

During 2012-2014, NASA sponsored a study aimed at determining future directions for Computational Fluid Dynamics (CFD) research that would subsequently enable significant advancements in aeronautics. This study (CFD 2030 Study: A Path to Revolutionary Computational Aerosciences (http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140003093.pdf), noted many shortcomings in the existing technologies used for conducting high-fidelity simulations, and made specific recommendations for investments necessary to overcome these challenges. Chief among the recommendations was the need for robust higher-order discretization schemes, scalable solvers on high-performance computing (HPC) platforms, and adaptive h-p mesh refinement. 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. Similarly, providing access to the underlying geometry definition, as needed for both high-order simulations and adaptive gridding, is currently not available and is a further roadblock to the ubiquitous use of these technologies.

In the area of geometry definition, a critical need arises from the fact that laser scans of the aircraft surfaces are often used to generate computer aided design (CAD) files. This often leads to surface geometries with unphysical surface waviness as part of the surface fitting process of the laser scan point clouds resulting in poor CFD meshes and, hence, erroneous CFD solutions. Also, in some cases the CAD geometry is only represented as a tessellated surface while continuous and differentiable surfaces are needed for meshes that would yield accurate solutions and accurate mesh refinement results. A tool that could remove unphysical surface waviness as well as fit tessellated CAD surfaces and output a continuous and watertight spline surface is needed for practical applications.

To enable accurate CFD solutions, proposals are solicited in two areas:

- To develop robust means for generating meshes suitable for high-order accurate flow solvers, that can be demonstrated not to compromise the accuracy of the simulations. The three-dimensional unstructured grid tool developed during this research effort should be capable of creating mixed-element meshes. In conjunction with these meshes, geometry information must be easily accessible in a heterogeneous distributed computing environment through well-defined, yet lightweight, Application Programming Interface (API).
- To develop a CAD tool that could generate high-quality, continuously splined surfaces free of unphysical waviness and tessellated faces.

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. The proposers must present a convincing case that the proposed approach has the potential of meeting these metrics.

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 on more complex configurations.

Note: This subtopic is focused on addressing high fidelity meshes and geometry tools as they relate to large scale, complex fluid dynamics simulations. If you are interested in proposing to the broader topic of computational technologies addressing emerging high performance computing hardware, you should NOT propose to this subtopic but instead view subtopic ID# S5.01.

A1.06 Vertical Lift Technology
Lead Center: GRC
Participating Center(s): ARC, LaRC

The Vertical Lift subtopic is primarily interested in innovative technologies to improve reliability and performance and reduce environmental impact of small-scale, autonomous, vertical lift UAVs.

The use of small UAVs for commercial operations is rapidly increasing, and the rapid pace of technology advancements in electric and hybrid-electric power and autonomy systems expands the range of commercial missions that these vehicles are performing. With increased vehicle use there will be challenges self-monitoring performance and health status to efficiently maintain these vehicles, while detecting faults and degradations before they impact mission performance or cause the loss of the vehicle or payload. In addition, there will be trade-offs in vehicle operation between maximizing mission and propulsion system performance, while minimizing the environmental impact and annoyance from noise. These trade-offs will have to be taken into account within the vehicle health management system for mission planning and execution, given that the trade-offs may be different for different parts of a mission.

Areas of interest include:

- Development and demonstration of all-electric and/or hybrid-electric technologies for vertical lift UAV propulsion systems, including validated modeling and analysis tools and prototype demonstrations, that show benefits in-terms of weight, efficiency, low noise, emissions and fuel consumption and include:
    - Development and demonstration of reconfigurable power and energy management system technologies that can maintain performance, noise and efficiency based on vehicle mission, operating environment and system status.
    - Development and demonstration of design tools integrated with on-board health-state awareness and regime recognition technologies that can predict the system life cycle and degradation over the dynamic operational life of the vehicle.
    - Development and demonstration of integrated flight/propulsion control and energy management systems that can maintain optimal power efficiency while adapting to changes in mission from the on-board intelligent health-state awareness and regime recognition technologies.

Proposals on other rotorcraft technologies will also be considered but the primary emphasis of the solicitation will be on the above identified technical areas.

A1.07 Propulsion Efficiency-Propulsion Materials and Structures
Lead Center: GRC
Participating Center(s): AFRC, LaRC

Materials and Structures research and development contributes to NASA's ability to achieve its long-term Aeronautics goals, including the development of advanced propulsion systems. Responding to this call will require a proposal describing the intent to conduct novel research in materials and structures that is linked to enhancing aircraft propulsion efficiency. Reductions in vehicle weight, fuel consumption and increased component durability/life will increase propulsion efficiency. The extreme temperature and environmental stability requirements of advanced aircraft propulsion systems demand the development of new, reliable, higher performance materials. Research in the areas of high-temperature metals/alloys and ceramics and polymers (and their composites) provides fundamental understanding of the underlying process-structure-property relationships of these materials. Study of the interactions of material systems with harsh environmental conditions and the modes of failure of these systems are of particular importance to developing more advanced materials for future aircraft propulsion systems, which will be operating at higher temperatures than today's turbine engines. Heat transport, diffusion, oxidation and corrosion, deformation, creep, fatigue and fracture are among the complex phenomena that can occur in the component materials in the extreme environment of turbine engine propulsion systems.

Many of the significant advances in aircraft propulsion have been enabled by improved materials and materials manufacturing processes. Additional advances in the performance and efficiency of jet propulsion systems will be strongly dependent on the development of lighter, more durable high-temperature materials. The specific topics of interest include:

- Advanced high temperature materials technologies including fundamental materials development/processing, testing and characterization, and modeling.
- Innovative approaches to enhance the durability, processability, performance, and reliability of advanced materials including advanced blade and disk alloys, ceramics and CMCs (ceramic matrix composites), polymers and PMCs (polymer matrix composites), nanostructured materials, hybrid materials, and coatings to improve environmental durability.

In particular, proposals are sought in:

- Disk materials and concepts such as innovative joining methodologies for bonding powder metallurgy disk material to directionally solidified/single crystal rim alloy.
- Corrosion/oxidation resistant coatings for turbine disk materials operating at temperatures in excess of 760°C (1400°F).
- High strength fibers for reinforcing ceramic matrix composites and environmental barrier coatings to enable a CMC temperature capability of 1482°C (2700°F) or higher.
- Innovative methods for the evaluation of advanced materials and structural concepts under simulated operating conditions, including combinations of thermal loads and mechanical loads during environmental (application) exposure.
- Innovative processing methods that enhance high temperature material and coating properties and reliability, and/or lower cost.
- Development and evaluation of shape memory alloys for applications across the lower temperature range of the subsonic aircraft flight path, i.e., experiencing shape-changing phase transitions between 0 to -50°C.
- Using the unique properties of nanomaterials to tailor composite properties using nanocomposites, nano-engineered, thermally-conductive composites and micro-engineered porous structures with metals, polymer, and ceramic composites.
- Advanced structural concepts; new concepts for propulsion components incorporating new lightweight concepts as well as smart structural concepts to reduce mass and improve durability.
- 3-D additive manufacturing of complex structures/subelements demonstrating mechanical properties and environmental durability for propulsion system applications.
- Multifunctional materials and structural concepts for gas turbine engine structures, such as novel approaches to power harvesting, thermal management, self-sensing, and materials for actuation.
- Fabrication of unique structures (such as lattice block) using shape memory alloys for lightweight multifunctional/adaptive structures for engine component applications.
- Innovative approaches for use of shape memory alloys for actuation of components in gas turbine engines.
- Computational materials and multiscale modeling tools--including methods to predict properties, and/or durability of propulsion materials based upon chemistry and processing for conventional as well as functionally-graded, nanostructured, multifunctional and adaptive materials.
- Robust and efficient modeling/design methods and tools for advanced materials and structural concepts (in particular multifunctional and/or adaptive components) including variable fidelity methods, uncertainty-based design and optimization methods, multi-scale computational modeling, and multi-physics modeling tools.
- Development of physics-based models of the various failure mechanisms of the EBC (environmental barrier coatings), particularly those associated with environmental degradation (e.g., oxidation, diffusion, cracking, crack + oxygen interaction, creep, etc.).

- Multiscale design tools for aircraft engine structures that integrate novel materials, mechanism design, and structural subcomponent design into systems level designs.
- Use of multiscale modeling tools to design multifunctional and adaptive structures.
- Robust and efficient methods/tools to design advanced high temperature materials based on first principles and microstructural models that can be used in a multi-scale framework.
- Development of models to predict degradation of CMCs due to combined effect of environment and mechanical loading at high temperatures.

A1.08 Aeronautics Ground Test and Measurements Technologies
Lead Center: LaRC
Participating Center(s): GRC

NASA's ground-based test facilities, which include low speed, transonic, supersonic, and hypersonic wind tunnels, hypersonic propulsion integration test facilities, air-breathing engine test facilities, and simulation and loads laboratories, play an integral role in the design, development, evaluation, and analysis of advanced aerospace technologies and vehicles. In addition to design databases, 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 ground-based test facilities to revolutionize wind tunnel testing and measurement capabilities and improve utilization and efficiency. 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 [1]. Systems that can provide planar or volumetric measurements of flow quantities such as multi-component velocities, density, and pressure in the airflow upstream and downstream of test articles are required to quantify tunnel inflow and outflow conditions and specify boundary conditions for numerical simulations. NASA envisions using these systems in large test sections (6 feet wide by 6 feet high and larger) and desires the system design to include provisions for combining these data into the regular stream of test data provided by a given facility.
- *Model Attitude and Position Monitoring* - Measurements of wind tunnel model attitude and position (e.g., roll, pitch, yaw angles and spatial coordinates X, Y, Z relative to a defined origin and coordinate system) 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 high data rates of 10 Hz and with sufficient accuracy (0.005± 0.0025 degrees in pitch 0.025±0.025 degrees in roll and yaw). The setup and calibration time required for these systems should be 4 hours or less to minimize the impact on tunnel operations. With regard to position monitoring, many NASA wind tunnel facilities conduct tests at elevated temperatures (above 300°F) or at extremely low temperatures (-250°F). Displacement measurement components used in actuator systems for setting hydraulic cylinder positions and other hardware used in test article support and positioning systems must operate routinely in these extreme environments. Innovative designs for sensors, position measurement and monitoring, and hardware solutions are desired to provide accurate and reliable performance at these extreme conditions.
- *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. Currently, PAI tests can be quite expensive due to issues related to the integration of the system 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 simulation systems that are more compact and capable of accurately simulating the flow, 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 propulsion simulation systems. Example measurement systems and techniques include, but are not limited to, simulators that permit the measurement of loads on individual blades for studies involving boundary layer ingestion, force and moment balances capable of transferring high pressure air and/or power across the balance and operating at high temperatures (up to 350°F), and wireless sensor networks that are self-powered, intelligent (e.g., self-organizing, sensor fusion], and capable of performing preprocessing at or near the sensor to reduce bandwidth requirements.

Reference:

Slotnick, J., et al., "CFD Vision 2030 Study: A Path to Revolutionary Computational Aerosciences", NASA/CR–2014-218178, March 2014.

A1.09 Vehicle Safety- Internal Situational Awareness and Response
Lead Center: GRC
Participating Center(s): AFRC, ARC, LaRC

Achieving a vision for a safer and more efficient National Airspace (NAS) with increasing traffic and the introduction of new vehicle types requires increasingly intelligent vehicle systems able to respond to complex and changing environments in a resilient and trustworthy manner. Future air vehicles, especially autonomous vehicles, must operate with a high degree of awareness of their own well-being, and possess the internal intelligence to provide warning and potentially take action in response to off-nominal states. A vehicle's capability to independently assure safety may be the only recourse in some situations, and addresses the recurring issue of inappropriate crew response. Further, early warning of impending maintenance conditions reduces maintenance cost and vehicle down-time through improved vehicle availability and throughput. Understanding the vehicle state also has impact on vehicle performance, efficiency, and environmental impact. This Subtopic seeks technologies to enable intelligent vehicle systems with an internal situational awareness and ability to respond to off-nominal conditions for piloted vehicles augmented with autonomous capabilities, as well as increasingly autonomous unmanned air systems (excluding vertical lift vehicles).

Areas of interest include:

- Networked sensors and algorithms to provide necessary vehicle full-field state information ranging from the component level to the subsystem and system level.
- On-board hardware and software systems that are modular, scalable, redundant, high reliability, and secure with minimal vehicle impact.
- Information fusion technologies to integrate information from multiple, disparate sources and evaluate that information to determine health and operational state.
- Diagnostic and prognostic technologies that inform decision making functions with critical markers trending to unsafe state.
- Decision-making algorithms and approaches to enable trustworthy real-time operations, take preventive actions as needed in complex uncertain environments, and appropriately communicate status to other components of the NAS.
- Develop integrated systems technologies that enable the mitigation of multiple hazards, while effectively dealing with uncertainties and unexpected conditions.
- Develop approaches that combine improved inflight vehicle state safety awareness with adaptive methods to achieve improved efficiency, performance, and reduced environmental impact.
- Significantly enhance the fidelity and relevance of information provided to ground systems by the vehicle in-flight for use in on-demand maintenance.

A1.10 Hypersonic Technology-Improvement in Solar Operability Predictions using Computational Algorithms
Lead Center: LaRC
Participating Center(s): GRC

The improvement of isolator operability (as defined by unstart) and performance prediction are of import to a practical dual-mode scramjet design, since the operability limits determine the optimal performance bounds of the system. Due to uncertainties in these bounds, which are typically obtained via computations and/or experiments (and extrapolated to flight environments), one must accept degraded system performance. To this end, this solicitation seeks innovative concepts to significantly advance the state-of-the-art in the predictive capability of computational algorithms, with the ultimate goal of incorporating these advances into RANS-CFD algorithms, in order to both reduce and quantify the margins and uncertainty of the coupled inlet-isolator-combustor (engine) unstart mechanism/process, applicable to relevant flight regimes and relevant dual-mode scramjet designs.

Focus Area 19: Integrated Flight Systems

Participating MD(s): ARMD

This focus area includes goals that contribute to the Integrated Aviation Systems Program's (IASP) to demonstrate integrated concepts and technologies to a maturity level sufficient to reduce risk of implementation for stakeholders in the aviation community.

A2.01 Flight Test and Measurements Technologies
Lead Center: AFRC
Participating Center(s): GRC, LaRC

NASA continues to see 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 aerospace industry will be able to conduct flight research more effectively and also meet the challenges presented by NASA 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 electric propulsion, transonic civil transport, supersonic civil transport and hypersonic speeds for trans-atmospheric flight or space access vehicles. 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.

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:

- 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.
- Improve 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 distributed propulsion systems using an adaptive embedded control system.
- Methods for 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.

The emphasis of this work is on flight test and flight test facility needs. Aspects of specific development of the above technologies is also addressed as appropriate elsewhere in the NASA SBIR call.

A2.02 Unmanned Aircraft Systems Technology
Lead Center: AFRC
Participating Center(s): GRC, LaRC

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 other known and 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 2016 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 reward. 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.
- 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

Participating MD(s): ARMD

This focus area includes technologies addressing both the Airspace Operations and Safety Program (AOSP), and NASA's ARMD Strategic Thrust #1. AOSP is targeting system-wide operational benefits of high impact for NextGen both in the areas of airspace operations and safety management, while the Advanced Air Traffic Management System Concepts subtopic directly supports and is focused on conducting the research and 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.

A3.01 Advanced Air Traffic Management Systems Concepts
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 full integration of Unmanned Aerial Systems (UAS) 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 Autonomy of the National Airspace Systems (NAS)
Lead Center: ARC
Participating Center(s): LaRC

Develop concepts or technologies focused on increasing the efficiency of the air transportation system within the mid-term operational paradigm (2025-2035 timeframe), in areas that would culminate in autonomy products to improve mobility, scalability, efficiency, safety, and cost-competitiveness. Proposals in the followings areas in product-oriented research and development are sought, but are not limited to:

- Autonomous and safe Unmanned Aerial Vehicle (UAV) operations for the last and first 50 feet, under diverse weather conditions.
- Autonomous or increasing levels of autonomy for, or towards, any of the following:
    - Networked cockpit management.
    - Traffic flow management.
    - Airport management.
    - Metroplex management.
    - Integrated Arrival/Departure/Surface operations.
    - Low altitude airspace operations.
- 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.
    - Adaptive automation/human-system integration concepts, technologies and solutions that increase operator (pilot and or controller) efficiency and safety, and reduce workload to enable advances in air traffic movement and operations.

A3.03 Future Aviation Systems Safety
Lead Center: ARC
Participating Center(s): LaRC

The Aeronautics Research Mission Directorate (ARMD) Airspace Operations and Safety Program (AOSP) is leading research in the area of integrated safety monitoring and assurance that detects, predicts and prevents safety problems in real-time. ARMD sees its future, safety-related research focused in a forward looking, more comprehensive system-wide direction and is currently vetting a roadmap for Real-Time System-Wide Safety Assurance (RSSA) strategic activities.

Tools are being sought for use in creating a prototype of a RSSA capability. 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:

- 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 TBO environment
- Develop and demonstrate strategies for optimal human-machine coordination for real-time hazard mitigation.
- 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

Participating MD(s): STMD

NASA's technology, science, exploration, and space operations organizations are identifying a growing number of potential applications for very small spacecraft. Such spacecraft can accomplish missions at a fraction of the cost of larger conventional spacecraft and can be developed quickly and more responsively. In some cases, their small size and ability to be delivered in relatively large numbers may enable mission applications not possible with larger satellites. A small spacecraft can also serve as a low-cost platform for spaceflight testing of new technologies that are appropriate for spacecraft of any size.

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. Cubesats are a special category of small spacecraft and are of particular interest because launch opportunities tend to be more frequent and affordable compared to other small spacecraft, due to the standard sizes and containerization of cubesats.

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.
- 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).
- Tolerant of extreme thermal and/or radiation environments.
- 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.

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 Small Spacecraft Propulsion Systems
Lead Center: GRC
Participating Center(s): GSFC, JPL, MSFC

There are currently a wide range of technologies for propulsion systems, however the miniaturization of these systems for small spacecraft is a particular challenge. While cold gas or pulsed plasma systems are targeted for small delta-v, Δv application, modules that can provide more demanding maneuvers still need development. Small spacecraft buses other than cubesats have more flexibility to accommodate systems with several thruster units to provide more attitude control and also large single axis maneuvers. Missions have demonstrated these technologies successfully and performance data gathered has paved the way for future modifications of the existing hardware in order to re-adapt the designs to satisfy demanding constraints.

Specifically, proposals are solicited in the following areas:

- High Impulse per unit volume (>2000 Ns/U):
  - Example applications: Interplanetary/Deep space, orbit capture.
  - Electric Propulsion with thrust greater than 1.25 mN.
  - Long life Chemical Propulsion.
  - High thrust/power ratio.
  - Delta-v > 1 km/sec.
  - Includes ACS functionality
- High Thrust per unit volume (>750 Ns/U):
  - Example applications: Orbit raising (MEO, GEO), long life LEO.
  - Electric Propulsion with thrust greater than 1.25 mN.
  - Chemical Propulsion thrust > 100 mN.
  - Includes ACS functionality.
  - Low soakback temps, (i.e., minimal increase to local bus temperature).
- Precision Control (I-bit < 0.2 microN-sec) for spacecraft < 180 kg:
  - Example applications: Formation flying, tight pointing requirements.
  - Sub-microN thrust levels.

Proposers are expected to quantify improvements over relevant SOA technologies that will substantiate the investments in the new technology. Key metrics for that comparison can include, but is not limited to, recurring cost, total impulse, thrust, life, sail characteristic acceleration, 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.

For concept/component development, proposals are solicited to mature propulsion concepts of TRL 2 or higher and mature them to TRL 6 at the component level. For system level maturation, proposals are solicited to mature integrated system solutions capable of delivering potential qualification or flight hardware within the constraints of a Phase II SBIR with no or minimal need for enhancements or Phase III investments.

The desired features for a SmallSat propulsion system is one that balances reliability, high performance (i.e., relatively high specific impulse [Isp] and thrust), has no/minimal chemical or electromagnetic contamination issues, is low pressure (or pressurizes post deployment), safely contains propellant (hazardous or non-hazardous), low cost, and has the simplest design feasible in order to meet performance requirements.

Z8.02 Small Spacecraft Communication Systems
Lead Center: GRC
Participating Center(s): ARC, GSFC, JPL, JSC, LaRC, MSFC

Space communications is an enabling capability to conduct NASA missions. Communications systems should impose the least possible constraints on mission spacecraft in order to meet required performance. Innovations and novel approaches are sought to reduce the mass, power consumption, volume, and operational constraints in order to increase the total data return, advance the technology readiness level, and reduce the cost and risk of communications systems for small spacecraft (generally considered to be on the order of 180 kg or less). Small spacecraft communication systems must be increasingly robust, flexible and diverse to support a wide variety of stand-alone and interconnected missions 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. Infusion of new technologies or best commercial standards and practices (e.g., DVB-S2 standard, CubeSat form factors) that can demonstrably improve performance and be applied or adapted for use in Government, non-Government or commercial networks is desirable.

Proposals for innovations and advancements in technology readiness are sought in any of the following areas of small spacecraft communications systems:

- *High-gain Antennas (HGAs)* - Development of HGAs 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 to, from and among small spacecraft. Operations compatible with NASA's space communications infrastructure1 and Government exclusive or Government/non-Government shared frequency spectrum allocations (e.g., 25.5-27.0 GHz) is required. However, applicability or adaptability of the HGA technologies to non-Government use spectrum is also desirable [See References for applicable Government frequency spectrum allocations in the near Earth and deep space regions].
- *Transceivers and Radios* - This area includes but is not limited to: radio frequency (RF) transmitters; amplifiers; low noise receivers, full duplex frequency selectable RF front-ends, integrated Global Navigation Satellite Service (GNSS) receivers, software defined or reconfigurable radios, or integrated transceivers and radios for links to relay satellites or direct to ground stations. 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].
- *Network and Application Service Protocols* - 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 space flight communications. Innovations or advancements are sought in software and hardware systems that implement NASA's delay/disruption tolerant networking (DTN) standards to support scalable, robust mission communications for small spacecraft missions. Implementation of protocols to enable low-power application communications among clusters of small spacecraft are also invited (e.g., Constrained Application Protocols, CoAP) [See References for applicable NASA and commercial networking standards].

- *Optical Communications* - One-way optical communications for direct data downlink from small spacecraft can provide a useful communications mode for NASA and non-government missions while avoiding some of the complications associated with a two-way optical link (i.e., requiring an uplink beacon). Technology advancements or system-level solutions (i.e., space and ground segment components) are sought that increase the data rate or availability of optical communications for small spacecraft, or reduce mission risk, complexity or cost.

A typical approach to advance the technology readiness level (TRL) leading to future flight hardware/software demonstration of any of the small spacecraft communications technologies would include:

Phase I - Identify, evaluate and develop candidate small spacecraft communications technologies that 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 systems through Phase II efforts and beyond.

Phase II - Emphasis should be placed on developing and demonstrating the candidate technologies under simulated small spacecraft spaceflight conditions or in the relevant 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 technologies developed under this subtopic area should be compatible with existing NASA space communications infrastructure1, 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, NASA's Deep Space Network (DSN) of ground stations, and other assets such as the Wallops range ground station.

References – Please see the following references for more details:

- NASA Spectrum Policy: http://www.nasa.gov/directorates/heo/scan/spectrum/policy_and_guidance.html.
- Spectrum Guidance for NASA Small Satellite Missions: http://www.nasa.gov/sites/default/files/atoms/files/spectrum_guidance_smallsats_cubesats_2015.pdf.
- Near Earth Network (NEN) Users Guide: http://sbir.gsfc.nasa.gov/sites/default/files/450-SNUG_V10.pdf.
- Space Network Users' Guide (SNUG): http://sbir.gsfc.nasa.gov/sites/default/files/453-NENUG%20R2.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.
- Constrained Application Protocol (CoAP):
  - Internet Engineering Task Force (IETF) Constrained RESTful environments (CoRE) Working Group: http://datatracker.ietf.org/wg/core/charter/.
  - IETF RFC 7252: http://tools.ietf.org/html/rfc7252%20h.

Z8.03 Small Spacecraft Power and Thermal Control
Lead Center: GRC
Participating Center(s): GSFC, JPL, MSFC

SmallSats and CubeSats offer several new opportunities for space science, including multipoint in-situ measurements and disaggregation of larger science missions into constellations. These missions require reliable operation for several years in potentially harsh radiation environments. Industry has developed numerous cubesat components, but they lack the robustness needed for long duration missions. To address this capability gap, this subtopic will develop high reliability smallsat power generation and storage and thermal control systems that meet the performance and resource requirements of upcoming missions, while maximizing flexibility. An emphasis should be considered for energy management systems that combine power generation, storage and heat rejection in the compact cubesat platform as well as systems that enable electric propulsion.

The development of advanced power generation and energy storage technologies are critical to enabling and expanding the use of future small satellite missions. Proposed research may focus on the development of new power generation and storage technologies, with particular interest in technologies that are approaching readiness for spaceflight testing. This subtopic solicits the development of modular, highly-reliable solar array, battery, power system electronics technologies that enable scalable smallsat and cubesat power systems with the following specifications:

- Solar array input power ranging from 15 W to 100 W.
- Battery capacity ranging from 5 Amp-hours to 20 Amp-hours (volume dependent).
- Provides from 12 to 20 switched power services to users, with output voltages configurable to meet mission-specific requirements.
- Maximum board size of 90 mm x 90 mm for power system electronics.
- Configurable via I2C, SPI, or CAN bus interface.
- Simple/modular power component designs (“plug and play”).
- Supports body mounted or deployed solar arrays.
- Supports power system reset initiated by external command (typically received from radio).
- Tolerant of extreme thermal and/or radiation environments.
- Ability to be stored in space for several years prior to use.
- Novel and/or integrated power with other subsystems (i.e., power and communications, energy storage and satellite structure, combined power/propulsion subsystems, etc.).

Integration of the power and thermal subsystems is a synergistic combination that can result in mission-enabling resource savings. For example, batteries often carry the most restrictive temperature range of all spacecraft hardware, which can drive the thermal design. An integrated heat transfer turn-down device that helps to regulate temperature in extreme environments is a technology sought in this solicitation. Examples include miniaturized heat switches and lightweight thermal capacitance devices that are integrated into the battery assembly, each being scalable and tunable to a specific mission’s requirements.

Deployable solar array systems are associated with higher waste heat dissipations, which in turn leads to higher volumetric heat fluxes for the small spacecraft. With limited area for suitable radiator placement, deployed radiator systems will also become necessary. Combining the radiator with the solar array will reduce the need for another deployment while also taking advantage of the environmental views. Technologies are sought to provide efficient heat transfer across the deployment mechanism. Thin radiator assemblies are needed to minimize increases in solar array thickness while also providing thermal isolation from the side with solar cells. Radiator concepts can be passive (e.g., solid-state material or heat pipes) or active (e.g., integrated fluid tubing is assumed to interface with a spacecraft-provided pumped loop).

Integrating high thermal conductivity pathways from high heat flux power electronics components to chassis interfaces can provide incremental reductions in radiator sizes. Order of magnitude improvements over copper thermal ground plane/card-lock technologies are sought.

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. 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.

Z8.04 Small Spacecraft Structures, Mechanisms, and Manufacturing
Lead Center: ARC
Participating Center(s): GSFC, JPL, LaRC, MSFC

Smallsats, including cubesats, are quickly maturing technologically towards advanced capabilities, which will result in significant contributions to the achievement of NASA's scientific and exploration missions. In fact, smallsats are seriously being considered for complex, long duration missions to deep space locations and for Earth observing constellations. However, while smallsats have the benefit of small size and mass making them generally easier and cheaper to launch, many space applications require larger physical sizes or alternate structural architectures. These applications can be realized through the innovative blending of structural elements with other functional elements; reconfigurable, reusable structures; reliable deployment mechanisms and aggregation techniques; and novel manufacturing techniques driving the utility of smallsats even further. Three main thrust areas are envisioned for this subtopic.

Structures

In the area of smallsat structures, NASA is interested in materials and structural systems that optimize component or instrument packaging. This includes techniques to integrate or combine structural elements with other subsystem elements (multi-functionality; i.e., spacecraft chassis with electrical power management, or internal spacecraft communications). See related discussion below on Manufacturing on embedded systems into structures.

Also of interest are technologies that can allow aggregation of smaller elements in space to create larger structures that cannot be launched as a single element, or that do not have to be designed to withstand launch loads. This implies integrative structural technologies that can share or distribute power, communications or thermal resources between the individual building blocks that can be arranged to perform a specific function in space. Further, these systems of building blocks can be reconfigured once launched to enable in space assembly architectures.

Mechanisms

This area focuses on the stowage (during launch) and deployment (during space operations) of various elements and subsystems. Included in this category are deployable solar cell arrays, radiators, antennas or other mission-enabling elements. These deployable mechanisms should be reliable in a wide variety of space environments (LEO and/or deep space) and be compatible with existing smallsat architectures. Ideally, deployable mechanisms should include methods to verify proper deployment (i.e., latch sensors, etc.) and should also employ robust technologies such as motorized actuators versus passive stored energy systems such as springs. Inflatable and on-orbit reconfigurable systems are also of interest.

Manufacturing and Materials

NASA is interested in technologies that take advantages of manufacturing advances as they apply to small spacecraft. Examples include model-based additive manufacturing technologies that can create fluid manifolds, propellant tanks, small thrusters, or unique geometries not currently possible via traditional manufacturing techniques. A related dimension to this area is multiple (or mass) production technologies that can be applied for the manufacturing of large numbers of spacecraft such as swarms or constellations. Other concepts involve integrating electrical components and interconnects within structural elements, especially when such integration results not only in mass savings, but also decreased integration and test flow timelines and increased overall systems reliability through the use of built-in-test approaches.

Finally, NASA is interested in manufacturing technologies using novel materials that are low mass/density yet compatible with high radiation and extreme temperature deep space environments.

Z8.05 Small Spacecraft Avionics and Control
Lead Center: GSFC
Participating Center(s): ARC, JPL, MSFC

Smallsats and cubesats offer several new opportunities for space science, including multipoint in-situ measurements and disaggregation of larger science missions into constellations. These missions require reliable operation for several years in potentially harsh radiation environments. Industry has developed numerous cubesat components, but they lack the robustness needed for long duration missions in harsh mission environments. To address this capability gap, this subtopic will develop high reliability smallsat avionics and control technologies that meet the performance and resource requirements of upcoming missions, while maximizing flexibility.

This subtopic solicits the development of smallsat and cubesat single board avionics with the following specifications:

- Minimum 100 DMIPS processing performance.
- 3W power dissipation.
- Maximum board size of 90 mm x 90 mm.
- 16 Mbytes of EDAC protected RAM.
- 4 Gbytes ofnon-volatile memory storage.
- 256 kbytes on non-volatile memory for boot software.
- Optionally supports I2C, CAN, SPI, and SpaceWire busses.
- 4 8b/10b SERDES interfaces.
- Provides FPGA to implement mission specific processing functions and interfaces (including general purpose I/O), either in combined in a System-On-a-Chip (SOC) or separate from the processor package.
- Accepts and digitizes 16 thermistor inputs and 8 active analog inputs.
- Provides watchdog timer and external reset signal

This subtopic also solicits ACS/GN&C component hardware that has a minimum of 3-year operational life as well as radiation-hard and low mass implementation to survive the typical LEO radiation environment for the same duration. Specific component technologies include:

- Integrated Attitude Detection and Control Systems (ADCS) for 3U and 6U CubeSat:
    - Minimum Target Pointing Spec:
        - Knowledge 10.0 arc-second - 3 sigma.
        - Control 40.0 arcsec - 3 sigma.
        - Stability 0.3 arcsec over 1.0 sec - 3 sigma.
    - 10.0 Hz ctrl cycle.

- Desired Target Pointing Spec:
    - Integrated Attitude Detection and Control Systems (ADCS) that can provide pointing for 3U and 6U CubeSat:
        - Knowledge 1.0 arc-second - 3 sigma.
        - Control 4.0 arcsec - 3 sigma.
        - Stability 0.05 arcsec over 1.0 sec - 3 sigma.
    - 10.0 Hz ctrl cycle
- Actuators.
- Slew rate on the order of 1 deg/sec.
- Momentum capacity: 4 orbits.
- Handle tipoff rates on the order of 5.0 deg/sec per axis:
    - Ensure a stable platform can be achieved after separation.
- Low jitter reaction wheels or reaction control systems (RCS).
- Sensors:
    - Small, low power (<1 W) star trackers and innovative baffle design.
    - Low Noise Gyro:
        - Can propagate on Gyro for 4 orbits.

To allow infusion into multiple smallsat architectures, it is highly desirable for ACS/GN&C components to provide options to support multiple onboard data busses (i.e., I2C, SPI, CAN).

For the above components, the environmental specifications are; operating temperature -40 to- +85°C, radiation hard to at least 40 krad TID, latch up immune to an LET of at least 80, and a device SEE rate of not greater than 0.01 event/day in Adams 90% worst case GEO environment. Successful proposals for the above technologies will address reliability and radiation tolerance at the part level all the way up through their component/subsystem implementation. For descriptions of radiation effects in electronics, the proposer may visit http://radhome.gsfc.nasa.gov/radhome/background.htm.

Beyond the higher reliability technologies listed above, this subtopic also solicits technologies offering significant improvements in cubesat/smallsat capabilities. These technologies would not need to have sufficient reliability and radiation tolerance to be directly infused into long duration missions. However, there should be a viable path by which these technologies could be matured for such missions. Technologies solicited include:

- Low power, high throughput processors, SoC or MPSoC with an order of magnitude performance improvement over state-of-the-art.
- Radiation resistant, self-repairing technologies (both in hardware and software).
- Modular, reconfigurable flight software environments and architectures.
- Technologies that enable rapid software integration, test and validation.
- Radiation tolerant GN&C systems and components with an order of magnitude performance improvement over state-of-the-art.
- Small, low thrust RCS systems for smallsats with an order of magnitude performance improvement over state-of-the-art.
- Alternate technologies for attitude determination (i.e., navigation via x-ray sources, or planetary bodies).
- Technologies to isolate sources of spacecraft vibration from sensors or payloads.
- Advanced GN&C software programs and algorithms.
- Miniature rate gyros with an order of magnitude performance improvement over state-of-the-art MEMS gyros in drift and noise.
- Innovative miniature angular momentum exchange devices that are not susceptible to reliability issues associated with bearing wear.
- Miniature sensors and actuators for smallsat rendezvous, docking and spacecraft servicing, including include vision systems, miniature robotics, and docking actuators.

Z9.01 Small Launch Vehicle Technologies and Demonstrations
Lead Center: MSFC
Participating Center(s): KSC, LaRC

As small spacecraft capabilities steadily expand the demand for low-cost dedicated launch capability is expected to grow and give rise to a viable small payload market segment. Servicing this market segment will likely require a variety of small launch vehicle capabilities to deliver payload masses ranging from 5-kg cubesats up to 180-kg ESPA-Class spacecraft. Orbital altitudes of interest range between 350 to 700 km with inclinations between 28 to 98.2 degrees to support CONUS operators and sun synchronous orbits at maximum altitude. Affordability objectives are focused on reducing launch costs below $60,000/kg with a goal of less than $20,000/kg.

NASA is interested in fostering the small spacecraft commercial launch sector by investing in new technologies and innovations that are poised for rapid maturation and subsequent commercialization. It is recognized that a combination of multiple technologies and production practices will likely be needed, and it is highly desirable that disparate but complementary technologies formulate and adopt standardized interfaces to better allow for transition and integration into small spacecraft launch systems.

Technologies of specific interest under this subtopic are as follow:

- Innovative Propulsion Technologies.
- Affordable Guidance, Navigation & Control.
- Manufacturing Innovations for Launch Vehicle Structures & Components.

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 5 or 6 by the end of Phase II effort. Technologies that can be developed and readied for flight-testing by the end of Phase II effort are of particular interest. A brief descriptive summary of desired technical objectives and goals are provided below.

Innovative Propulsion Technologies

Innovative chemical propulsion technologies and system 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 solid, liquid, or hybrid propellants. Technical approaches that address the critical challenges associated with downward scaling of launch vehicles are 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 in-flight 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.

Focus Area 22: ISS Utilization and Microgravity Research

Participating MD(s): 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
Lead Center: JSC
Participating Center(s): ARC, GRC, JPL, KSC, LaRC, MSFC

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 are portable and 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 leading to the development of new research facilities and the enhancement of others in focus areas involving granular material research, material science for polymerization, soldiering, thermal diffusivity of organic liquids, particles suspension in plasma, and safe containment of samples while undergoing microscopy imaging. Additionally, projects that address enabling on-orbit capability for utilization of larger rodents for neuroscience research are of high interest.

- 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.
- Innovative software and hardware to facilitate enhanced station operations. The technology should increase the efficiency of crew operations by simplifying training and procedures, and provide teleoperation and tele-collaboration capabilities within the station, and between the station and ground operations.
- Instruments that can be used as inspection tools for locating and diagnosing material defects, leaks of fluids and gases, and abnormal heating or electrical circuits. The technology should be suitable for hand-held portable use. Battery powered wireless operation is desirable. Specific issues to be addressed include: pitting from micro-meteoroid impacts, stress fractures, leaking of cooling gases and liquids and detection of abnormal hot spots in power electronics and circuit boards.
- Mid-TRL space technology experiments are solicited to fly on a new space environmental effects platform on the outside of the ISS. The new platform is called MISSE-FF (MISSE-Flight Facility). 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 (1 inch by 1 inch up to 7.84 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 MISSE-FF commercial partner, Alpha Space Test & Research Alliance, LLC, plans to service MISSE-FF every 6 months. The MISSE-FF data will be made available to the global community of researchers through the NASA Physical Sciences Informatics (PSI) system. Phase I deliverables could be data from ground testing the candidate technology and passive specimens for flight on MISSE-FF. Phase II deliverables could include an active technology experiment, packaged and ready for flight on MISSE-FF.

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.

9.2 STTR

The STTR Program Solicitation subtopics are aligned with the priorities of NASA's Space Technology Roadmaps, as well as reflect NASA's current highest priority technology thrusts being worked through each of its ten Centers.

Focus Area 1: In-Space Propulsion Technologies

NASA is interested in technologies for advanced in-space propulsion systems to reduce travel time, reduce acquisition costs, and reduce operational costs 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, and nuclear thermal propulsion systems related to human exploration, sample return missions to Mars, small bodies (like asteroids, comets, and Near-Earth Objects), outer planet moons, and Venus. Propulsion technologies will focus on a number of mission applications included ascent, descent, orbit transfer, rendezvous, station keeping, and proximity operations.

T1.01 Affordable Nano/Micro Launch Propulsion Stages
Lead Center: MSFC
Participating Center(s): AFRC, KSC

There has been recent significant growth in both the Quantity and Quality of Nano and Micro Satellite Missions:

- The number of missions has outpaced available ride share opportunities.
- Dedicated access to space increases small sat mission capability & allows new & emerging low-cost technologies to be flight qualified.

Stage concepts are sought that can be demonstrated within the scope & budget of a Phase II STTR project:

- MSFC is actively pursuing multiple technologies to significantly reduce orbital access cost.
- The scale of many Nano and Micro Launch vehicles allows stages to be completed within the scope and budget of a Phase II proposals.
- Accepted proposals will be limited to stages that plug and play into existing or proposed architectures for orbital launch vehicles with payload capabilities from 5-50 kg. A flight test is expected in Phase II.
- The university/small business partnership is ideal to provide the correct technology combination allowing for this affordable access to space.

State of the Art

Small launch vehicles are targeting a total launch cost of ~$1-2M. Proposed stages must demonstrate significant cost savings over state of the art.

What is the compelling need for this subtopic?

- This subtopic is necessary because there are currently no available rides for experimental propulsive stages.
- Technological advancements like additive mfg. must be demonstrated to produce aerospace quality parts at low fixed cost. These technologies must be validated for use in propulsive stages.
- The correct combination of new technologies and approaches will enable affordable, dedicated, on-demand access to space.
- Technologies that are demonstrated and validated at the nano/micro scale can be robustly infused into large launch vehicles where loads and vibrations are not as severe.
- The success of Nano/Micro Launch vehicles benefit every NASA center by enabling unprecedented experimental access to space.
- Commercial development opportunities abound since the small satellite market is robust and growing.

STMD/NASA/NARP/National-Affordable access to space is a key objective for NASA. The Nano/Micro Launch scale is an affordable avenue that will enable the development and validation of key technologies and approaches to reduce fixed cost, recurring costs and range costs.

T1.02 Detailed Multiphysics Propulsion Modeling & Simulation Through Coordinated Massively Parallel Frameworks
Lead Center: MSFC
Participating Center(s): SSC

Detailed modeling and simulation to assess combustion instability of recent large combustors while successful to a degree showed the need for significant advances in two-phase flow, combustion, unsteady flow, and acoustics. Additionally, simulation of water spray systems for launch acoustic sound suppression and test stand rocket engine acoustic sound suppression showed the need for advances in two-phase flow, droplet formation, and particulate trajectory. In these cases, and others, the need for improved physics based models is accompanied by the requirement for high fidelity and computational speed.

Rocket combustion dynamic simulations are 3D, multiphase, reacting computations involving the mixing of hundreds of individual injection elements which require a long time history to be computed. Methods are sought (VOF, SPH, DNS/LES, PIC, etc.) to accurately capture the physics of the injection elements in a computationally efficient manner. Experimental validation of individual submodels are required.

NASA successfully leveraged advances/ innovation in computer science technology to leapfrog the barriers to massive parallelism via the adoption of the Loci framework in the late 1990's. Computer science has evolved in the last two decades with respect to technology of massive parallelism. The intent of this subtopic is to infuse newest technologies, i.e., improved physics based models accompanied by the requirement for high fidelity and computational speed, into tools for propulsion related fluid dynamic simulation. This solicitation seeks simultaneously coordinated computer science (CS) technology advances, multi-physics (MP) simulation, and high fidelity (HF) models. The value and requirement for proposals is this coordinated CS-MP-HF framework. Ideally, technologies that are up to this point only Lower TRL demonstrations are strong candidates if they are developed to fit in a coordinated CS-MP-HF framework that can be applied to propulsion system fluid dynamics.

Tools developed in this framework are expected to enable propulsion system production & DDT&E cost reductions.

T2.01 Advanced Nuclear Propulsion
Lead Center: SSC
Participating Center(s): GRC, MSFC

The objective of this subtopic is to advance low TRL (<3) nuclear propulsion technologies that have the potential to transform space transportation and space exploration to Mars and other planets/moons in our solar system. Radical improvements in in-space propulsion technologies beyond the current state of the art (SOA) are required to enable new missions that safely transport humans and/or robotic systems with increased reliability to meet mission requirements, transport them quickly to reduce transit times and provide quicker scientific results, increase the payload mass to allow more capable instruments and larger crews, and reduce the overall mission cost. SOA in-space transportation systems typically employ chemical propulsion or electric propulsion systems. In parallel, thought must go into how best to ground test these concepts to allow a smoother, more efficient and safer path for future development.

This subtopic specifically seeks proposals for innovative research and development of advanced nuclear propulsion technologies that have the potential for significant improvement over the current SOA, primarily to achieve:

- High specific impulse (Isp) and thrust-to-weight ratio (T/W) to consume less propellant and provide shorter trip times.

Other design requirements to consider in the proposed concept include:

- Low system mass and volume (includes propellant, power system, thermal control/radiators) to reduce the total mass and number of launches to orbit.
- Safety, affordability, and reliability

Most of the known advanced nuclear propulsion candidate technologies are listed in the 2015 NASA OCT Roadmap TA02: In-Space Propulsion Technologies (http://www.nasa.gov/offices/oct/home/roadmaps/index.html). Advanced nuclear propulsion technologies are identified in section 2.3.3 Fusion Propulsion, section 2.3.5 Antimatter Propulsion, and section 2.3.6 Advanced Fission. Technology SOA and technical challenges are included for each.

Other advanced nuclear propulsion technologies not listed in the 2015 OCT TA02 Roadmap are welcome and within the scope of the subtopic (e.g., various nuclear hybrid concepts), including novel system and component ground test approaches and associated supporting/enabling technologies.

Proposed technologies must be theoretically credible and proposals must describe how the technology will make a significant improvement over SOA in-space propulsion systems. Proposals must describe the ultimate objective of the effort and detail the planned investigative approach. The planned experimentation should be described, including the test equipment to be used and/or developed. The proposal should describe the development risks and mitigation plans.

Proposals should strive to advance the proposed technology to TRL 3: perform experimental critical function and/or proof-of-concept. If a significant increase in the TRL of a particular propulsion technology is not realizable, the proposal should clearly indicate the value proposition of the proposed effort to mature the candidate technology in the context of an overall development plan, describing how the award would support the maturation of the technology through phase II.

Focus Area 2: Power and Energy Storage

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. 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, power management, transmission, distribution and control. An overarching objective is to mature technologies from analytical or experimental proof-of-concept (TRL3) to breadboard demonstration in a relevant environment (TRL5). Successful efforts will transition into NASA Projects where the SBIR deliverables will be incorporated into ground testbeds or flight demonstrations.

T3.01 Energy Harvesting, Transformation and Multifunctional Power Dissemination
Lead Center: SSC
Participating Center(s): GRC, JSC, KSC, MSFC

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. As such, novel energy harvesting technologies are critical toward supporting future power generation systems to begin to meet these challenges. This subtopic addresses the potential for deriving power from waste engine heat, warm soil, liquids, kinetic motion, piezoelectric materials or other naturally occurring energy sources, etc. Development of energy harvesting (both capture and conversion) technologies would also address the national need for novel new energy systems and alternatives to reduce energy consumption. Conversion and transformation technologies for gathering energy naturally occurring in conjunction with induced energies are being pursued, and novel technologies capable of artificially saturating an environment with energy for storage and power dissemination along with non-conventional transmission via the surrounding environments such as wireless power are also applicable. Energy gathering is limited by the quantity of energy available within a system's immediate environment, and often the environment's energy contains prolonged periods of lulls in harvestable energy. Technologically bridging power from a distance would fundamentally alleviate issues with low energy environments by allowing energy to be supplementally broadcast through preexisting structures and environments while simultaneously reducing docking and interfacing for power transfer.

Technology development should support powering small remotely located equipment such as wireless instrumentation, or support power gathering for independently providing supplementary power to centralized equipment such as control consoles. Distributed Nano energy generating technologies are applicable for gathering scattered environmental energies into significant amounts of accumulated power along with supplementation for long-duration power utilization. This kind of distributed power should also be able to recover waste energy from rocket, nuclear, fission, and electrical propulsion devices while providing enhanced protection from energies contained within the work environment through transformation and consumption. Transforming harmful radiation, elevated temperatures, unwanted vibrations etc. into usable energy will support increased scope and duration of missions while enhancing protection from the waste energies (mitigation by transformation and consumption). Waste energies from warm soil, liquids (water, oils, hydraulic fluids), kinetic motion, piezoelectric materials, or various naturally occurring energy sources, etc. should also be transformable.

Areas of special focus for this subtopic include consideration of:

- Innovative technologies for the efficient broadcast, capture, regulation, storage and/or transformation of acoustic, kinetic, radiant (including radiation), electric, magnetic, radio frequencies and thermal energy types.
- Technologies which can work either under typical ambient environments for the above energy types and/or under high intensity energy environments for the above energy types as might be found in propulsion testing and launch facilities.
- As above, energy capture, transmission and transformation technologies that can work in very harsh environments such as those which are very hot and/or ablative (e.g., in the proximity of rocket exhaust) and/or very cold (e.g., temperatures associated cryogenic propellants) may be of interest.
- Innovations in miniaturization and suitability for manufacturing of energy capture, transmission and transformation systems so as to be used towards eventual powering of assorted sensors and IT systems on vehicles and infrastructures.
- High efficiency and reliability for use in environments that may be remote and/or hazardous and having low maintenance requirements.
- Employ green technology considerations to minimize impact on the environment and other resource usage.

- Reliable nano-engineered concept designs for generating charge and charge storage devices powering miniature (or “nano”) devices, such as members of a “swarm” are needed for exploration purposes. Designs should be capable of easy integration to miniaturize systems, subsystems, satellites, or “swarm” elements without compromising capability.
- Designs should maximize high energy density for charge storage with very low mass.

Rocket propulsion test facilities within NASA provide excellent test beds for testing and using the innovative technologies discussed above because they offer a wide spectrum of energy types and energy intensities for capture and transformation. Additional Federal mandates require the optimization of current energy use and development of alternative energy sources to conserve on energy and to enhance the sustainability of these and other facilities. Specific emphasis is on technologies which can be demonstrated in a ground test environment and have the ability/intention to be extrapolated for in-space applications such as on space vehicles, platforms or habitats. Energy transformation technologies to generate higher power output than what is presently on the market are a highly desired to an expected outcome from this subtopic.

Phase I will develop feasibility studies and demonstrate through proof-of-concept demonstrations. Phase II will develop prototypical hardware and demonstrate infusion readiness to be incorporated into other products.

T3.02 Intelligent/Autonomous Electrical Power Systems
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.

Focus Area 3: Autonomous Systems for Space Exploration

The exploration of space requires the best of the nation's technical community to provide the technologies that will enable human exploration beyond Low Earth Orbit (LEO): to visit asteroids, and to extend our reach to Mars. Autonomous Systems technologies provide the means of migrating mission control from Earth to spacecraft and habitats. This is enhancing for missions in the Earth-Lunar neighborhood and enabling for deep space missions. Long light-time delays, up to 42 minutes round-trip between Earth and Mars, require time-critical control decisions to be closed on-board autonomously through automation and 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 under 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. 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 human research program topic area is very relevant to autonomous systems technologies, and proposers are encouraged to review that subtopic description.

T11.01 Machine Learning and Data Mining for Autonomy, Health Management, and Science
Lead Center: ARC

Nearly all engineered systems in all of NASA's areas of interest have one key aspect in common---they generate substantial data. These data represent:

- Science and scientific applications.
- The operations of the data collecting instruments and their platforms.
- The health of these instruments and platforms.
- In some cases, other related data such as the performance and health of the humans involved in operations.

Machine learning, data mining, big data, and related methods have been used to study data in these four areas individually for offline study, with the goal of understanding how the system really operates, as distinct from how it was designed and intended to operate. However, these data-driven methods have not been used so far to study data across more than one of these four areas, and not during operations, with the goal of enabling a human and/or autonomous system to make adjustments to the system's operations on the fly. Allowing both online and offline learning would allow for both online (tactical) and offline (strategic) adjustments to operations. Allowing humans and autonomous systems to interact in making strategic and tactical decisions, including user interfaces that allow the autonomous system to show the human what it has learned and the human to specify high-level objectives and/or low-level actions, is a key problem to be addressed. Increasing the scope of the data covered to all of the four areas above would allow autonomous systems and human operators to account for both science and system health drivers in operations, and identify the trade-offs between increasing science operations, increasing availability, maintaining systems health, minimizing maintenance costs, and other considerations. Some of these considerations may extend to improvements in on-demand system responsiveness through optimal resource sharing of the computational burden between online and offline computing platforms. Integration of learning autonomous systems into existing mission operations and systems is a key problem that will need to be addressed.

The utilization of the above types of data to optimize all aspects of operations is important for missions/projects in all of NASA's areas of interest such as space science (e.g., Kepler, TESS), space exploration (human and autonomous rovers), Earth science (satellite-based and airborne instruments and platforms), and aeronautics (e.g., UAS in the NAS) to operate them in as cost-effective a manner as possible. This becomes more critical as NASA increasingly moves towards operating multiple platforms in a coordinated manner (e.g., Distributed Spacecraft Missions, airborne Earth science platforms coordinating with satellite instrument platforms) where the volume of relevant data will increase and autonomy will be needed to properly operate the multiple platforms.

This subtopic has three goals:

- Increase the scope of machine learning, data mining, and big data methods within NASA to encompass both online and offline learning.
- Use data across as many of the above four areas of data as possible.
- Explore the trade-offs in operational efficiency, energy efficiency, health management, and operational performance/goal achievement between onboard and offboard computational resource platforms.

Proposed solutions may have characteristics including but not limited to:

- Ability to incorporate human feedback into the learning algorithms.
- Ability for machine learning algorithms to generate results for direct use by autonomous systems and human operators.
- Ability to learn a controller (covering strategic and tactical operations) from data representing human expert operations.
- Demonstration of a core set of tools that works across different domains.

T11.02 Distributed Spacecraft Missions (DSM) Technology Framework
Lead Center: GSFC
Participating Center(s): ARC

A Distributed Spacecraft Mission (DSM) is a mission that involves multiple spacecraft to achieve one or more common goals; some DSM Instances include Constellations, Formation Flying missions, or Fractionated missions. Apart from Science goals that can only be attained with DSM, distributed missions are usually motivated by several goals, among which: increasing data resolution in one or several dimensions (e.g., temporal, spatial, spectral or angular), decreasing launch costs, increasing data bandwidths, as well as ensuring data continuity and inter-mission validation and complementarity. Constellations have been proposed in several NASA Decadal Surveys and recent studies; in Earth Science (e.g., a multi-spacecraft Landsat for increasing temporal resolution), in Heliophysics (e.g., the Geospace Dynamics Constellation) or in Planetary Science (e.g., the Lunar Geophysical Network). Many constellations and Formation Flying missions have also been proposed more recently in cubesat-related research projects. For the purpose of this subtopic, we do not assume the spacecraft to be of any specific sizes, i.e., we do not restrict this study to cubesats or smallsats.

The goal of this subtopic is to mature NASA capabilities to formulate and implement novel science missions based on distributed platforms. Technologies solicited in this call are the following:

- Novel DSM-enabling technologies such as:
    - Technologies for high-bandwidth and efficient inter-satellite communication.
    - Metrology systems capable of sensing and controlling relative position and/or orientation of multi-element DSMs to sub-milli-arcsecond angular resolution and sub-micro-meter positional accuracy.
    - Autonomous and scalable ground-based constellation operations approaches including science operations and data management, and compatible with the Goddard Mission Services Evolution Center (GMSEC) (open source software developed at NASA Goddard).
- Scalable DSM flight software systems such as:
    - Software components compatible with the Core Flight System (CFS) (open source software developed at NASA Goddard), enabling to control and navigate DSM formations and constellations; for example, discrete event supervisors offering a means to autonomously control systems based on selected mission metrics (e.g., spacecraft separation distance, number of active spacecraft, etc.).
    - Technologies for onboard collaborative processing and intelligence, including but not limited to, inter-spacecraft collaboration for collecting, storing and downloading data as well as multi-platform Science observation coordination and event targeting.

Research proposed to this subtopic should demonstrate technical feasibility and should discuss how it relates to NASA programs and projects. Proposed work is expected to be at an entry Technology Readiness Level (TRL) between 2 and 5, and to demonstrate a TRL increase of at least one level during each phase of the project. Proposals will be evaluated based on their degree of innovation and their potential for future infusion.

T12.01 Advanced Structural Health Monitoring
Lead Center: LaRC
Participating Center(s): ARC, GSFC, JSC, KSC

Future manned space missions will require spacecraft and launch vehicles that are capable of monitoring the structural health of the vehicle and diagnosing and reporting any degradation in vehicle capability. This subtopic seeks new and innovative technologies in structural health monitoring (SHM) and integrated vehicle health management (IVHM) automated systems and analysis tools. Techniques sought include modular/low mass-volume systems, low power, low maintenance systems, and complete systems that reduce or eliminate wiring, as well as smart-sensor systems that provide processed data as close to the sensor and systems that are flexible in their applicability. Examples of possible automated sensor systems are: Surface Acoustic Wave (SAW)-based sensors, passive wireless sensor-tags, flexible sensors for highly curved surfaces, flexible strain and load sensors for softgoods products (broadcloth, webbing or cordage), direct-write film sensors, and others. Damage detection modes include leak detection, ammonia detection, micrometeoroid impact and others. Reduction in the complexity of standard wires and connectors and enabling sensing functions in locations not normally accessible is also desirable. Proposed techniques should be capable of long term service with little or no intervention. Sensor systems should be capable of identifying material state awareness and distinguish aging related phenomena and damage conditions in complex composite and metallic materials. Techniques and analysis methods related to quantifying material properties, density, microcrack formation, fiber buckling and breakage, etc. in complex composite, metallic and softgoods material systems, adhesively bonded/built-up and/or polymer-matrix composite sandwich structures are of particular interest. Some consideration will be given to the IVHM /SHM ability to survive in on-orbit and deep space conditions, allow for changes late in the development process and enable on orbit modifications. System should allow NASA to gain insight into performance and safety of NASA vehicles as well as commercial launchers, vehicles, inflatable structures and payloads supporting NASA missions. Inclusion of a plan for detailed technical operation and deployment is highly favored.

State of the Art

Current tools for SHM are rudimentary and or need development for future space missions. Current data analysis methods are frequently non-ideal for the large scales of data needed for SHM analysis and/or require expert involvement in interpretation of data.

This technology enables:

- Monitoring of advanced structures/vehicles.
- Cost-effective methods for optimizing SHM techniques.
- Feasible methods for validating structural health monitoring systems.

Once developed this technology can be infused in any program requiring advanced structures/vehicles Aerospace companies are very interested in this enabling technology.

STMD/NASA/NARP/National - Directly aligns with NASA space technology roadmaps and Strategic Space Technology Investment plan.

Focus Area 4: Robotic Systems for Space Exploration

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 provides 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.

T4.01 Information Technologies for Intelligent and Adaptive Space Robotics
Lead Center: ARC

The objective of this subtopic is to develop information technologies that enable robots to better support space exploration. Improving robot information technology (algorithms, avionics, software) 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 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.

T4.02 Regolith Resources Robotics - R^3
Lead Center: KSC
Participating Center(s): ARC, LaRC

The use of robotics for In-Situ Resource Utilization (ISRU) in outer space on various planetary bodies is essential since it uses large quantities of regolith that must be acquired and processed. In some cases this will happen while the crew is not there yet, or it will take place at a remote destination where the crew cannot spend much time doing Extra Vehicular Activity (EVA) due to radiation exposure limits. Large communications latencies mandate autonomous robotics applications. Proposals are sought which provide solutions for the following regolith resources and robotics related technology areas:

Robotic Site Preparation and Construction for Civil Engineering Infrastructure

Future human bases on planetary surfaces, moons and asteroids will require infrastructure to ensure the survival of the crew as well as to prolong the life times of equipment operating in harsh and extreme environments. Since humans will not be at the destination in the early phases of the base construction, robotic equipment that operates autonomously will be required. Civil engineering infrastructure such as landing pads, berms, roads, equipment hangars, dust free zones, thermal wadis, shelters, radiation shielding and habitats will be needed. Regolith handling systems, fully autonomous site preparation, paver laying robots, inter-locking brick stacking robots, modular structure assembly robots and regolith 3D additive construction systems are encouraged. Proposals are sought for innovative robotic site preparation and construction mission concepts, technology development, and demonstrations. Proposals will be evaluated on the basis of mass, power, volume, feasibility of the concept of operations and complexity.

Regolith Derived Feed Stocks for In-Situ Robotic Manufacturing

By manufacturing spare parts, structures and surface systems on planetary surfaces, moons and asteroids, large logistics reductions can be achieved by avoiding the transportation of raw materials, commodities and goods from Earth. The regolith contains many minerals that can be processed to extract resources for manufacturing such as metals, organics, ceramics, glasses and polymers. In addition, the regolith can be used as a bulk aggregate which can be melted, sintered, or consolidated with a binder material such as in-situ manufactured polymers or other naturally occurring binder materials to form concrete like materials. Proposals are sought for regolith derived feed stocks that can be used to manufacture spare parts, structures or surface systems. Digital materials and associated regolith derived materials for use in voxel based manufacturing and innovative additive manufacturing methods are also encouraged. Other innovative manufacturing methods such as automated casting, materials deposition or automated assembly methods are also in scope. The emphasis in Phase I shall be on proving that a viable material can be developed with a proof of concept demonstration and related materials properties shall be provided. In Phase II a full scale robotic manufacturing demonstration shall be accomplished which would show how the feedstock could be used to make useful parts, structures or surface systems. Proposals will be evaluated on the basis of material accessibility, economic viability of the ore, feasibility of extraction or processing, materials properties, the concept of manufacturing and applications.

Proposals are sought for associated innovative resource utilization mission concepts, technology development, and demonstrations but must be based on regolith materials, robotic methods and highly innovative technologies.

Focus Area 6: Life Support and Habitation Systems

This Focus Area seeks key capabilities and technologies in areas of Habitation Systems, Environmental Control and Life Support Systems (ECLSS), Environmental Monitoring, Radiation Protection and Extravehicular Activity (EVA) 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, and spacecraft will experience a more challenging radiation environment in deep space than in LEO. Technologies are of interest that enable long-duration, safe and sustainable deep-space human exploration with advanced extra-vehicular capability.

Habitation systems encompass process technologies, equipment and monitoring functions necessary to provide and maintain a livable environment within the pressurized cabin of crewed spacecraft. Vehicle outfitting provides the equipment necessary for the crew to perform mission tasks as well as provide a comfortable and safe habitable volume. Three of the largest logistics consumables in spacecraft include logistical packaging, clothing, and food. 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. Environmental control and life support focus in this solicitation includes aspects of atmosphere revitalization and environmental monitoring for air, water and microbial contaminants.

Advanced radiation shielding technologies are needed to protect humans from the hazards of space radiation. All space radiation environments in which humans may travel in the foreseeable future are considered, including the Moon, Mars, asteroids, geosynchronous orbit (GEO), and low Earth orbit (LEO). Radiation of interest includes galactic cosmic radiation (GCR), solar energetic particles (SEP), and secondary neutrons. Computational tools for the evaluation of the transport of space radiation through highly complex vehicle architectures as represented in detailed computer-aided design (CAD) models are needed. Processing and construction that utilize in situ resources for radiation shielding for habitation systems on Mars are of interest.

Advanced Extra-Vehicular Activity (EVA) needs include innovative, robust, lightweight pressure structures for the hard upper torso of the spacesuit, oxygen-compatible gas flow meters for in-suit operation, and advanced sensors to measure space suit interactions with the human body.

Please review each subtopic for specific details on content of interest within this solicitation.

T6.01 Closed-Loop Living System for Deep-Space ECLSS with Immediate Applications for a Sustainable Planet
Lead Center: ARC
Participating Center(s): MSFC
Related Subtopic Pointers: H6.01

NASA's plans to explore space beyond Low Earth Orbit will push the performance of life support systems toward closed loop living systems. Deep space missions will require life support systems that will be self-sustaining since we cannot expect to carry enough spares and consumables for year-long missions. Achieving the development of such systems will provide the understanding for managing the limited availability of resources. The parallel with earth planetary resources management is useful as the world population grows and resources and infrastructure availability decreases. We anticipate that technologies developed for closed loop living systems could be made available to provide near term planetary sustainability as well.

State of the Art

An immediate example of such endeavors exists in the form of the NASA Ames Sustainability Base where technologies for deep space exploration have been used to create one of the greenest buildings in the federal building inventory. These technologies include power generation with fuel cells, water recovery systems, advanced HVAC, automated environmental control, recyclable materials and use of local resources. Even though these technologies are readily available for deep space travel, each has its own set of challenges for adaption to earth application along with integration challenges.

Closed-loop living systems are based on the thermodynamics laws of the conservation of mass and energy. We hope to maximize the conservation so that only a minimal amount of spare resources needs to be taken on crewed deep space missions.

Innovations are sought to enable:

- Development of processes and technologies to allow for closed loop living applications in space and on earth.
- Transfer of advanced deep space life support technologies and systems to earth based applications.
- Development of viable off-the-gridhabitation in remote areas where infrastructure is inexistent.

Potential deliverables include a demo of ECLSS concept(s), enhanced process and control techniques for multiple life support subsystems (e.g., environment, water recovery, power usage, etc.), or prototype(s) of relevant hardware and/or software.

For integrated system health management and monitoring capabilities that support sustainable systems, respondents are encouraged to consider SBIR subtopic - H6.01.

T6.02 Liquid Quantity Sensing Capability
Lead Center: JSC

In the current design of the Advanced Space Suit, the water necessary to provide cooling to the human and avionics is stored in the Feedwater Supply Assembly (FSA) which resides inside the habitable volume of the Space Suit. The FSA is a flexible reservoir which takes advantage of the suit pressure as the means of maintaining water loop pressure at operation conditions. During the EVA timeline, it is paramount that crew member cooling is uninterrupted. An interruption could cause overheating of the crew member. Therefore, insight in to the quantity of water remaining is important.

The ability to determine the quantity of a consumable liquid (e.g., water for cooling) remaining in a soft-walled, flexible reservoir via the use of one (ideally) or more sensors presents a difficult challenge for spaceflight applications. It presents a problem because the reservoir is flexible and it will be in micro-gravity during operation.

Typically, flexible reservoirs in micro-gravity are maintained at a relatively constant external pressure. Therefore, they will collapse as the liquid is consumed from the reservoir. This occurs as such a low rate, it has presented a challenge for traditional flow rate sensors. Also, numerous conditions contribute to the challenge. These challenges include the potential for gas(s) to be entrained in the liquid, the presence or lack of a gravity gradient, and motion of the liquid within the reservoir. Additionally, the constraints of spaceflight cause even more challenges such as:

- Sensor systems must be optimized for minimal mass, volume, and power consumption.
- They must be highly reliable and require minimal maintenance.
- Must cause minimal hazards to the vehicle, crew, and mission.

T6.03 Modeling and Estimation of Integrated Human-Vehicle Design Influences
Lead Center: JSC
Participating Center(s): MSFC
Related Subtopic Pointers: H6.01

The development of human space exploration vehicles and habitats requires an understanding of the relationships and interactions among the technical and human crew aspects of the system. This STTR subtopic seeks to enable creation of modeling and estimation capabilities that will inform system design decisions for enhancing mission success, crew task performance, and crew safety while reducing technical resource demands such as those on mission mass, power, volume and crew time. Currently there is no integrated framework in which to perform system design trades among various vehicle design capabilities taking into account the wide range of roles of the human crewmembers such as mission task performers, vehicle inhabitants, and even medical patients and caregivers. Life support inputs and outputs are accommodated in design considerations; however, this scope provides incomplete coverage of the human interactions with the system design. Just as vehicle and component life-cycle issues must be considered in system design, human adaption throughout a mission in areas such as individual and team behavioral health, physiological performance and clinical health must be folded in to inform vehicle and habitat system design decisions. Innovative approaches to modeling the mutual influences between the technical and human aspects of the exploration system are sought in to inform design trades and prioritization of system technology development. Methods are sought to systematically model and estimate impacts to the behavioral, physiological and clinical outcomes on crewmembers relative to vehicle design options, incorporating how the vehicle and humans will evolve and interact over the course of a mission. It is anticipated these methods will reveal attributes, or groups of attributes, of a system design as influential that would not otherwise be detected in the design phases of mission development. Model validation is not included in this topic call. Methods and demonstrations of application to informing system trade studies and technology development prioritization are included in the scope.

T7.01 Advanced Bioreactor Development for In-Situ Microbial Manufacturing
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 in the space environment, including reduced gravity.
- Bioreactors that incorporate novel microbial biomass separation/harvesting/purification methods, and materials recycling/recovery.
- 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.

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
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.

Nutrient Recycling

NASA seeks technologies that would enable generation and use of essential nutrients for plant growth (P, N, K) that would otherwise have to be provided by time release fertilizers shipped from Earth. Separation of targeted useful nutrients or sequestration of sodium from solution to leave useful nutrients are both desired. Sources of nutrients could include urine, urine that has been pretreated with strong acids or oxidizers, waste biomass from the inedible portions of plants, other spacecraft wastes, or possibly planetary surface regolith.

Cultivation and Growth Systems

Spacecraft systems are constrained to utilize minimal volume and require minimal crew time for management and operation. 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, potatoes), are adaptive for the entire life cycle (from anchoring the seed, managing the plant growth from seedling through harvest), and is 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.

Greenhouse Films

NASA seeks new materials that are flexible, transparent to light used by plants, and survive pressurization. They need to survive the challenges of a Mars surface environment, such as UV, temperature extremes, and exterior particulate and dust damage and accumulation.

Focus Area 9: Sensors, Detectors and Instruments

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 2017 program year, we are restructuring the Sensors, Detectors and Instruments Topic, adding new, rotating out, splitting and retiring some of the subtopics. Please read each subtopic of interest carefully. There are two new subtopics for this year. The first 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. The second seeks instruments and component technologies that will enable unambiguous determination of whether extant life is present in target environments on other solar system bodies. The microwave technologies subtopic has been split this 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.

T8.01 Technologies for Planetary Compositional Analysis and Mapping
Lead Center: JPL
Participating Center(s): GSFC, LaRC

This subtopic is focused on developing and demonstrating technologies for both orbital and in-situ compositional analysis and mapping that can be proposed to future planetary missions. Technologies that can increase instrument resolution, precision and sensitivity or achieve new and innovative scientific measurements are solicited. For example missions, see (http://science.hq.nasa.gov/missions). For details of the specific requirements see the National Research Councils, Vision and Voyages for Planetary Science in the Decade 2013-2022 (http://solarsystem.nasa.gov/2013decadal/).

Possible areas of interest include:

- Improved sources such as lasers, LEDs, X-ray tubes, etc. for imaging and spectroscopy instruments (including Laser Induced Breakdown Spectroscopy, Raman Spectroscopy, Deep UV Raman and Fluorescence spectroscopy, Hyperspectral Imaging Spectroscopy, and X-ray Fluorescence Spectroscopy).
- Improved detectors for imaging and spectroscopy instruments (e.g., flight-compatible iCCDS and other time-gated detectors that provide gain, robot arm compatible PMT arrays and other detectors requiring high voltage operation, detectors with improved UV and near-to-mid IR performance, near-to-mid IR detectors with reduced cooling requirements).
- Technologies for 1-D and 2-D raster scanning from a robot arm.
- Novel approaches that could help enable in-situ organic compound analysis from a robot arm (e.g., ultra-miniaturized Matrix Assisted Laser Desorption-Ionization Mass Spectrometry).
- "Smart software" for evaluating imaging spectroscopy data sets in real-time on a planetary surface to guide rover targeting, sample selection (for missions involving sample return), and science optimization of data returned to earth.

- Other technologies and approaches (e.g., improved cooling methods) that could lead to lower mass, lower power, and/or improved science return from instruments used to study the elemental, chemical, and mineralogical composition of planetary materials.
- Projects selected under this subtopic should address at least one of the above areas of interest. Multiple-area proposals are encouraged. Proposers should specifically address:
    - The suitability of the technology for flight applications, e.g., mass, power, compatibility with expected shock and vibration loads, radiation environment, interplanetary vacuum, etc.
    - Relevance of the technology to NASA's planetary exploration science goals.

Phase I contracts will be expected to demonstrate feasibility, and Phase II contracts will be expected to fabricate and complete laboratory testing on an actual instrument/test article.

T8.02 Photonic Integrated Circuits
Lead Center: GSFC

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, and integrated optic science instrument optical systems, subsystems and components. This is particularly critical for small spacecraft platforms. On July 27, 2015 - Vice President Joe Biden, at an event in Rochester, NY, announced the New York consortium has been selected to lead the Integrated Photonics Institute for Manufacturing Innovation. For details see (http://manufacturing.gov/ip-imi.html). Proposed as part of President Obamas National Network for Manufacturing Innovation (NNMI), the IP-IMI was established to bring government, industry and academia together to advance state-of-the-art photonics technology and better position the United States relative to global competition in this critical field. The use of the IP-IMI for work proposed under this topic is highly encouraged. 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.
- 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 microresonantors 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.
- Integrated photonic circuits for very high speed computing: Advanced computing engines that approach TeraFLOP per second computing power for spacecraft in a fully integrated combined photonic and electronic package.

T13.01 Intelligent Sensor Systems
Lead Center: SSC
Participating Center(s): KSC, MSFC

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 topic area 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 or inaccessible measurement locations. All this while eliminating cabling and auxiliary power. It is focused on near-term products that augment and enhance proven, state-of-the-art propulsion test facilities. 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.

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. 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 allowing for more complete and accurate health assessments including structural health monitoring for long-duration missions. Structural health monitoring is one of the Top 83 Technical Challenges (12.3.5). 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.
- 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.).
- Sensors are needed with capability to function reliably in extreme environments, including rapidly changing ranges of environmental conditions, such as those experienced in 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.
- The proposed innovative systems must lead to improved safety and reduced test, and space flight costs by allowing 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.

T15.02 Bio-inspired and Biomimetic Technologies and Processes for Earth and Space
Lead Center: GRC
Participating Center(s): ARC, LaRC

Biomimicry is the imitation of life, natural systems and life's principles characterized by reduced use of energy, water and raw materials. Energy and material use is minimized through 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. While most of the areas described here pertain to aeronautics, biological models have multiple applications and cross cutting solutions are also welcomed that apply to space technology.

Proposals must demonstrate that the proposed technology complies with natural principles, patterns and mechanisms.

Some resources are provided here: NASA workshop: https://www.grc.nasa.gov/vibe; www.asknature.org; http://toolbox.biomimicry.org/.

Technology is sought in the following areas:

Bio-inspired air breathing propulsion technology to mitigate engine and airframe icing, to reduce fuel burn, noise and emissions (ARMD Strategic Thrust 3)

Community performance goals for subsonic transports include specific levels of reduction in energy consumption, emissions of nitrogen oxides (NO), and noise, represented as N+1, N+2, and N+3 performance levels. These goals support reductions in carbon emissions expressed in an IATA resolution that calls for a 1.5% average annual fuel efficiency improvement between 2010 and 2020, carbon neutral growth from 2020 onward, and a reduction of 50% in net emissions by 2050 compared to 2005 levels.

This subtopic calls for proposals to reduce fuel burn, noise and emissions through bio-inspired propulsion system technology including but not limited to blade design, coatings, combustor lining, fuel injectors. Some areas of interest are:

- Management of 'leakage' flow (over blade tips and from purge cavities) in engines that becomes increasingly significant as engine core sizes decrease below 2.5lbm/s compressor exit corrected flow.
- Cooling technology for turbines that must withstand 3000° F inlet temperature. More generally, technology that can enable OPRs (Overall Pressure Ratios) higher than 60 are sought with linkages clearly demonstrated.
- Acoustic liners and turbomachinery concepts to reduce engine noise to reach ARMD's targeted 52dB reduction by 2025 (TRL 4-6 in 2025).
- Some common biological models are shark skin, owl wings and nautilus shell.
- Bio-inspired icephobic materials and structures for aeronautics (ARMD Strategic Thrust 1). ARMD plans for continued research in engine and airframe icing to enable air vehicles to safely fly into various types of icing environments. This research will include validated computational and experimental icing simulations, as well as complementary on-board icing sensing radar to enable avoidance of icing conditions and to facilitate safe operation of current and future air vehicle concepts. Icing mechanisms on airframes and in engines differ significantly from each other. Icing is also dependent on flight speed and atmospheric conditions. Thus, methods used for refrigerators may not be applicable to aeronautics. Proposals sought include materials or structures that delay ice formation relative to state of the art, that are relatively low energy to de-ice and multifunctional de-icing or icephobic systems. Well known biological systems or models should not be proposed unless the technology proposed is using a known biological model in a novel way. Examples of such models include shark skin, lotus leaves, pitcher plants.

Bio-inspired 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. Goals of this subtopic overlap with subtopic T3.01 Energy Transformation and Multifunctional Power Dissemination.

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.

Cross cutting technology making use of bio-inspired processes in conjunction with 1 or more of big data analytics, synthetic biology and additive manufacturing.

Specific areas of interest include:

- 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 15: Lightweight Materials, Structures, Assembly, and Construction

As NASA strives to explore deeper into space than ever before lightweight structures and advanced materials have been identified as a critical need for NASA space missions. The Lightweight Materials, Structures and 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. Improvement in all of these areas is critical to future missions. Applications include structures and materials for launch, in-space, deployable nondestructive evaluation, integrated structural health monitoring (SHM) and surface systems. 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.

The specific needs and metrics for this year’s focus technology needs are requested in detail in the topic and subtopic descriptions.

T12.02 Technologies to Enable Novel Composite Repair Methods
Lead Center: KSC
Participating Center(s): JSC, MSFC

As composite structures become more prevalent on launch vehicles, it will become necessary to have the capability to inspect and repair these structures during ground processing prior to launch. Current composite repair methods developed for the aviation industry are time consuming and require complex infrastructure in order to restore the structural strength. Aerospace structures have structural and thermal profiles which are different than aircraft and require different considerations; for example, unlike a commercial aircraft, a launch vehicle sees high loading but is only a one time use vehicle. Advancements are needed to repair materials and methods which allow for a structural repair to be performed in locations with minimal access and in a short time frame. Small damages may be accepted by analysis with no repair. Large damages may require extensive repair or component replacement. This subtopic focuses on developing novel composite repair methods for damages that fall in between these two categories. These novel materials and methods should consider the following:

- Use of out of autoclave composite materials and processes, which are being investigated for large launch vehicle components, such as fairings, skirts and tanks on the Space Launch System vehicle. Advancements in these material systems has begun to approach properties of autoclave materials but allow for larger structures to be fabricated.
- Simplified preparation of the damaged structure. Current methods require very precise methods, which is time consuming and can be a risk for further damage.
- Material systems and methods which reduce or eliminate the need for external heat and/or vacuum. These require complex infrastructure, which can be difficult to accommodate at the launch pad, and can be time consuming, which could cause a launch delay.
- Ability to acquire data on the state of the repair, during repair and/or during the launch. This may include data such as temperature at the bondline during cure, strain across the repair patch, etc.

Development of a material system and repair method which increases the performance of the repair and reduces the complexity and time required to perform a repair increases the launch capability and success rate. Improvements or modifications to current materials and processes can be made to meet NASA requirements. This technology can also be expanded to develop methods for in-situ repairs to spacecraft on long missions.

T12.03 Thin-Ply Composites Design Technology and Applications
Lead Center: LaRC

The use of thin-ply composites is one area of composites technology that has not yet been fully explored or exploited by NASA. Thin-ply composites are those with cured ply thicknesses below 0.0025” and commercially available prepregs are now available with ply thicknesses as thin as 0.00075”. By comparison, a standard-ply-thickness composite would have a cured ply thickness of approximately 0.0055”. 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.
- Increased scalability.

These characteristics can make thin-ply composites attractive for a number of applications. 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 laminates by 30%. The resistance to microcracking makes thin-ply composites an excellent candidate for a deep-space habitation structure where hermeticity is critical. Additionally, since a deep-space habitat may need to be pre-positioned in space for a long period of time prior to crew arrival, the enhanced aging and fatigue resistance and resistance to cryogenic-induced microcracking will also be a benefit. Finally, since the designs of these types of pressurized structures are typically constrained by minimum gage considerations, the ability to reduce that minimum gage thickness offers the potential for significant mass reductions. For these reasons, NASA is interested in exploring the use of thin-ply composites for applications requiring very high structural efficiency, and for pressurized structures (such as habitation systems and tanks) for deep-space exploration systems. 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: 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, and/or analysis and design tool validation and calibration to ensure that the technology to appropriately design and certify thin-ply composite components is matured sufficiently to be used for NASA applications. 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.

T12.04 Experimental and Analytical Technologies for Additive Manufacturing
Lead Center: MSFC
Participating Center(s): GSFC

Additive manufacturing is becoming a leading method for reducing costs, increasing quality, and shortening schedules for production of innovative parts and component that were previously not possible using more traditional methods of manufacturing. In the past decade, methods such as selective laser melting (SLM) have emerged as the leading paradigm for additive manufacturing (AM) of metallic components, promising very rapid, cost-effective, and on-demand production of monolithic, lightweight, and arbitrarily intricate parts directly from a CAD file. In the push to commercialize the SLM technology, however, the modeling of the AM process and physical properties of the resulting artifact were paid little attention. As a result, commercially available systems are based largely on hand-tuned parameters determined by trial and error for a limited set of metal powders. The system operation is far from optimal or efficient, and the uncertainty in the performance of the produced component is too large. This, in turn, necessitates a long and costly certification process, especially in a highly risk-aware community such as aerospace. Modeling and real time process control of selective laser melting is needed coupled with statistically significant correlations and understanding of the important process parameters and the resultant microstructural and mechanical properties, validated with detailed metallurgical investigations of the as-fabricated structures.

State-of-the-Art

This topic seeks technologies that close critical gaps between SOA and needed technology in both experimental and analytical areas in materials design, process modeling and material behavior prediction to reduce time and cost for materials development and process qualification for SLM.

Technological advancements are needed in the areas of:

- Real-time additive manufacturing process monitoring for real-time material quality assurance prediction.
- Reduced-order physics models for individual phases of additive manufacturing technique.
- Analytical tools to understand effects of process variables on materials evolution.

- Digital models to standardize the use of structured light scanning or equivalent within manufacturing processes.
- Software for high-fidelity simulation of various SLM phases for guiding the development, and enabling the subsequent verification.

Focus Area 16: Ground and Launch Processing

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 focus area 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.

T1.03 Real Time Launch Environment Modeling and Sensing Technologies
Lead Center: KSC
Participating Center(s): SSC

Launch and landing operations through the atmosphere of a planet are strongly affected by environmental and atmospheric conditions. Even the most robust vehicle design has physical limits that restricts the conditions through which it can be launched. Divergent fluid dynamics, lightning, and other severe conditions can overstress vehicle structures and cause a mishap. In addition, the safety of personnel performing launch preparations must be protected from extreme weather such as lightning in a manner that minimizes risk to the launch schedule. A key metric of launch architecture is the overall system's launch availability, which is in turn impacted by the accuracy with which the environmental conditions can be characterized. Advanced technologies are being solicited to improve the accuracy of launch and landing environment forecasting and evaluation. This technology is of interest not only for earth-based launches, but also to enable routine launch and landing activity on other planets such as Mars, where range infrastructure will be extremely limited. Specific areas of interest include the following:

Remote Sensing

During launch preparations, an acceptable launch environment that does not impart vehicle damage during ascent is critical. Currently, launch environment conditions such as wind direction, speed, temperature, humidity, and pressure are measured by launching several balloons with rawinsondes on launch day. The data is then used to construct a vertical profile initializing meteorological models that derive atmospheric stresses on a launch vehicle. Current technology is used for remote measurements of wind speed and direction as a function of altitude; however, there is no current capability to measure temperature and humidity as a function of altitude remotely in a cloudy environment. This capability needs to be satisfied by remote methods in order to improve accuracy by measuring overhead and improving timeliness by reducing the lag time to make the measurement and reducing the interval between measurements. In addition, a remote sensing approach would enable a lower cost simplified launch environment analysis with less infrastructure by eliminating the need for balloons and rawinsondes.

Technology is being sought which provides a remote sensing capability to measure thermodynamic data with respect to altitude from 300 meters to at least 10 km. The technology must have a vertical measurement resolution of 150 m or smaller and a full vertical profile of the thermodynamic data at least once an hour. The sensor must provide valid data in both cloudy and clear environments. Phase I should include a design for remote measurement of at least temperature and humidity as a function of altitude. Phase II should be prototype development, testing, and evaluation of the sensing technology in a subtropical environment as well as continued development to measure, or derive all three temperature, humidity, and pressure. Locally available rawinsonde data should be used to verify system accuracy.

Three-Dimensional Launch Window Modeling

During launch countdown, data from several disparate meteorological systems are used to evaluate environmental hazards such as triggered lightning during vehicle ascent. There are several rules based upon radar data, lightning location, electric field and the presence of clouds. For example, in certain circumstances, the launch vehicle cannot pass through a radar echo greater than 7.5 dBz. NASA is seeking a capability to simultaneously, and in real-time, visualize three-dimensional (3D) atmospheric data, and rocket/vehicle trajectories. The region in which a rocket/vehicle trajectory can safely travel through will be a 3D solid shape based upon the launch trajectory with allowable trajectory variations, and user-determined standoff distance. E.g., for a given rocket with trajectory variations of 4.5 miles and a safety standoff distance of 10 miles, a 3D shape such as a tube would be centered around the nominal trajectory line, and at all locations occupy the space 10 + 4.5 miles along the nominal trajectory. Atmospheric data will include: satellite, radar, and lightning data as well as meteorological model products (i.e., forecasts of radar data). The user must be able to manipulate the display to change orientation, scale and products/layers within the intersecting area.

At a minimum, the system should be able to identify areas where the trajectory shape intersect or enclose lightning data from 3D lighting data sources, and cloud data as identified by radar and a local Weather Research and Forecasting (WRF) model. Any data used for the technology or verification will be from the meteorological instrumentation used at KSC and owned by the USAF. Phase I would be development of requirements, proposed capabilities, and demonstration of sample products. Phase II would be development of application to ingest NASA and USAF meteorological data and products, and manipulate the data within the volume of interest.

Focus Area 18: Air Vehicle Technology

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 (2015).

T15.01 Distributed Electric Propulsion Aircraft Research
Lead Center: AFRC
Participating Center(s): ARC, GRC, LaRC

Distributed Electric Propulsion (DEP) Aircraft employ multiple electric propulsors to achieve unprecedented performances in air vehicles. The propulsor could be ducted/un-ducted fans, propellers, cross-flow-fans, etc. Some of the benefits identified using this propulsion system are reductions in fuel burn/energy usage, noise, emissions, and/or field length. Addressing ARMD's Strategic Thrust #3 (Ultra-Efficient Commercial Vehicles) and #4 (Transition to Low-Carbon Propulsion), innovative approaches in designing and analyzing the DEP aircraft are investigated and encouraged. In support of these two Strategic Thrusts, the following DEP aircraft research areas are to be considered under this solicitation.

- *Explore Subsonic Fixed Wing Aircraft Concepts with the DEP System* - Vehicle classes are to be from small on-demand aircraft to large subsonic transport aircraft. The study shall include vehicle system level assessment including feasibility, design, and benefits assessment.
- *Develop Analytical Tools and Methods to Assess DEP Aircraft Concepts* – Assessing a feasibility of vehicle concept requires reliable analytical, computational, experimental, and/or simulation tools and methods. Since the DEP aircraft involve multi-disciplinary subjects, some form of optimization process will be preferred and needed.
- *Assess Propulsion Airframe Integration (PAI) Benefits* – Synergistic benefit assessment capability needs to be established for aircraft with the DEP system. Some of the PAI examples include boundary layer ingestion (BLI), aero-propulsive acoustics, induced drag reduction using wing-tip propulsor, use of DEP coupled aeroelasticity effects to improve vehicle performance, etc.
- *Develop Aircraft Control Concept using DEP* – Aircraft control using differential and/or thrust vectoring of distributed electric propulsors shall be explored. This may allow reduction or elimination of conventional aerodynamic control surfaces.

Expected outcome (TRL 2-3) of Phase I awards, but not limited to:

- DEP aircraft concept definition and system level assessment.
- Initial development of analytical/computational/experimental/simulation tools and methods in assessing DEP concepts and aircraft.

Expected outcome (TRL 4-6) of Phase II awards, but not limited to:

- Detailed feasibility study and demonstration of the subscale hardware.
- Refinement of tools and methods in assessing DEP concepts and aircraft.
- Experimental (e.g., wind tunnel) results that assess the validity of the DEP/aircraft concept.

Focus Area 21: Small Spacecraft Technologies

NASA's technology, science, exploration, and space operations organizations are identifying a growing number of potential applications for very small spacecraft. Such spacecraft can accomplish missions at a fraction of the cost of larger conventional spacecraft and can be developed quickly and more responsively. In some cases, their small size and ability to be delivered in relatively large numbers may enable mission applications not possible with larger satellites. A small spacecraft can also serve as a low-cost platform for spaceflight testing of new technologies that are appropriate for spacecraft of any size.

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. Cubesats are a special category of small spacecraft and are of particular interest because launch opportunities tend to be more frequent and affordable compared to other small spacecraft, due to the standard sizes and containerization of cubesats.

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.
- 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).
- Tolerant of extreme thermal and/or radiation environments.
- 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.

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

T4.03 Coordination and Control of Swarms of Space Vehicles
Lead Center: JPL

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).

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: NASA SBIR/STTR Technology Taxonomy

Aeronautics/Atmospheric Vehicles
Aerodynamics
Air Transportation & Safety
Airship/Lighter-than-Air Craft
Avionics (see also Control and Monitoring)
Analysis
Analytical Instruments (Solid, Liquid, Gas, Plasma, Energy; see also Sensors)
Analytical Methods
Astronautics
Aerobraking/Aerocapture
Entry, Descent, & Landing (see also Planetary Navigation, Tracking, & Telemetry)
Navigation & Guidance
Relative Navigation (Interception, Docking, Formation Flying; see also Control & Monitoring; Planetary Navigation, Tracking, & Telemetry)
Space Transportation & Safety
Spacecraft Design, Construction, Testing, & Performance (see also Engineering; Testing & Evaluation)
Spacecraft Instrumentation & Astrionics (see also Communications; Control & Monitoring; Information Systems)
Tools/EVA Tools
Autonomous Systems
Autonomous Control (see also Control & Monitoring)
Intelligence
Man-Machine Interaction
Perception/Vision
Recovery (see also Vehicle Health Management)
Robotics (see also Control & Monitoring; Sensors)
Biological Health/Life Support
Biomass Growth
Essential Life Resources (Oxygen, Water, Nutrients)
Fire Protection
Food (Preservation, Packaging, Preparation)
Health Monitoring & Sensing (see also Sensors)
Isolation/Protection/Radiation Shielding (see also Mechanical Systems)
Medical
Physiological/Psychological Countermeasures
Protective Clothing/Space Suits/Breathing Apparatus
Remediation/Purification
Waste Storage/Treatment
Communications, Networking & Signal Transport
Ad-Hoc Networks (see also Sensors)
Amplifiers/Repeaters/Translators
Antennas

Architecture/Framework/Protocols
Cables/Fittings
Coding & Compression
Multiplexers/Demultiplexers
Network Integration
Power Combiners/Splitters
Routers, Switches
Transmitters/Receivers
Waveguides/Optical Fiber (see also Optics)
Control & Monitoring
Algorithms/Control Software & Systems (see also Autonomous Systems)
Attitude Determination & Control
Command & Control
Condition Monitoring (see also Sensors)
Process Monitoring & Control
Sequencing & Scheduling
Telemetry/Tracking (Cooperative/Noncooperative; see also Planetary Navigation, Tracking, & Telemetry)
Teleoperation
Education & Training
Mission Training
Outreach
Training Concepts & Architectures
Electronics
Circuits (including ICs; for specific applications, see e.g., Communications, Networking & Signal Transport; Control & Monitoring, Sensors)
Manufacturing Methods
Materials (Insulator, Semiconductor, Substrate)
Superconductance/Magnetics
Energy
Conversion
Distribution/Management
Generation
Sources (Renewable, Nonrenewable)
Storage
Engineering
Characterization
Models & Simulations (see also Testing & Evaluation)
Project Management
Prototyping
Quality/Reliability
Software Tools (Analysis, Design)
Support

Imaging
3D Imaging
Display
Image Analysis
Image Capture (Stills/Motion)
Image Processing
Radiography
Thermal Imaging (see also Testing & Evaluation)
Information Systems
Computer System Architectures
Data Acquisition (see also Sensors)
Data Fusion
Data Input/Output Devices (Displays, Storage)
Data Modeling (see also Testing & Evaluation)
Data Processing
Knowledge Management
Logistics
Inventory Management/Warehousing
Material Handing & Packaging
Transport/Traffic Control
Manufacturing
Crop Production (see also Biological Health/Life Support)
In Situ Manufacturing
Microfabrication (and smaller; see also Electronics; Mechanical Systems; Photonics)
Processing Methods
Resource Extraction
Materials & Compositions
Aerogels
Ceramics
Coatings/Surface Treatments
Composites
Fluids
Joining (Adhesion, Welding)
Metallics
Minerals
Nanomaterials
Nonspecified
Organics/Biomaterials/Hybrids
Polymers
Smart/Multifunctional Materials
Textiles
Mechanical Systems
Actuators & Motors

Deployment
Exciters/Igniters
Fasteners/Decouplers
Isolation/Protection/Shielding (Acoustic, Ballistic, Dust, Radiation, Thermal)
Machines/Mechanical Subsystems
Microelectromechanical Systems (MEMS) and smaller
Pressure & Vacuum Systems
Structures
Tribology
Vehicles (see also Autonomous Systems)
Microgravity
Biophysical Utilization
Optics
Adaptive Optics
Fiber (see also Communications, Networking & Signal Transport; Photonics)
Filtering
Gratings
Lenses
Mirrors
Telescope Arrays
Photonics
Detectors (see also Sensors)
Emitters
Lasers (Communication)
Lasers (Cutting & Welding)
Lasers (Guidance & Tracking)
Lasers (Ignition)
Lasers (Ladar/Lidar)
Lasers (Machining/Materials Processing)
Lasers (Measuring/Sensing)
Lasers (Medical Imaging)
Lasers (Surgical)
Lasers (Weapons)
Materials & Structures (including Optoelectronics)
Planetary Navigation, Tracking, & Telemetry
Entry, Descent, & Landing (see also Astronautics)
GPS/Radiometric (see also Sensors)
Inertial (see also Sensors)
Optical
Ranging/Tracking
Telemetry (see also Control & Monitoring)
Propulsion
Ablative Propulsion

Atmospheric Propulsion
Extravehicular Activity (EVA) Propulsion
Fuels/Propellants
Launch Engine/Booster
Maneuvering/Stationkeeping/Attitude Control Devices
Photon Sails (Solar; Laser)
Spacecraft Main Engine
Surface Propulsion
Tethers
Sensors/Transducers
Acoustic/Vibration
Biological (see also Biological Health/Life Support)
Biological Signature (i.e., Signs Of Life)
Chemical/Environmental (see also Biological Health/Life Support)
Contact/Mechanical
Electromagnetic
Inertial
Interferometric (see also Analysis)
Ionizing Radiation
Optical/Photonic (see also Photonics)
Positioning (Attitude Determination, Location X-Y-Z)
Pressure/Vacuum
Radiometric
Sensor Nodes & Webs (see also Communications, Networking & Signal Transport)
Thermal
Software Development
Development Environments
Operating Systems
Programming Languages
Verification/Validation Tools
Spectral Measurement, Imaging & Analysis (including Telescopes)
Infrared
Long
Microwave
Multispectral/Hyperspectral
Non-Electromagnetic
Radio
Terahertz (Sub-millimeter)
Ultraviolet
Visible
X-rays/Gamma Rays
Testing & Evaluation
Destructive Testing

Hardware-in-the-Loop Testing
Lifetime Testing
Nondestructive Evaluation (NDE; NDT)
Simulation & Modeling
Thermal Management & Control
Active Systems
Cryogenic/Fluid Systems
Heat Exchange
Passive Systems
Vehicle Health Management
Diagnostics/Prognostics
Recovery (see also Autonomous Systems)

Appendix C: 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	1.2.0 Liquid Rocket Propulsion Systems	Detailed Multiphysics Propulsion Modeling & Simulation Through Coordinated Massively Parallel Frameworks	T1.02
		1.5.0 Unconventional/Other Propulsion Systems	Small Launch Vehicle Technologies and Demonstrations	Z9.01
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	Methane In-Space Propulsion	Z10.02
		2.2.0 Non-Chemical Propulsion	Propulsion Systems for Robotic Science Missions	S3.02
			Nuclear Thermal Propulsion (NTP)	Z10.03
			Small Spacecraft Propulsion Systems	Z8.01
			Advanced Nuclear Propulsion	T2.01
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
			Surface Power Generation	Z1.03
		3.3.0 Power Management and Distribution	Power Electronics and Management, and Energy Storage	S3.03
			High Power, High Voltage Electronics	Z1.01
			Energy Harvesting, Transformation and Multifunctional Power Dissemination	T3.01
			Intelligent/Autonomous Electrical Power Systems	T3.02
		3.4.0 Cross Cutting Technology	Surface Energy Storage	Z1.02
			Small Spacecraft Power and Thermal Control	Z8.03

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	Planetary Entry, Descent and Landing and Small Body Proximity Operation Technology	S4.01
		4.2.0 Mobility	Robotic Systems - Mobility Subsystems	Z5.02
		4.3.0 Manipulation	Robotic Mobility, Manipulation and Sampling	S4.02
			Spacecraft Technology for Sample Return Missions	S4.03
		4.5.0 Autonomy	Resilient Autonomous Systems	H6.02
			Spacecraft Autonomous Agent Cognitive Architectures for Human Exploration	H6.03
			Information Technologies for Intelligent and Adaptive Space Robotics	T4.01
		4.7.0 RTA Systems Engineering	Contamination Control and Planetary Protection	S4.05
			Payload Technologies for Free-Flying Robots	Z5.01
		Not Mapped	Coordination and Control of Swarms of Space Vehicles	T4.03

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
		5.2.0 Radio Frequency Communications	Intelligent Communication Systems	H9.02
			Advanced RF Communications	H9.04
			Small Spacecraft Communication Systems	Z8.02
		5.4.0 Position, Navigation, and Timing	Flight Dynamics and Navigation Technology	H9.03
			Slow and Fast Light	S3.07
		5.5.0 Integrated Technologies	Small Spacecraft Avionics and Control	Z8.05
		5.6.0 Revolutionary Concepts	Transformational/Over-the-Horizon Communications Technology	H9.05
			Terrestrial and Planetary Balloons	S3.05

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	Habitat Outfitting	H3.01
			Environmental Control and Life Support	H3.03
			Logistics Reduction	H3.04
			Closed-Loop Living System for Deep-Space ECLSS with Immediate Applications for a Sustainable Planet	T6.01
		6.2.0 Extravehicular Activity Systems	Damage Tolerant Lightweight Pressure Structures	H4.01
			Small, Accurate Oxygen Compatible Gas Flow Meter for Suit Operations	H4.02
			Sensors to Measure Space Suit Interactions with the Human Body	H4.03
			Advanced Model-based Adaptive Interfaces and Augmented Reality	H12.02
		6.3.0 Human Health and Performance	Environmental Monitoring for Spacecraft Cabins	H3.02
		6.4.0 Environmental Monitoring and Safety	Radiation Shielding Technologies for Human Protection	H11.01
		6.5.0 Radiation	Radioprotectors and Mitigators of Space Radiation-induced Health Risks	H12.01
		Not Mapped	Liquid Quantity Sensing Capability	T6.02
			Modeling And Estimation Of Integrated Human-Vehicle Design Influences	T6.03
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 Acquisition, Separation, and Conditioning for ISRU	H1.01
			Mars Soil Acquisition and Processing for In Situ Water	H1.02
			Lunar Resources	H2.01
			ISS Utilization and Microgravity Research	H8.01
			Regolith Resources Robotics - R^3	T4.02
			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
			Particles and Field Sensors and Instrument Enabling Technologies	S1.06
			In Situ Instruments/Technologies for Planetary Science	S1.07
			Surface & Sub-surface Measurement Systems	S1.08
			Atomic Interferometry	S1.10
			In Situ Instruments/Technologies for Ocean Worlds Life Detection	S1.11
			Sample Processing For Life Detection Investigations for Ocean Worlds	S1.12
			Command, Data Handling, and Electronics	S3.08
			Sample Collection For Life Detection in Outer Solar System Ocean World Plumes	S4.06
			Technologies for Planetary Compositional Analysis and Mapping	T8.01
		8.2.0 Observations	Proximity Glare Suppression for Astronomical Coronagraphy	S2.01
			Precision Deployable Optical Structures and Metrology	S2.02
			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	Technologies for Active Microwave Remote Sensing	S1.02
			Technologies for Passive Microwave Remote Sensing	S1.03
			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
			Cryogenic Systems for Sensors and Detectors	S1.09
			Guidance, Navigation and Control	S3.04
			Extreme Environments Technology	S4.04
			Integrated Science Mission Modeling	S5.04

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	Deployable 3D Woven Thermal Protection Materials	Z7.02
			Deployable Aerodynamic Decelerator Technology	Z7.03
		9.2.0 Descent	Supersonic Parachute Inflation Materials Testing, And Instrumentation	Z7.01
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	Technologies for Large-Scale Numerical Simulation	S5.01
			High Performance Space Computing Technology	Z6.01
		11.2.0 Modeling	Enabling NASA Science through Large-Scale Data Processing and Analysis	S5.03
			Distributed Spacecraft Missions (DSM) Technology Framework	T11.02
		11.4.0 Information Processing	Integrated System Health Management for Sustainable Habitats	H6.01
			Earth Science Applied Research and Decision Support	S5.02
		Not Mapped	Machine Learning and Data Mining for Autonomy, Health Management, and Science	T11.01
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	Advanced Metallic Materials and Processes Innovation	Z3.02
			Thin-Ply Composites Design Technology and Applications	T12.03
		12.2.0 Structures	Mars Surface Solar Array Structures	H5.01
			Advanced Structural Health Monitoring	T12.01
		12.4.0 Manufacturing	In-Space Manufacturing of Electronics and Avionics	H7.01
			In-Space Manufacturing of Precision Parts	H7.02
			In-Situ Sensing of Additive Manufacturing Processes for Safety-Critical Aerospace Applications	Z3.01
		12.5.0 Cross-Cutting	Flight Test and Measurements Technologies	A2.01
			NDE Sensors	Z11.01
			NDE Simulation and Analysis	Z11.02
			In-Space Structural Assembly and Construction	Z4.01

			Small Spacecraft Structures, Mechanisms, and Manufacturing	Z8.04
		Not Mapped	Technologies to Enable Novel Composite Repair Methods	T12.02
			Structural Efficiency-Tailored Airframe & Structures	A1.01
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
		13.3.0 Technologies to Increase Reliability and Mission Availability	Improved Operations via Interface Design	H10.02
			Cryogenic Purge Gas Recovery and Reclamation	H10.03
			Real Time Launch Environment Modeling and Sensing Technologies	T1.03
			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	14.1.0 Cryogenic Systems	Cryogenic Fluid Management	Z10.01
		14.2.0 Thermal Control Systems	Thermal Control Systems	S3.06
			Thermal Management	Z2.01
TA	**STR Technology Area (TA) Level 1 Description**	**STR Technology Area (TA) Level 2 Description**	**Subtopic Description**	**Subtopic**
TA15	15.0.0 Aeronautics	15.3.0 Ultra-Efficient Commercial Vehicles	Quiet Performance - Airframe Noise Reduction	A1.02
			Aerodynamic Efficiency-Active Flow Control Actuators and Design Tools	A1.04
			Computational Methods & Tools - High Fidelity Mesh and Geometry Tools	A1.05
			Vertical Lift Technology	A1.06
			Bio-inspired and Biomimetic Technologies and Processes for Earth and Space	T15.02
		15.4.0 Transition to Low-Carbon Propulsion	Low Emissions Propulsion and Power-Turboelectric and Hybrid Electric Aircraft Propulsion	A1.03
			Distributed Electric Propulsion Aircraft Research	T15.01
		15.5.0 Real-Time System-Wide Safety Assurance	Vehicle Safety- Internal Situational Awareness and Response	A1.09
		Not Mapped	Aeronautics Ground Test and Measurements Technologies	A1.08
			Hypersonic Technology-Improvement in Solar Operability Predictions using Computational Algorithms	A1.10