National Aeronautics and Space Administration

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

Fiscal Year 2016 General Solicitation

Opening Date: November 12, 2015
Closing Date: February 1, 2016

Fiscal Year 2016 SBIR/STTR Solicitation Noteworthy Changes

General Document Formatting

The previously separate Phase I and Phase II instructions of the Solicitation have been merged. Subsections are used as necessary to specify the differences. For example, Proposal Preparation Instructions and Requirements are documented in Section 3.2 for Phase I and in Section 3.3 for Phase II.

Chapter 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.

1.3 Three-Phase Program

The Phase II Enhancement and Phase II Expanded options have been merged into the new Phase II Extended option. For more information on the Phase II Extended option please visit: http://sbir.nasa.gov/content/post-phase-ii-initiatives.

1.6 Commercialization Technical Assistance

The $5k Commercialization Technical Assistance is now only available for Phase II proposals.

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.

1.8 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.

3.2.4 Technical Proposal

Use of Federal Laboratory/facilities or equipment (Phase I):
Due to the complexity of the process for entering into the appropriate agreements with Federal agencies to use their facilities (such as a NASA Space Act Agreement) the use of federal laboratories/facilities for Phase I contracts is highly discouraged, due to the potential loss of period of performance time. Approval for use of federal facilities and labs, for a Phase I proposal, requires Program Executive approval.

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 2016 Solicitation period for Phase I proposals begins November 12, 2015 and ends February 1, 2016.

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 2016. 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.

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 and technology needs for their respective programs and projects. The range of 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 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

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	12months
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 past the basic Phase I and Phase II elements of the program. Specifically, the NASA SBIR/STTR program has the Phase II Extended (Phase II-E) contract option, and the Commercialization Readiness Program (CRP). These programs will be included as options in Phase II awards.

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, NASA is not considering this change. Currently, 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 anon-exclusive, royalty-free 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. 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 its SBIR/STTR Phase II protégé.

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 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

1.9 General Information

1.9.1 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:

NASA SBIR/STTR Program Management Office
MS 202A-3, Ames Research Center
Moffett Field, CA 94035-1000
ARC-SBIR-PMO@mail.nasa.gov

1.9.2 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 28, 2016.

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 needs 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 and other potential 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 fine of up to $10,000, up to five years in prison, or both. The Office of the Inspector General has full access to all proposals submitted to NASA.

3.2.2 Format Requirements

<u>Proposals that do not follow the formatting requirements shall be rejected during administrative screening.</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).

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:

(8) Firm Level Certifications, are not included in the 23-page limit.
(9) Audit Information, is not included in the 23-page limit.
(10) Prior Awards Addendum, is not included in the 23-page limit.
(11) 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: (https:/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 shall 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 (https:/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 (https:/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 (https:/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 shall be rejected during administrative screening. The required table of contents is provided below:

Phase I Table of Contents

Part 1: Table of Contents……………………………………………………………………….………Page 4
Part 2: Identification and Significance of the Innovation
Part 3: Technical Objectives
Part 4: Work Plan
Part 5: Related R/R&D
Part 6: Key Personnel and Bibliography of Directly Related Work
Part 7: Relationship with Phase II or Future R/R&D
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 a need or needs, within a subtopic described in section 9; and
(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 2015and 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.

The offeror must execute an SBIR Support Agreement before using any NASA Services, Facilities, or Equipment. The content of the SBIR Support 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. The SBIR Support Agreement consists of a standard form that identifies the Performing Organization, i.e., the NASA Center or Component Facility, and the Contractor, and includes the appropriate responsibilities, schedule and pricing for work to be performed.

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). 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 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.

3.2.7 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 (https:/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.

3.2.8 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.

3.2.9 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.

3.2.10 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

3.2.11 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 (https:/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 needs, 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 and other potential 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 fine of up to $10,000, up to five years in prison, or both. The Office of the Inspector General has full access to all proposals submitted to NASA.

3.3.2 Format Requirements

Proposals that do not follow the formatting requirement shall be rejected during administrative screening.

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: (https:/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 shall 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 (https:/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 (https:/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 (https:/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 has a new program requirement which mandates that the SBIR/STIR contracts will be written with 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 a 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; and
(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 Support Agreement before using any NASA Services, Facilities, or Equipment. The content of the SBIR Support 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. The SBIR Support Agreement consists of a standard form that identifies the Performing Organization, i.e., the NASA Center or Component Facility, and the Contractor, and includes the appropriate responsibilities, schedule and pricing for work to be performed.

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 (https:/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 (https:/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 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.

4.1.1 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 offering the most advantageous technology 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. 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. Commercialization encompasses the infusion of innovative technology into products and services for NASA mission programs, other Government agencies and non-Government markets.

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 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.

4.2.1 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.

4.2.2 Phase II Evaluation Criteria

NASA intends to select for award those proposals that best meet the Government's need(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.

Commercialization encompasses the infusion of innovative technology into products and services for NASA mission programs, other Government agencies and non-Government markets.

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. Proposals receiving acceptable numerical scores will be evaluated and rated for their commercial potential. 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 II proposals, commercial merit is a critical factor. 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.

4.2.3 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.

4.3 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.

4.3.1 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.

4.3.2 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).
(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 submitted 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: https://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 via the SBIR/STTR website in the EHB.

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 uploaded to 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 Firm 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.

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 fine of up to $10,000, up to five years in prison, or both. The Office of the Inspector General has full access to all proposals submitted to NASA.

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 3.2.6).
(5) NASA Research License Application (only if the use of TAV is proposed).
(6) The 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 Monday, February 1, 2016 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:

Cassandra Williams
NASA Shared Services Center
Building 1111, C Road
Stennis Space Center, MS 39529
Cassandra.Williams-1@nasa.gov

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

7. Scientific and Technical Information Sources

7.1 NASA Websites

General sources relating to scientific and technical 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

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

8. Submission Forms and Certifications

Please note: Previews of all forms and certifications are available via the NASA SBIR/STTR Firm Library, located at: (https:/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, and C 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. **Proposals must be received no later than 5:00 p.m. EST on February 1, 2016 (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, 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 February 1, 2016 (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 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, 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

9.1 SBIR Research Topics

Introduction

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

There are four Mission Directorates (MDs):

Aeronautics Research
Human Exploration and Operations
Science
Space Technology

9.1.1 AERONAUTICS RESEARCH

NASA's Aeronautics Research Mission Directorate (ARMD) expands the boundaries of aeronautical knowledge for the benefit of the Nation and the broad aeronautics community, which includes the Agency's partners in academia, industry, and other government agencies. ARMD is conducting high-quality, cutting-edge research at the fundamental level and integrated systems level to support current and emerging applications as well as revolutionary concepts and technologies. This could one day enable radical change to both the airspace system and the aircraft that fly within it, facilitating a safer, more environmentally friendly, and more efficient air transportation system. At the same time, we are ensuring that aeronautics research and critical core competencies continue to play a vital role in support of NASA’s goals for both manned and robotic space exploration.

ARMD is also directly addressing fundamental research challenges that must be overcome in order to implement the Next Generation Air Transportation System (NextGen). NextGen is the name given to a new National Airspace System that proposes to transform America’s air traffic control system from an aging ground-based communication, navigation and surveillance system to a satellite-based system. NextGen technology will provide advanced levels of automated support to air navigation service providers and aircraft operators enabling shortened routes for time and fuel savings, reduced traffic delays, increased capacity, and permitting controllers to monitor and manage aircraft with greater safety margins. This transformation has the aim of reducing gridlock, both in the sky and at airports. In conjunction with expanding air traffic management capabilities, research is being conducted to help address substantial noise, emissions, efficiency, performance, and safety challenges that are required to ensure vehicles can support the NextGen vision.

NASA's Aeronautics Research Mission Directorate (ARMD) supports the Agency's goal (Goal 4) to advance aeronautics research for societal benefit. The ARMD research plans directly support the National Aeronautics Research and Development Policy and accompanying Executive Order signed by the President on December 20, 2006.

In 2012 ARMD introduced more focused solicitations by rotating some of the subtopics every other year. The reduction in the scope of some solicitations does not imply a change in interest in a given area. For example, in 2012 we solicited proposals for airframe noise reduction and efficiency improvement (through drag reduction). In 2013 we solicited proposals for air engine noise and efficiency reductions. Then in 2014 we returned to airframe noise reduction and efficiency improvement.

(http://www.aeronautics.nasa.gov/)

Topic: A1 Air Vehicle Technology

The Air Vehicle Technology topic solicits cutting-edge research in aeronautics to overcome technology barriers and challenges in developing safe, new vehicles that will fly faster, cleaner, and quieter, and use fuel far more efficiently. The primary objective is the development of knowledge, technologies, tools, innovative concepts and capabilities needed as the Nation continues to experience growth in both domestic and international air transportation while needing to protect and preserve the environment. This topic solicits tools, technologies and capabilities to facilitate assessment of new vehicle designs and their potential performance characteristics. These tools, technologies and capabilities will enable:

- The best design solutions to meet performance and environmental requirements and challenges.
- Technology innovations for future air vehicles.

It also solicits focused research in revolutionary aircraft technologies enabling improved structural, aerodynamic, and propulsion efficiency and reduced noise and emissions while maintaining vehicle safety in order to meet the performance, efficiency and environmental requirements of future aircraft operating in the Next Gen airspace. This topic 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). The topic focuses on the needs of NASA's Advanced Air Vehicles Program (AAVP) which consists of five projects, three that target a specific vehicle class/type, and two crosscutting projects focused on commonly encountered challenges associated with composite materials and capabilities necessary to enable advanced technology development.

- Advanced Air Transport Technologies (AATT) Project explores and develops technologies and concepts for improved energy efficiency and environmental compatibility of fixed wing, subsonic transports.
- Revolutionary Vertical Lift Technologies (RVLT) Project develops and validates tools, technologies, and concepts to overcome key barriers for rotary wing vehicles.
- Commercial Supersonics Technology (CST) Project enables tools and technologies and validation capabilities necessary to overcome environmental and performance barriers to practical civil supersonic airliners and sustains NASA competence in hypersonic air-breathing propulsion necessary to support the nearer-term Department of Defense (DoD) hypersonic mission.
- Advanced Composites (AC) Project focuses on reducing the timeline for development and certification of innovative composite materials and structures.
- Aeronautics Evaluation & Test Capabilities (AETC) Project sustains and enhances those specific research and test capabilities necessary to address and achieve the future air vehicles and operations as described above.

A1.01 Structural Efficiency - Aeroelasticity and Aeroservoelastic Control
Lead Center: LaRC
Participating Center(s): AFRC

The technical discipline of aeroelasticity is a critical ingredient necessary in the design process of a flight vehicle for maintaining optimal performance while ensuring freedom from aeroelastic and aeroservoelastic instabilities. This discipline requires a thorough understanding of the complex interactions between a flexible structure and the steady and unsteady aerodynamic forces acting on the structure, with interactive control systems for flight vehicle performance and stability. This fundamental aeronautics work is focused on active/adaptive aerostructural control for lightweight flexible structures, specifically related to load distribution, flutter prediction and suppression, gust load prediction and alleviation, and aeroservoelasticity for Ultra-Efficient and Supersonic Commercial Vehicles.

The program's work on aeroservoelasticity includes conduct of broad-based research and technology development to obtain a fundamental understanding of aeroelastic and unsteady-aerodynamic phenomena experienced by aerospace vehicles in subsonic, transonic, supersonic, and hypersonic speed regimes.

The program content includes theoretical aeroelasticity, experimental aeroelasticity, and advanced aeroservoelastic concepts. Of interest are:

- Aeroelastic, aeroservoelastic, and unsteady aerodynamic analyses at the appropriate level of fidelity for the problem at hand.
- Aeroelastic, aeroservoelastic, and unsteady aerodynamic experiments to validate methodologies and to gain valuable insights available only through testing.
- Development of computational-fluid-dynamic, computational-aeroelastic, and computational-aeroservoelastic analysis tools that advance the state of the art in aeroservoelasticity through novel and creative application of aeroelastic knowledge.

Specific subjects to be considered include:

- Development of aerostructural control design methodologies that include CFD steady and unsteady aerodynamics, flexible structures, and active control systems.
- Development of efficient methods to generate mathematical models of wind-tunnel models and flight vehicles for performing aeroservoelastic studies.
- Development of CFD-based methods (reduced-order models) for aeroservoelasticity models and simulation that can be used to predict gust loads, ride quality issues, flight dynamics stability, and aerostructural control issues.
- Development of novel aeroservoelasticity sensing and control approaches, including active/adaptive control concepts and architectures that employ smart materials embedded in the structure and aerodynamic sensing and control schemes for suppressing aeroelastic instabilities and improving performance.
- Development of techniques that support simulations, ground testing, wind-tunnel tests, and flight experiments for aerostructural control of aeroservoelastic phenomena.

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

To reduce noise emissions from aircraft, tools and technologies are needed to design aircraft that are both efficient and low noise. As such, developments/improvements in noise reduction technology, noise prediction tools, and flow & noise diagnostic methods are necessary to mitigate the environmental impact of aircraft noise. The focus of this call is on aircraft propulsion noise and innovations are solicited in the following areas:

Noise Reduction:

- Advanced liners including broadband liners (i.e., liners capable of appreciable sound absorption over at least two octaves), low-frequency liners (i.e., liners with optimum absorption frequencies half of the current ones but without increasing liner depth), and low-drag liners (i.e., liners that maintain current acoustic performance while reducing aerodynamic impact.
- Low-noise propulsor concepts that are significantly quieter than the current generation fans and open rotors;
- Concepts for active control of propulsion broadband noise sources including fan, open rotor, jet compressor, combustor and turbine.
- Adaptive flow and noise control technologies including smart structures for inlets, nozzles, and low-drag liners.
- Concepts to mitigate the effects of distorted inflow on propulsor noise.

Noise Prediction:

- High-fidelity fan and turbine noise prediction models including Large Eddy Simulation of broadband noise, 3D fan and turbine acoustic transmission models for tone and broadband noise.
- Accurate models for prediction of installed noise for jet surface interaction, fan inlet distortion, and open rotors.

Noise Diagnostics:

- Tools/Technologies for quantitative characterization of fan in-duct broadband noise in terms of its spatial and temporal content.
- Phased array and acoustical holography techniques to measure realistic propulsion noise sources in low-signal-to-noise ratio wind tunnel environments.
- Characterization of fundamental jet noise sources and structures.
- Innovative measurement of radiated acoustic fields from aeroacoustic sources.

A1.03 Low Emissions/Clean Power - Combustion Technology/Emissions Measurement Techniques
Lead Center: GRC
Participating Center(s): LaRC

Achieving low emissions and finding new pathways to cleaner power are critical for the development of future air vehicles. Vehicles for subsonic and supersonic flight regimes will be required to operate on a variety of certified aircraft fuels and emit extremely low amounts of gaseous and particulate emissions to satisfy increasingly stringent emissions regulations. Future vehicles will be more fuel-efficient which will result in smaller engine cores operating at higher pressures. Future combustors will also likely employ lean burn concepts which are more susceptible to combustion instabilities. Fundamental combustion research coupled with associated physics based model development of combustion processes will provide the foundation for technology development critical for these vehicles.

Combustion involves multi-phase, multi-component fuel, turbulent, unsteady, 3-D, reacting flows where much of the physics of the processes are not completely understood. CFD codes used for combustion do not currently have the predictive capability that is typically found for non-reacting flows. Low emissions combustion concepts require very rapid mixing of the fuel and air with a minimum pressure loss to achieve complete combustion in the smallest volume. Areas of specific interest where research is solicited include:

- Development of laser-based diagnostics for quantitative spatially and temporally resolved measurements of fuel/air ratio in reacting flows at elevated pressure.
- Development of ultra-sensitive instruments for determining the size-dependent mass of combustion generated particle emissions.
- Low emissions combustor concepts for small high pressure engine cores.
- Development of miniature high-frequency fuel modulation valve for combustion instability control able to withstand the surrounding high-temperature air environment.

Infusion/Commercial Potential – These developments will impact future aircraft engine combustor designs (lower emission, control instabilities) and may have commercial applications in other gas-turbine based industries (such as power generation and industrial burners). The modeling and results can be and will be employed in current and future hydrocarbon rocket engine designs (improving combustion efficiency, ignition, stability, etc.).

A1.04 Aerodynamic Efficiency - Active Flow Control Actuation Concepts
Lead Center: LaRC
Participating Center(s): AFRC

Active flow control (AFC) technology has the potential to be a key contributor to achieving NASA's aeronautics goal of revolutionizing the energy efficiency and environmental compatibility of fixed wing transport aircraft. Active flow control is the on-demand addition of energy into a boundary layer for maintaining, recovering, or improving vehicle performance. Since Prandtl's discovery of the boundary layer, AFC actuation methods have included steady mass transfer via suction or blowing, and unsteady perturbations created by zero net mass flux actuators, plasma actuators, 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 actuators and 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 also 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 robust, energy-efficient, reliable actuation systems with the control authority needed to control turbulent separation thus improving circulation on simply hinged flaps systems and other aircraft control surfaces during the subsonic portion of the flight regime and/or to control shock induced separation on vehicles in cruise during the transonic portion of the flight regime.

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

- Experimental or computational investigations aimed at control of turbulent boundary layer separation due to large adverse pressure gradients or shock/boundary layer interactions.
- Development of novel, energy-efficient, and robust actuators for controlling boundary layer separation.
- Development of computational tools to model the performance of a proposed actuator concept.
- Development of closed-loop active flow control systems with demonstrated improvements in AFC efficiency measured by the energy consumed by the AFC actuator.
- Experimental evaluation of realistic AFC actuators applied to separated flows.
- Experimental and computational studies that demonstrate the efficiency of the proposed actuation system.
- Development of computational tools to model the flowfield resulting from the application of active flow control on an airfoil or wing.

A1.05 Physics-Based Computational Tools - Stability and Control/High Lift Design Tools
Lead Center: LaRC
Participating Center(s): GRC

NASA continues to investigate the potential of advanced, innovative propulsion and airframe concepts to improve fuel efficiency and reduce the environmental footprint of future generations of commercial transports across the breadth of the flight speed regimes. Advanced concepts are viewed as potential options for helping to meet aggressive, long range (i.e., 'N+3' timeframe) fuel burn, noise, and emission reduction targets. Conceptual design and analysis of unconventional airframe and propulsion concepts and technologies is used within NASA for technology portfolio investment planning, development of advanced concepts to provide technology pull, and independent technical assessment of new concepts, so the agency's systems analysts need the best conceptual design and analysis tools possible to support these efforts.

Historically, only empirical and semi-empirical analysis methods have been used during the conceptual design phase. These techniques work well for the conceptual design of conventional systems with parameters that reside within the historical databases used to develop the methodologies. However, these methods are not well suited for unconventional concepts, or even conventional concepts which reside outside of the database. Substantial progress has been made recently in incorporating more physics-based analysis tools in the conceptual design process, and NASA has developed a capability that integrates several analysis tools and models in engineering frameworks, such as ModelCenter and OpenMDAO, with a geometry-centric approach built around tools such as OpenVSP and GeoMACH. However, modeling gaps still remain in many disciplines.

Developing higher-order, more-accurate tools suitable for conceptual design is a difficult challenge. To perform the configuration trades and optimization typical in conceptual design, runtimes measured in seconds or minutes, instead of hours or days, are required. Additionally, because it is not possible to model every detail of the design and account for all the underlying physics in the problem formulation, it is difficult to predict the 'as-built' characteristics with physics-based methods alone. Finally, the gap between the analysis capability and the maturity of the design being analyzed currently limits the usefulness of high order analysis in conceptual design. Physics-based tools for conceptual design are needed which can rapidly and accurately predict the as-built characteristics of unconventional aircraft designs, while remaining consistent with the amount of design knowledge that is available at the conceptual design stage.

Sizing of an aircraft design can be strongly affected by its takeoff and landing characteristics, yet for both conventional and unconventional aircraft concepts it can be difficult to accurately estimate the aerodynamic performance in the high-lift configuration. In addition, many traditional methods of sizing aircraft controls surfaces and assuring acceptable handling qualities have lost their validity as more unconventional aircraft are being studied, and additional dynamic modes might become unstable. For FY2016, specific capabilities are being sought in the following areas:

- Methods for aerodynamic analysis, weight estimation, and design of aircraft high-lift systems.
    - Analysis of the aerodynamic performance of externally-blown flaps.
    - Robust prediction of maximum lift coefficient with flaps and slats extended.
    - Estimation of high-lift system weight as a function of design parameters.
    - Optimization of high-lift component design, trading aerodynamic performance and weight/complexity to minimize overall aircraft system weight, fuel burn and cost as an objective function.
- Methods for analysis of aircraft static and dynamic stability characteristics suitable for unconventional aircraft.
    - Physics-based sizing of tails and control surfaces that is more sensitive to aircraft design parameters than traditional tail volume coefficients.
    - Calculation of mass moments of inertia for the complete aircraft system throughout the full mission.
    - Simulation of the dynamics of unconventional aircraft configurations with tight coupling of propulsion and aerodynamics characteristics, including evaluation of active control systems.
    - Definition of handling qualities for unmanned aerial systems.

The desired capabilities are physics-based methods that are of higher order than traditional empirical methods, but can be applied in the conceptual design phase with limited requirements on the availability of detailed design information. Newly-developed methods and methods integration activities should include verification and validation of results, and will ideally address quantification of uncertainty and calculation of sensitivity derivatives for use in adjoint design.

A1.06 Vertical Lift - VL Measurement Techniques and Condition-Based Maintenance
Lead Center: ARC
Participating Center(s): GRC, LaRC

The Vertical Lift subtopic is primarily interested in the following two areas:

- Health management of drive systems for vertical lift vehicle is critical to reliable operations and safety. Predictive Condition-Based Maintenance (CBM) improves safety, decreases maintenance costs, and increases system availability. A topic of interest in CBM includes analysis capabilities and models to simulate operating drive systems and components, including the modeling of realistic anomalies and faults that can help design and qualify CBM systems, and test their utility in making maintenance decisions. These CBM simulation capabilities should be of sufficient fidelity, demonstrated by validation and verification performance metrics, to allow development of CBM systems that include: differentiation between different failure modes, detection of onset and progression of failures, identification of the damaged component, assessment of damage severity, measurement of usage to predict remaining life, and recommendation of maintenance actions required. Proposals based only on novel post-processing of accelerometer data will not be considered for award.
- Accurate measurements of lift systems and blade aerodynamics are key to developing and validating high-fidelity analyses and designing next-generation high-performance vertical lift systems. A topic of interest is instrumentation and measurement techniques for assessing blade boundary layer state (e.g., laminar flow, transition, turbulent flow) of a rotating blade system in hover and forward flight conditions. IR thermography is one technique for identifying transition but the technique typically requires heating (or cooling) the blade to enhance temperature differentials between the blade and the ambient air. Techniques, IR or non-IR, are sought that are non-intrusive or minimally non-intrusive. Both on-surface and off-surface techniques that can be efficiently applied to new or existing blades for testing in a wind tunnel or in flight are desired.

Proposals on other vertical lift technologies will also be considered however the primary emphasis of this solicitation will be on the above two identified technical areas.

A1.07 Propulsion Efficiency - Turbomachinery Technology for Reduced Fuel Burn
Lead Center: GRC

System and technology studies have indicated that advanced gas turbine propulsion will remain critical for future subsonic transports. Turbomachinery includes the rotating machinery in the high and low pressure spools, transition ducts, purge and bleed flows, casing and hub. We are interested in traditional gas turbine turbomachinery, as well as in innovative concepts as exo-skeletal engines, intercooled gas turbines, cooled cooling air, waste heat recovery, and other concepts.

NASA is looking for improvement in aeropropulsive efficiency. Areas of interest include: Improved components of current architectures and cycles, novel components and cycles to improve cycle limits, and novel architectures to improve mission efficiency limits.

In the compression system, advanced concepts and technologies are required to enable higher overall pressure ratio, high stage loading and wider operating range. In the turbine, the very high cycle temperatures demanded by advanced engine cycles place a premium on the cooling technologies required to ensure adequate life of the turbine component. New capabilities as well as challenges are provided with expected increased use of ceramic matrix composites (CMC's). Reduced cooling flow rates and/or increased cycle temperatures enabled by these technologies have a dramatic impact on the engine performance. Such improvements will enable reduced fuel burn, reduced weight and part count, and will enable advanced variable cycle engines for various missions.

Innovative proposals in the following turbomachinery and heat transfer areas are solicited:

- *Small core turbomachinery* - Higher fan Bypass Ratio (BPR) will require more compact engine core sizes rather than by growing the fan diameter, resulting in large tip/endwall and purge flow losses. Tip-leakage mitigation technologies for small-core turbomachinery and concept for circumvent the issue via innovative gas turbine designs. Desensitizing to losses due to tip leakage, secondary flows, seals, purge flows, and cooling air. Shorter transition ducts.
- *Optimized integrated combustor – turbine systems* - Integration concepts of combustor and turbine for improved overall and component performance are being sought.
- *Flow control in turbomachinery* - Advanced turbomachinery active and passive flow control concepts to enable increased high stage loading in single and multi-stage axial compressors while maintaining or improving aerodynamic efficiency and operability. Technologies are sought that would reduce dependence on traditional range extending techniques (such as variable inlet guide vane and variable stator geometry) in compression systems. These may include flow control techniques near the compressor end walls and on the rotor and stator blade surfaces. Technologies are sought to reduce tip clearance leakage as well as rapid acting tip clearance control in compressors and turbines. Technologies are sought to eliminate flow separation in low pressure turbines and transition ducts, improve off-design operation and enable variable cycle operation.
- *Cooling and thermal management* - Novel turbine cooling concepts are sought to enable very high turbine cooling effectiveness. The concepts are mainly for ceramic-based turbine materials such as ceramic matrix composite (CMC) vanes and blades. The availability of advanced manufacturing techniques may enable improved cooling designs beyond the current state-of-the-art. These concepts may include film cooling concepts, internal cooling concepts, and innovative methods to couple the film and internal cooling designs. Innovative high performance heat exchangers to cool the cooling air and for intercooling cycles are sought.
- *Computational technologies for turbomachinery* - Computational technologies allowing accurate predictions of turbomachinery flows and heat transfer including active and passive flow control features and flow structures. Advanced turbulence and LES models that can account for complex three-dimensional flows common in turbomachinery. Models of flow control devices that enable incorporating them in RANS based CFD codes. Particular interest is in CFD method based on overset moving grids that will enable flexibility in studies of small features as cooling holes and active and passive flow control devices. Interfacing LES and RANS codes for unsteady rotating bounded flows. As engines get smaller, interaction issues dominate and CFD methods to enable simulation of the interactions are needed.

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 enhance testing and measurement capability and improve utilization and efficiency. For this solicitation, NASA seeks proposals for innovative research and development in the following areas:

- *Force and Moment Balances* - Internal and external balances provide foundational data to evaluate aerodynamic performance and validate numerical solutions. To meet future testing and accuracy requirements, NASA is interested in new innovative balance designs for full- and semi-span test articles that incorporate new sensors, materials, manufacturing techniques, and calibration methods. Systems that are capable of transferring high pressure air and/or power across the balance and operating at high temperatures (up to 350F) are especially desired.
- *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]. Non-intrusive measurement systems offering multi-component velocities, density, and pressure in the tunnel stream upstream and downstream of test articles are required to routinely quantify tunnel inflow and outflow conditions for the purposes of establishing boundary conditions for advanced numerical simulations. These systems should 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, model orientations where gravity based sensors are not applicable, and test configurations that require multiple angle of attack systems. To address some of these limitations, optical, non-intrusive techniques are needed to provide real-time or near real-time measurements of model attitude at high data rates (10 Hz – 8kHz) and with sufficient accuracy (0.005± 0.0025° in pitch 0.025±0.025° 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. Many NASA wind tunnel facilities conduct tests at elevated temperatures (above 700° F) or at extremely low temperatures (-250° F). Displacement measurement components in actuator systems for the setting of hydraulic cylinder positions and other hardware used in test article support and positioning systems must operate routinely in these environments. Innovative designs and hardware solutions are desired to provide accurate and reliable performance at these extreme conditions.
- *Improved Operational Efficiencies and Data Throughput.* - Technologies are needed to significantly increase the amount of data acquired per test point, including simultaneous measurement of multiple flow parameters at high acquisition rates to capture rapidly evolving or oscillatory flow phenomena. Methods that exploit wireless sensor capabilities to reduce instrumentation cabling are of interest, including wireless strain gauge systems and technologies that can be applied for strain measurement on high speed rotating fan/rotor blades. Virtual environments that provide data fusion for real-time comparisons between wind tunnel data and computational results are also desired as well as technologies that integrate knowledge capture, training, and best practices for improved operational efficiencies, especially for activities that occur on an infrequent basis like calibration and characterization.

References:

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

A1.09 Vehicle Safety - Inflight Icing Hazard Mitigation Technology
Lead Center: GRC

NASA is concerned with the prevention of encounters with hazardous in-flight conditions and the mitigation of their effects when they do occur. Under this subtopic, proposals are invited that explore new and dramatically improved icing mitigation technologies and research tools related to inflight airframe and engine icing hazards for manned and unmanned vehicles. Technologies of interest should address the detection, measurement, and/or the mitigation of the hazards of flight into supercooled liquid water clouds and flight into regions of high ice crystal density. Of particular interest are technologies that can address emerging icing issues of advanced aircraft configurations (N+2/N+3 aircraft, as well as vertical lift and unmanned systems).

Topic: A2 Integrated Flight Systems

One of the greatest issues that NASA faces in transitioning advanced technologies into future aeronautics systems is the gap caused by the difference between the maturity level of technologies developed through fundamental research and the maturity required for technologies to be infused into future air vehicles and operational systems. Integrated Aviation Systems Program's (IASP) goal is to demonstrate integrated concepts and technologies to a maturity level sufficient to reduce risk of implementation for stakeholders in the aviation community. IASP conducts integrated system-level research on those promising concepts and technologies to explore, assess, and demonstrate the benefits in an operationally relevant environment. IASP matures and integrates technologies for accelerated transition to practical application, and supports the flight research needs across the ARMD strategic thrusts, the Programs, and all research phases of technology development. IASP consists of three projects, the Environmentally Responsible Aviation (ERA) Project, the UAS Integration in the National Airspace System (NAS) Project and the Flight Demonstrations and Capabilities Project (FDC).

The FDC Project consists of an integrated set of flight test capabilities and demonstrations. The flight test capabilities include the Dryden Aeronautical Test Range, and the aircraft required to support research flight tests and mission demands. The project capabilities also include the Armstrong Flight Research Center (AFRC) Simulation and Flight Loads Laboratories, which include a suite of ground-based laboratories that support flight research and mission operations. These facilities and assets are able to perform tests covering the flight envelope from subsonic through hypersonic speeds and include unique capabilities ranging from simulating icing environments to modeling extreme dynamic situations.

NASA will demonstrate the feasibility and maturity of new technologies through flight tests, utilizing collaborative partnerships from across the aeronautical industry, and including international partners as appropriate. These activities support research within all six aeronautics strategic thrust areas.

A2.01 Flight Test and Measurements Technologies
Lead Center: AFRC
Participating Center(s): 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 the 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, and supersonic civil transport. Therefore, this solicitation can cover a wide range of flight conditions and craft. NASA also requires improved measurement and analysis techniques for acquisition of realtime, in-flight data used to determine aerodynamic, structural, flight control, and propulsion system performance characteristics. These data will also be used to provide test conductors the information to safely expand the flight and test envelopes of aerospace vehicles and components. This requirement includes the development of sensors (both in-situ and remotely) 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 include:

- 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 technique and/or system to enable high data rate, high volume IP based telemetry for flight test. 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.
- Intelligent health monitoring for hybrid and/or all electric distributed propulsion systems.
- Methods for significantly extending the life of electric aircraft propulsion energy sources (e.g., batteries, fuel cells, etc.).
- Test techniques for conducting quantitative in-flight boundary layer flow visualization, global surface pressure, shock wave propagation, Schlieren photography, near and far-field sonic boom determination, atmospheric modeling.
- Measurement technologies for in-flight steady & 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 operations of aircraft.

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.

Topic: A3 Airspace Operations and Safety

The Airspace Operations and Safety Program (AOSP) seeks innovative and feasible concepts and technologies to enable significant increases in the capacity and efficiency of the Next Generation Air Transportation System (NextGen) while maintaining or improving safety and environmental acceptability. AOSP activities and projects will target system-wide operational benefits of high impact for NextGen both in the arenas of airspace operations and safety management. Projects will be formulated with near-term end dates or deliberative evaluation points consistent with the accomplishment of program-defined Technical Challenges. AOSP aligns with the ARMD Strategic Thrusts of Safe and Efficient Growth in Global Aviation, Enable Real-Time System-Wide Safety Assurance, and Enable Assured Machine Autonomy for Aviation. Distribution of work area across the AOSP project structure is described below. AOSP is comprised of three projects:

- Airspace Technology Demonstrations (ATD).
- Shadow Mode Assessment Using Realistic Technologies for the National Airspace System (SMART-NAS).
- Test-Bed for Safe Trajectory-Based Operations, and Safe Autonomous Systems Operations (SASO).

The three projects are formulated to make major contributions to operational needs of the future through the development and research of foundational concepts and technologies and their analysis, integration, and maturation in relevant, system-level environments. Each of the projects are, much like the airspace system itself, highly integrated and require attention to critical system integration and transition interfaces with the NAS. The Airspace Technology Demonstrations (ATD) Project will accelerate the maturation of concepts and technologies to higher levels of maturity for transition to stakeholders, including research supporting the existing ATD-1:

- Interval Management - Terminal Area Precision Scheduling and Spacing effort.
- Integrated Arrivals/Departures/ Surface Operations.
- Applied Traffic Flow Management.
- Technologies for Assuring Safe Aircraft Energy and Attitude State (TASEAS).

The SMART-NAS Testbed for Safe Trajectory Based Operations Project will deliver an evaluation capability, critical to the ATM community, allowing full NextGen and beyond-NextGen concepts to be assessed and developed. This simulation and modeling capability will include the ability to assess multiple parallel universes, accepts data feeds, allows for live/virtual/constructive- distributed environment, and enable integrated examinations of concepts, algorithms, technologies, and NAS architectures. The Safe Autonomous System Operations (SASO) Project will develop autonomous system concepts and technologies; conduct demonstrations, and transfer application specific matured technologies to increase affordability, efficiency, mobility of goods and passengers, safety, and scalability and mix of airspace operations. Proposals for this topic will develop innovative feasible concepts and technologies to enable significant increases in the capacity, efficiency, scalability and cost effectiveness of the Next Generation Air Transportation System (NextGen) while maintaining or improving safety and environmental acceptability.

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 time frame) 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 time frame), 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) has concluded the successful Aviation Safety Program (AvSP). The Airspace Operations and Safety Program (AOSP) is succeeding AvSP's significant achievements and stepping up to lead the ARMD research in the area of Real-Time System-Wide Safety Assurance (RSSA). As currently envisioned, ARMD sees its future, safety-related research focused in a forward looking, more comprehensive system-wide direction. ARMD's RSSA will focus on the current and future NAS, towards a gate-to-gate trajectory-based system capability that satisfies a full vision for NextGen and beyond. The ultimate vision for RSSA would enable the delivery of a progression of capabilities that accelerate the detection, prognosis and resolution of system-wide threats. Proposals under this sub-topic are sought, but not limited to, the following areas:

- Identify and characterize (causation, consequence, criticality) safety threats and anomalies that could and should be monitored for by an RSSA system. For each threat/anomaly, identify triggers, precursors, and data needed to analyze/determine if a trigger or precursor has occurred.
- 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 HMI concepts and technologies for alerting and resolution guidance delivery/visualization/execution to ensure timely avoidance or mitigation of predicted safety threats.
- Determine optimal human-machine function allocation for handling emerging safety threats, including threats communication, prioritization, alerting, and mitigation.
- 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.

9.1.2 HUMAN EXPLORATION AND OPERATIONS

The Human Exploration and Operations Mission Directorate (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. This new deep space exploration era starts with increasingly challenging test missions in cis-lunar space, including flights to the Lagrange points, followed by human missions to near-Earth asteroids (NEAs), Earth's moon, the moons of Mars, and Mars itself as part of a sustained journey of exploration in the inner solar system. HEOMD accomplishes its mission through the following goals:

- Development and use of launch systems and in-space transport capabilities permitting exploration of various regions of space.
- Development of space habitats that permit the processing and operation of physical and life science experiments in the space environment.
- Development of means to return data and explorers to Earth from these in-space operations. HEOMD encapsulates several key technology areas, including Space Transportation, Space Communications and Navigation, Human Research and Health Maintenance, Radiation Protection, Life Support and Habitation, High Efficiency Space Power Systems, and Ground Processing/ISS Utilization. These areas of focus, along with enabling technologies and capabilities, will continue to evolve synergistically as the directorate guides their development and enhancement to meet future needs.

In addition, operational capacity will continue to grow by including these enhancements as other NASA programs develop new mission capabilities and requirements. To generate new capabilities and contribute to the knowledge required for humans to explore in-space destinations, HEOMD is responsible for:

- Conducting technology development and demonstrations to reduce cost and prove required capabilities for future human exploration.
- Developing exploration precursor robotic missions to multiple destinations to cost-effectively scout human exploration targets.
- Increasing investments in Human Operations and research to prepare for long-duration missions in deep space.
- Enabling U.S. commercial human spaceflight capabilities.
- Developing communication and navigation technologies.
- Maximizing ISS utilization HEOMD looks forward to incorporating SBIR-developed technologies into current and future systems to contribute to the expansion of humanity across the solar system while providing continued cost effective space access and operations for its customers, with a high standard of safety, reliability, and affordability.

Topic: H1 In-situ Resource Utilization (ISRU)

In-situ Resource Utilization (ISRU) involves any hardware or operation that harnesses and utilizes 'in-situ' resources (natural and discarded) to create products and services for robotic and human exploration. ISRU products and services can be used to reduce Earth launch mass or lander mass by not bringing everything from Earth, reduce risks to the crew and/or mission by reducing logistics, increasing shielding, and providing increased self-sufficiency, or reduce costs by needing less launch vehicles to complete the mission and/or through the reuse of hardware and lander/space transportation vehicles. An important aspect of ISRU is to make mission critical consumables for propulsion, life support, and fuel cell power systems and feedstock for in-situ manufacturing and construction. Production of propellants allows for significant savings in launch or landed mass and transportation and lander reuse. Production of feedstock for manufacturing and construction processes from local and recycled materials with little or no Earth provided binders/reactants can provide significant improvements in failure recovery, shielding, self-sufficiency, and eventual infrastructure growth. Since ISRU can be performed wherever resources may exist, ISRU systems will need to operate in a variety of environments and gravities and need to consider a wide variety of potential resource physical and mineral characteristics. Also, because ISRU systems and operations have never been demonstrated before in missions, it is important that ISRU concepts and technologies be evaluated under relevant conditions (gravity, environment, and vacuum) as well as anchored through modeling to regolith/soil, atmosphere, and environmental conditions.

H1.01 In-situ Resource Utilization - Production of Feedstock for Manufacturing and Construction
Lead Center: JSC
Participating Center(s): ARC, GRC, JPL, KSC, LaRC, MSFC

The overall goal of in-situ Resource Utilization (ISRU) is to transform available resources, both natural and man-made, on extraterrestrial surfaces into usable materials and products that assist in sustaining and growing human exploration capabilities. ISRU involves all the steps associated with identifying, collecting, and converting local resources into products that can reduce mission mass, cost, and/or risk. It is imperative that novel technologies be developed to effectively utilize these resources for mission critical consumables, as well as to produce feedstock for additive manufacturing of replacement parts, construction for habitat, and infrastructure expansion. In the case of Mars, carbon dioxide and other atmospheric constituents, along with regolith and water/ice can be harvested for basic elements that could be utilized to generate various simple and complex organic and inorganic compounds, composites and products. The subtopic seeks proposals for critical technologies associated with the design, fabrication, and testing of hardware associated with one or more of the areas of interest below:

- *Plastic production for in-space additive manufacturing* - Production of plastic that can be fed into in space manufacturing devices. Define and demonstrate all steps required for conversion of some or all of the following in-situ constituents (H_2, CO, CO_2, O_2, N_2, and CH_4) into a final plastic product. It is expected that intermediate products, such as longer chain hydrocarbons, alcohols, aromatics, etc. will be required to achieve final plastic production. Proposals will need to identify all the steps and intermediate products. Phase I proposals will need to demonstrate critical steps, especially the first step from the list of starting constituents. Each step in Phase I can be performed/demonstrated individually. Phase II proposals will need to demonstrate all steps in an integrated manner. Production rates for plastic production will initially be low at 1 to 5 kg/day. Ability to breakdown and recycle the plastic produced is desired but not required. If additional constituents are required to make in-situ plastic, proposer can include them but will need to identify whether the constituents can be obtained in-situ or needs to be brought from Earth. Information on thermoplastic feedstock glass transition temperature and melting point properties for 3D printer plastic feedstocks that might be useful can be found at: (http://3dprintingfromscratch.com/common/3d-printer-filament-types-overview/). Since the loads and environments of the parts made using the feedstock are not known at this time, it is recommended that the properties be commensurate with commercially available feedstocks. Some desired characteristics of the parts made from the feedstock are high temperature resistance, low moisture adsorption, and ability to bond using adhesives. Feedstock produced must be tested in a commercially available additive manufacturing device in Phase II.

- *Metal extraction from extraterrestrial material for additive manufacturing* - Metal extraction from extraterrestrial material including lunar regolith, Mars soil, and ordinary and carbonaceous chondrites asteroidal material. Regeneration of any reactants used in the metal extraction process is required. Metals found in extraterrestrial material such as iron, aluminum, silicon, magnesium, and nickel are desired for future in-situ additive manufacturing. It is not expected that the quality and purity of the extracted metals will be to the same standard obtained from terrestrial processes so proposer needs to consider the possible extraction method and subsequent purity of the feedstock. In Phase I, the proposer is required to demonstrate the feasibility of extracting the desired feedstock. Methods used for extraction can be physical/chemical or biological. In Phase II, these feed stocks should be ready for introduction into a fabrication process by being pre-processed to have appropriate physical properties and forms (e.g., granulated, spooled wire, plate, billet, ingots, etc.). Manufacturing processes should be identified and feasibility demonstrated using the regolith derived feed stocks in partial and/or micro gravity environments. Regolith acquisition and delivery of up to 100 kg/hour can be assumed as an input material stream. Using a waste stream from another ISRU process to produce feedstock for fabrication may be considered such as regolith that has already been processed to extract water or oxygen from minerals.
- *ISRU for additive construction techniques* - Bulk or modified regolith can also be used as a construction material (with or without a binder) to form a material that can be extruded to produce a floor, structural wall, or ceiling, or into bricks or slabs for landing pads, roads, and shielding. These construction material can be used for making structures, shelters, radiation shielding, and thermal shading and for micrometeorite protection. Binders and additives must be less than 10% by mass of the construction material feedstock. Use of binders that can also be produced in-situ are preferred. Use of water is not excluded, but steps to be taken mitigate losses and amounts used and lost must be clarified to compare to non-water based construction materials. In Phase II, demonstration of the feasibility of additive construction using construction material feedstock is required (demonstration in partial or micro gravity environments is desired). For extruded materials a linear printing rates 30 to 100 cm/minute is desired. Bricks and slabs should have ability to be joined or interlocked.

All proposals need to identify the state-of-the-art of applicable technologies and processes. Proposals must address the physical/mineral properties of the regolith/soil used. Proposers must specify whether the process is performed in batches or by continuous processing with appropriate sealing techniques to minimize reactant/product losses identified.

Topic: H2 Space Transportation

Achieving space flight remains a challenging enterprise. It is an undertaking of great complexity, requiring numerous technological advances conducted by a wide range of engineering disciplines with a high level of organizational skill. Human Exploration requires advances in space transportation systems, operations, and testing, for transport to the earth orbit, the moon, Mars, and beyond. NASA is interested in making space transportation systems more capable and less expensive. NASA is interested in technologies for advanced in-space propulsion systems to support exploration that reduce travel time, reduce acquisition costs, and reduce operational costs. The goal is a breakthrough in cost and reliability for a wide range of payload sizes and types supporting future orbital and exploration flight vehicles. Lower cost and reliable space access will provide significant benefits to civil space (human and robotic exploration beyond Earth as well as Earth science), to commercial industry, to educational institutions, to the International Space Station National Laboratory, and to national security. While other strategies can support frequent, low-cost and reliable space access, this topic focuses on the in–space propulsion technologies that dramatically alter acquisition, reusability, reliability, and operability of space transportation systems.

H2.01 LOX/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, 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.

The goal of this subtopic is to examine novel technology options that include the use of additive manufacturing or other low cost processes which save mass and/or cost compared to current state-of-the-art (SOA) technologies and fabrication methods. Technologies of interest for operation with liquid oxygen and methane specifically are sought.

Proposers shall show how their technology works and provide the following:

- 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 how the technology and/or fabrication technique proposed saves cost and/or mass is desired.
- Provide quantitative assertions (e.g., x% improvement of y, z kg of mass savings, xx% in cost savings, etc.) to the advancement over the SOA.

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.

For reference, current anticipated performance goals for liquid oxygen/liquid methane systems are:

- Reaction control thruster development in the 100-800 lbf thrust class. The reaction control engines would operate cryogenic liquid-liquid for applications requiring integration with main engine propellants; or would operate gas-gas or gas-liquid for small total impulse type applications. RCEs operating on liquid cryogenic propellant(s) should be able to tolerate operation for limited duty cycles with gaseous or saturated propellants of varying quality. Integrated RCS (IRCS) capability desired (common propellant tanks for RCS and main engines).
- Descent pump-fed engine development with 50,000 lbf thrust and a minimum vacuum specific impulse of 360-sec. The propulsion system should be capable of stable throttling to 5:1 (20% power). Space survival time of greater than 3 years.
- Ascent pump-fed engine development with 25,000 lbf thrust and a minimum vacuum specific impulse of 360-sec. The propulsion system should be capable of stable throttling to 5:1 (20% power). Space survival time of greater than 4 years.
- Integrated Propulsion and Feed System technologies, such as for integrated reaction control systems (RCS). This would include thermal conditioning features, self-pressurization/re-pressurization control, and system isolation control.

For reference, some specific propulsion technologies of interest are included below. In all cases – interest in using additive manufacturing or novel fabrication methods to save cost and mass are desired to achieve the specific component objectives identified below:

- Injector concepts with throttle range greater than 4:1 while maintaining stable combustion over the range of operation and inlet conditions and meeting performance goals at full throttle condition.
- Regenerative cooled combustion chamber technologies which offer improved performance, especially at sub-critical or trans-critical conditions, and provide adequate chamber life. This includes methods for addressing differential boiling within regenerative channels and/or start up transients (gas/gas, to two-phase, to high-quality liquid/liquid) for both fuel and oxidizer circuits.
- Turbopump technologies specific to liquid methane that are lightweight with a long shelf life that can meet deep-throttle requirements, including small durable high speed turbines, high speed lightweight electric direct current (DC) motor driven pumps, high fatigue life impellers, zero net positive suction head (NPSH) inducers, low leakage seals, and long life in-situ propellant fed bearings.
- Engine valves with a focus on light-weight (at the system level, considering supporting pneumatics, batteries, etc.), fast-acting, low-leakage 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, with leakage in the 10^{-4} to 10^{-6} standard cubic centimeters per second (SCCS) range (gaseous phase oxygen and methane).

H2.02 Nuclear Thermal Propulsion (NTP)
Lead Center: MSFC
Participating Center(s): GRC, SSC

Solid core NTP has been identified as an advanced propulsion concept which could provide the fastest trip times with fewer SLS launches than other propulsion concepts for human missions to Mars over a variety of mission years. 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. In addition, the engine components and surrounding structures are exposed to a radiation environment formed by the reactor during operation.

This solicitation will examine 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.

Specific technologies of interest to meet the proposed requirements include:

- Reactor fuel element designs with high temperature (> 2600K), high power density (>5 MW/L) to maximize hydrogen propellant heating. New additive manufacturing processes to quickly manufacture the fuel with uniform channel coatings and/or claddings to reduce fission product gas release and particulates into the engine's exhaust stream.
    - Composite or carbide designs with low burn-up coating technology.
    - Ceramic-metallic (cermet) based nuclear fuels need improved methods to apply W coatings on small UO_2 spheres and the best way to bond W-UO_2 wafers with integral claddings.
- 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 flexible criticality control 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.
- Ground test engine effluent processing technologies for efficient containment and/or filtering of radioactive particles and noble gases, and management of high temperature, high flow hydrogen exhausts (16-39 lbs/sec). In particular, to produce large quantities of hot hydrogen, and develop robust materials, advanced instruments and monitoring systems capable of operating in extreme temperature and radiation environments.
    - Advanced materials to resist high-temperature (<4400° F), hydrogen embrittlement and radiation environment.
    - Efficient non-nuclear generation of high temperature (<5000° F), high flow rate hydrogen (<39 lb/sec).
    - Effluent processing 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 99.9%.
        - 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 that provide diagnostic capability to detect reactor fuel degradation in the engine exhaust.
    - Technologies providing an affordable low power (<20 MW) nuclear furnace to ground test a variety of fuel elements at conditions replicating a full scale NTP engine.

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.

H2.03 High Power Electric Propulsion
Lead Center: GRC
Participating Center(s): JPL, MSFC

The goal of this subtopic is to develop innovative, high-power (>100-kW) electric propulsion systems. High-power solar or nuclear electric propulsion may enable dramatic mass and cost savings for lunar and Mars cargo missions, including Earth escape and near-Earth space maneuvers, at power levels that enable a wide range of exploration missions. Innovations and advancements leading to improvements in the end-to-end performance of high power electric propulsion systems are of interest. Methods are sought to increase overall system efficiency; improve system and/or component life or durability; reduce system and/or component mass, complexity, and development issues; or provide other definable benefits. In general, thruster systems providing total impulse values greater than 10^7 N-sec are desired. Specific impulse values of interest range from a minimum of 1500-sec for Earth-orbit transfers to over 6000-sec for planetary missions.

Advanced high-power concepts that provide quantifiable benefits over state-of-the-art electric propulsion systems are to be developed. Key figures of merit include: thrust density (to decrease thruster footprint), thruster efficiency (>60%), lifetime (>10's khrs), reliability, and scalability. A practical and affordable method of performing relevant ground testing should be discussed, taking into account the pumping capabilities of state-of-the-art vacuum facilities. The proposed propulsion system should be mindful of the development of an efficient, low specific mass power processing unit, with an emphasis on reducing complexity and cost. Specific technologies of interest include but are not limited to:

- Nesting/clustering moderately powered thrusters to reach a desired total throughput: This component development can include: an assessment of system performance and plasma plume interactions, a thermal characterization of the system, and an assessment of the system lifetime during multi-thruster operation. The impact of multi-thruster operation on the power processing unit and feed system performance should also be addressed.
- High-current electromagnetic accelerators that directly addresses thruster efficiency and lifetime. This component development can include an investigation of electrode geometries, thermal management designs, and material selection to mitigate electrode erosion, the major lifetime limiter. Innovative, high efficiency power processor architectures/convertors for high-amperage thrusters that can be evolved into space flight hardware and survive thermal and radiation environments are desired.
- Scalable, high-perveance gridded ion engines with thrust densities that significantly exceed the current state-of-the-art (~3 N/m^2 for the NEXT ion engine). This component development can include the development of novel designs of the discharge chamber and ion optics for maximizing anode current and beam extraction capability, respectively.
- Long-life hollow cathode technologies for use with high-power electrostatic engines. The cathodes should be tested in a relevant environment (e.g., comparable magnetic field environment) and provide sufficient current densities for high-power thruster operation.
- Components for inductively pulsed plasma thrusters, in particular highly accurate flow controllers and fast acting valves; and solid state switches capable of high current (MA), high repetition rate (up to 1-kHz), long life (≥ 109 pulses) operation. High-voltage converters for pulsed power applications with a high-efficiency, low-complexity architecture that can be evolved into space flight hardware and survive thermal and radiation environments are desired.
- Advanced manufacturing methods for the fabrication of high power thruster components and associated systems; of particular interest is additive manufacturing for complex geometries, which may include: ceramic insulators, ion optics, and magnetic poles. Figures of merit include lower cost, rapid turnaround, and material and structural integrity comparable to or better than components or systems produced using current fabrication methods.

Proposals addressing advanced technology concepts should include a realistic and well-defined roadmap defining critical technology development milestones leading to an eventual flight system. Sub-scale, proof-of-concept experiments are highly desired for the Phase I effort. In addressing technology requirements, proposers should identify candidate thruster systems and potential mission applications that would benefit from the proposed technology.

H2.04 Cryogenic Fluid Management for In-Space Transportation
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 the Exploration Upper Stage (EUS), In-situ Resource Utilization in cooperation with Mars Landers, and the evolvable Mars Campaign.

Specifically, listed in order of importance:

- High Power/High Efficiency cryocoolers and cryocooler components (specifically compressors, turbines/expanders, or recuperative heat exchangers) for systems designed to reject >150 W at 90 K with a specific power of less than 15 W (input power)/W (heat rejection) and specific mass of less than 12 kg/W (of heat rejection) at the design point. The cryocooler components should be suitable for space flight.

- Novel structural solutions that can be partially disconnected post launch which the upper stage has successfully reached orbit. Full scale structural solutions (5 – 10 m diameter tanks) should be able to support > 20 mT at up to 5 g's sustained compressive loads and have no structural modes below 50 Hz. Post disconnection, the supports should still be able to support 20 mT, but at 0.2 g's sustained compressive loads. Solutions (which do not have to be full scale at this point) should also attempt to minimize the residual heat load to the propellant tank after disconnection.
- Liquid acquisition devices (or propellant management devices) capable of preventing gas ingestion into engine feedlines in low gravity. The liquid acquisition devices should maintain bubble-free flows of 37 liters per minute while having an expulsion efficiency of 97%.
- Lightweight fluid coupling for low (< 50 psi, Cv > 5) pressure cryogenic liquids with low internal (~ 1 sccm) and external (~ 3 sccm) leakage on both halves. Coupling should be designed either for ease of use by Astronauts (i.e., bulky gloves and minimal force) or easy automation.

Topic: H3 Life Support and Habitation Systems

Life support and habitation encompasses the process technologies and equipment necessary to provide and maintain a livable environment within the pressurized cabin of crewed spacecraft. Functional areas of interest to this solicitation include environmental monitoring, solid waste management, crew accommodations, and water recovery systems. Technologies must be directed at long duration human missions, in microgravity, including Earth orbit and planetary transit, and planetary surfaces, including Mars. Requirements include operation in microgravity and compatibility with cabin atmospheres of up to 34% oxygen by volume and pressures ranging from 1 atmosphere to as low as 7.6 psi (52.4 kPa). 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. Non-venting processes may be of interest for technologies that have future applicability to planetary protection. Results of a Phase I contract should demonstrate proof of concept and feasibility of the technical approach. A resulting Phase II contract should lead to development, evaluation and delivery of prototype hardware. Specific technologies of interest to this solicitation are addressed in each subtopic.

NASA is investing in technologies and techniques geared towards advancing the state of the art of spacecraft systems through the utilization of the ISS as a technology test bed. For technologies that could benefit from demonstration on the ISS, proposals should be written to indicate the intent to utilize the ISS. 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 contract that could be turned into a proof-of-concept system which can be demonstrated in flight.

H3.01 Environmental Monitoring
Lead Center: JPL
Participating Center(s): ARC, GRC, JSC, KSC, 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, determine the most promising solutions, 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.

Methods for collection and concentration for microbial surface monitoring

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, systematic microbial monitoring of ISS is carried out for water and not for environmental surfaces or air. The sample collection and subsequent processing for either culturing or molecular methods require sample concentration. Presently, swabs are used to collect 25 cm^2 area before processing and often times this outdated technique is fraught with decreased sensitivity in removing biological materials from the surface. NASA is interested in an integrated sample collection/concentration/extraction system that could feed samples to conventional or molecular microbial monitoring techniques. Furthermore, integration of these steps and a sample delivery to the molecular instruments (such as PCR) as a single module is solicited. Required technology characteristics include a 2 year shelf-life and functionality in microgravity and low pressure environment (~8 psi). The proposed integrated sample collection/concentration/extraction delivery system for molecular microbial monitoring detection should be capable of collecting and concentrating all kinds of microorganisms including "problematic" microbial species on-board ISS (ISS MORD: SSP 50260; (http://emits.sso.esa.int/emits-doc/ESTEC/AO6216-SoW-RD9.pdf)).

Ethylene analyzer

Ethylene gas is a natural metabolite in plants and acts as a plant hormone. In closed settings, such as plant (food) production chambers, ethylene can build up to deleterious levels for the plants. NASA needs innovative concepts for monitoring ethylene on a real time or near real time basis. Detection limits should ideally be near 25 ppb to insure effective management of plant growth systems, both for fundamental space research and for using plants in bioregenerative life support applications.

Calcium, conductivity and pH monitors for urine and wastewater

A rugged calcium sensor is needed to optimize the percentage of the recovery from brine. The calcium sensor would allow engineers to process a urine batch by knowing precisely the actual calcium concentration, enabling the urine processor to approach the solubility limit of calcium species. The calcium sensor would need to be able to measure calcium at levels of 50-400 mg/L in urine that has been pretreated to a pH of 0.5-3.0. The sensor should be rugged and not require frequent calibration or replacement and should be accurate to within 10%. Rugged conductivity and pH sensors that monitor the conductivity and pH in the brine loop would allow brine to be processed more thoroughly to recover more water. As the brine becomes more concentrated during urine processing, the measurement of conductivity and pH would allow the processor to recover water just to the point of solids precipitation. The conductivity sensor should be able to measure conductivity from 10-250 mS/cm in a urine brine that has a pH of 0.5-5.0. Likewise the pH sensor should be able to measure pH from 0.5-5.0 in a urine brine that has the conductivity of 10-250 mS/cm. The sensor should not require frequent calibration or replacement and be accurate to within 15%.

H3.02 Environmental Control and Life Support for Spacecraft and Habitats
Lead Center: ARC
Participating Center(s): GRC, JSC, KSC, MSFC

Solutions and innovations are needed for technology that supports the mass- and energy-efficient maintenance of closed air, water, and waste systems in spacecraft habitats that operate on planetary surfaces such as Mars and that operate in the microgravity environment of space. Three specific focus areas have been identified:

New Applications of the Heat Melt Compactor for Contaminant Control and Waste Management

NASA is seeking new uses for the Heat Melt Compactor (HMC) to extend its capabilities as a multipurpose/multiuse platform with a focus on addressing the needs for Mars surface and planetary protection. These may include:

- Membrane bags and/or liner inserts to initially contain unprocessed trash and other wastes within the compactor chamber but that will allow water and gas to pass through during processing. The bags/liners can melt at process temperatures >120° C but upon cooling must encapsulate the solid dry trash and waste for long-term stable storage. The encapsulation of the processed final product should prevent inoculation by external microorganisms.

- Methods and supporting hardware, including consumables such as membrane bags and/or liner inserts, for safe drying, sterilization and compaction of feces, which allow for water to pass through during processing.
- Methods and supporting hardware, including consumables such as membrane bags and/or liner inserts, for safely recovering water from urine and wastewater brines.
- Design and demonstration of a modular subsystem that uses the existing functional capabilities of the HMC as an autoclave.

New applications of the HMC are not to be limited to the above aforementioned areas, as new and innovative uses for the HMC are welcome. Other considerations are the benefits that can arise from recycling and reutilization of materials from the trash and waste, and the recovery of useful resources such as water and oxygen. The system must work in the Mars gravity environment with micro-gravity operation highly desirable.

A detailed description of the HMC can be found in technical paper number ICES-2014-24, entitled “Generation 2 Heat Melt Compactor Development,” authored by Mark Turner, John Fisher and Greg Pace, 44th International Conference on Environmental Systems, 13-17 July 2014, Tucson, Arizona. The paper is available at the following link: (http://repositories.tdl.org/ttu-ir/handle/2346/59662). The HMC was primarily designed to compact and sterilize bulk trash and waste into a reduced volume, stable and sterile hard tile that is impregnated and encapsulated with plastics from the trash. The HMC consists of a nine inch wide cubic chamber (729 cu in) which can be heated to 180 C. Gas pressure in the chamber is controllable between 3 and 14 psia. A ram at one end of the chamber can create compression loads on materials within the chamber from 2000 to 4000 lb force. The downstream effluent processing system can collect approximately 200 ml of water per hour and oxidize noxious/toxic gases that evolve from processed materials.

Cleaning Agents and Physicochemical Treatments for Habitat Housekeeping and Laundering Clothes

Crew contact surfaces (hand rails, Velcro, acoustic blankets, racks) and food contact surfaces (utensils, table surfaces) are currently cleaned with pre-moistened wipes that are consumable intensive. A mechanism for the in-situ generation of cleaning/sanitizing solutions is needed that will enable these solutions to be applied to reusable fiber based wipes to remove particulate, food, and body oil soiling of surfaces. Solutions must be effective against a range of microbial organisms; their effectiveness against representative organisms must include, but is not limited to, food based bacteria, iodine resistant bacteria, and fecal coliform bacteria. Specific challenges include direct crew contact with cleaning/sanitizing solutions and direct off-gassing and accumulation of solutions in cabin atmosphere. Technologies that can reliably generate, provide short term storage, and dispense cleaning solutions are desired. Prepackaged cleaning solution wipe technologies are not requested.

There is currently no space based laundry technology. Traditional laundry surfactants combined with water and substantial agitation can return clothing to near original condition. However, used surfactants result in a substantial organic contaminant burden on downstream wastewater processors. Future space laundry or refreshing systems will not be required to fully restore clothing to its original condition but should enable clothing to be reused a number of times. Current clothing materials include cotton, poly blends, wool, modacrylic, elastic bands, metallic zippers, metallic snaps, Velcro®, Nomex®, Gore-Tex®, and will likely expand to include fabrics present in many current athletic garments. Generation of cleaning solutions or gases for refreshing/sanitizing clothing are needed that address particulate/dander, salts, body oils (such as squaleneor other representative compound), and bacteria that cause odors (including Staphylococcus epidermidis and Pseudomonas aeruginosa). Specific challenges include capability to adequately disperse cleansing solutions through a wide range of fibers and materials, minimize mineral and organic load to wastewater processors, and minimal foam generation. Processes are desired that can recover unused cleaning solution or regenerate >70% of consumables. This request is not specifically for the laundry/sanitation device that interacts with the garments. The capabilities of the future laundry device would provide ability to agitate, partially remove liquids, and garment drying. Use of fabric brighteners, fragrances, pearlizers, and other aesthetic compounds are undesirable.

Surface treatments that limit biofilm and scaling within water processing system plumbing lines

NASA is seeking technologies or surface treatments that limit biofilm and scaling within water processing system plumbing lines. Both laboratory and flight systems have shown a strong tendency towards biofilm formation and occlusion in wastewater collection systems, particularly small diameter plumbing (3-13 mm internal diameter). Accumulation and sloughing of biofilm increases pressure drop, reduces flow rate, and can cause blockage or premature component change out within wastewater piping. Prevention technologies are sought that will limit microbial growth in piping and water recovery system components for up five years but short timeframes are also useful. Periodic inactivation or remediation technologies that use introduced compounds should be capable of being generated in-situ or recovered after use to minimize consumables. Specific challenges include high microbial and total organic carbon loads. Technologies should be effective for wastewater typical of the International Space Station (urine and humidity condensate) as well as exploration ersatz body hygiene wastewater (see "Advanced Life Support Baseline Values and Assumptions Document", NASA/CR-2004-208941, available at the following link: (http://ston.jsc.nasa.gov/collections/TRS/_techrep/CR-2004-208941.pdf)). Proposed solutions should demonstrate compatibility with ISS type water processors, an ability to protect the wastewater system for a long quiescent period in a clean state, and the ability to withstand intermittent exposure to wastewater followed by additional quiescent periods.

Additional information on NASA needs can be found in draft 2015 NASA Technology Roadmaps including but not limited to sections TA06 6.1.4.1, TA06 6.1.3.3, TA06 6.1.4.6, TA06 6.1.4.8, and TA07 7.5.2.3. These roadmaps are available at the following link: (http://www.nasa.gov/offices/oct/home/roadmaps/index.html).

Topic: H4 Extra-Vehicular Activity (EVA)

Extra-Vehicular Activity (EVA) and crew survival systems technology advancements are required to enable forecasted microgravity and planetary human exploration mission scenarios and to support potential extension of the International Space Station (ISS) mission beyond 2020. Advanced EVA systems include the portable life support system (PLSS) and airlock vehicle to suit umbilical system, as well as the power, avionics and software (PAS) systems. PAS includes communications, controls, and informative displays and the common suit system interfaces. More durable, longer-life, higher-reliability technologies for Lunar and Martian environment service are needed. Technologies suitable for working on and around near earth asteroids (NEAs) are needed. Technologies are needed that enable the range and difficulty of tasks beyond state-of-the-art to encompass those anticipated for exploration. Reductions in commodity and life-limited part consumption rates and the size/mass/power of worn systems are needed. All proposed Phase I research must lead to specific Phase II experimental development that could be integrated into a functional EVA system.

NASA is investing in technologies and techniques geared towards advancing the state of the art of spacecraft systems through the utilization of the ISS as a technology test bed. For technologies that could benefit from demonstration on ISS, proposals should be written to indicate the intent to utilize ISS. 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.

H4.01 Dust Tolerant, High Pressure Oxygen Quick Disconnect for Advanced Spacesuit and Airlock Applications
Lead Center: JSC

In order to support the Extra Vehicular Activity (EVA) Systems development for more robust operation in LEO as well as enabling operation in the lunar and Martian environments, technology development is required for high pressure oxygen (3750 psia) quick disconnects. The current state of the art space suit ISS EMU Umbilical (IEU) and Service and Cooling Umbilical (SCU) connectors operate at a lower pressure and nearly zero contaminant environment. These next generation of quick disconnects (QDs) will enable the EVA systems to transfer high pressure oxygen between the vehicle and on-board tankage under adverse conditions including vacuum and dust (lunar regolith and Martian soil). The QDs expected operating thermal environment range is -50° F to 150° F. The QDs will limit dust intrusion into the internal flow such that when mated/demated 300 times with the environment per MIL-STD-810G, Method 510.5, Procedure I (Blowing Dust) using lunar soil simulant JSC Lunar-1A or JSC Mars-1A, the internal fluid flow downstream of internal filtration is maintained at Level 100A per JPR 5322.1. After those same mate/demate cycles, the fluid flow range will be 0-12 pph of gaseous oxygen at 2800-3750 psia with an allowable pressure drop of 49 psi. The allowable leakage at 3000 psia is 1 scc/hr oxygen. The QD shall exhibit low mating forces such that it can be mated by crew with gloved hands (wearing a spacesuit with a 4.3 psia or 8.3 psia operating pressure) using simple motions such as push/pull or push-twist/twist-pull. Single handed, gloved operation is preferred. A simple means of indicating positive QD engagement is preferred. The use of accessory tools to aid in QD mate/demate should be avoided if possible. The connector shall be capable of reacting a 125 lbf pull force at the strain relief. There are no specific requirements levied upon the exterior size and complexity of the QDs other to state that they are high criticality items that must be safe, practical, reliable; and a device that an exhausted crew member could operate easily and intuitively. Significant work has been done by NASA to identify a mechanical design for the basic size and operation of the device. Reference material has been attached describing existing and new designs, which NASA expects to heavily influence the general form, fit, and function of the future high pressure quick disconnect.

Research done in Phase I of these efforts should focus on technical feasibility with an emphasis on hardware development that can be further expanded in a future Phase II award cycle. Phase II products must include a demonstration unit suitable for testing by NASA. Prototyping should be tailored to applications to ongoing HEO Mission Directorate missions and possible collaborative use in both the governmental and commercial manned spaceflight disciplines. Minimum deliverables at the end of Phase I are analysis and/or test reports, with priority given to functional hardware prototypes for further evaluation. Technical maturation plans should be submitted with Phase I submittals, as well as any expected commercial applications both internal and external to the manned spaceflight enterprise.

ISS EMU UMBILICAL (IEU)

The ISS EMU Umbilical (Item 498) is an interface between the ISS Umbilical Interface Assembly (UIA) and the Extravehicular Mobility Unit (EMU). It provides electrical power and communication, water fill/drain, and water cooling capability from the International Space Station (ISS) for the EMU. The IEU consists of the following items: three water lines of which two are used for water cooling of the LCVG and one for feedwater charging and condensate draining of the PLSS, one oxygen line, one electrical harness assembly for power and communication, a tether restraint and the TMG. The Common Multiple Connector, Item 410, provides a single interface point for connecting and disconnecting the IEU from the DCM. An Umbilical Connector Manifold (UCM), which is government furnished equipment (GFE), provides a single IEU attachment point to the ISS UIA. The IEU provides recharge capability for the PLSS oxygen tank, water reservoir, and battery. In the event a decontamination EVA is needed, the umbilical is designed to withstand environments external to the Airlock.

The EMU umbilical terminates at each end with a ganged multiple connector that requires only a single operation to connect or disconnect the umbilical.

The outer layer of the IEU is a multi-layer Thermal Micrometeoroid Garment (TMG) to provide thermal insulation and protection from micrometeoroid impacts. The IEU includes a protective pouch that will provides thermal and impact protection for the IEU common multiple connector while disconnected from the EMU.

The Umbilical contains a strain relief strap which, during IV operations, attaches via a GFE tether hook to one of the Lower Torso Assembly (LTA) D-rings at the EMU end and to a separate tether ring on the Crew Lock (CL) wall. For EV operations, the hook is disengaged from the UIA panel ring and is secured to a D-ring near the UIA panel. In the event that an EVA decontamination bake out of the EMU is required, this tethering scenario will serve to ensure that UIA design loads are not exceeded.

While not in service (i.e., when completely disconnected from the UIA and EMU), the umbilical is stowed in the equipment lock. While attached to the UIA, the umbilical is restrained against the CL wall by GFE provided restraint straps.

The useful life (combination of the operational life and shelf life) of the Umbilical is 15 years from the date of PDA.

The dry weight of the Umbilical does not exceed 30 lbm. This weight includes all GFE provided hardware (2 tether hooks and the UCM).

Service and Cooling Umbilical (SCU)

The Service and Cooling Umbilical (Item 400) is an 11-ft umbilical consisting of three water hoses, a high-pressure oxygen hose, electrical harness, bacteria filter assembly, and a strain relief tether. The SCU supplies the PLSS with electrical power, communications, oxygen, waste water drainage and water cooling from the Orbiter during pre- and post-EVA operations. It also supplies the EMU with recharge of the oxygen tanks, water tanks, and battery.

The end of the SCU that connects into the airlock panel, otherwise known as the vehicle end of the SCU, consists of the four fluid ECLSS connections in addition to one electrical connector that attaches the SCU to the Orbiter airlock service panel AW82. The connections remain intact between flights and do not require crewmember operation. The vehicle waste water drain and potable water fill lines are connected to the bacteria filter housing located on the airlock wall. On both the drain side and the potable water fill side, a bacteria filter of iodine-impregnated epoxy resin spheres is incorporated, along with a particulate filter made of sintered stainless steel. These filters are used to prevent contamination from passing between the Orbiter ECLSS and the EMU. During normal IVA operations, the Orbiter Waste System is off and there is no ability to dump excess condensate. Approximately one pound of water is drained from the EMU water tanks after filling to allow room for condensate while IVA.

The common connector on the EMU end of the SCU combines the four fluid connections and one electrical circuit connector into a single unit operated by the crewmember. Disengagement of the connector is accomplished by pulling out on the SCU connector cam T-handle to retract a locking pin and then rotating the cam handle from the “locked” position approximately 180º to a detent, which is the “open” position. This rotation of the SCU connector cam disengages two pins on the mating is accomplished by pulling out on the SCU connector cam T-handle to retract a locking pin and then rotating the cam handle from the “locked” position approximately 180º to a detent, which is the “open” position. This rotation of the SCU connector cam disengages two pins on the mating connector. Engagement of the connector is accomplished by rotating the SCU connector cam T-handle to the “open” position, engaging the two pins on the mating connector with the cam, and then rotating the cam handle from the “open” position approximately 180º to the “locked” position, where a cam locking pin is engaged.

The SCU is stowed on the airlock wall when it is not being used. The common connector (SCU side) is attached to a mating stowage connector on the EMU mount (AAP). The SCU is unstowed and connected to the DCM during EMU donning to provide vehicle consumables for the suited EVA preparation activities in the airlock until life support from the EMU is initiated. Nominally, the SCU is disconnected at an airlock pressure of zero psia during airlock depressurization prior to an EVA and reconnected at an airlock pressure of zero psia during airlock re-pressurization after an EVA. The life support from the SCU is maintained during the suited post-EVA activities until the start of EMU doffing. The SCU is also connected to the EMU to supply Orbiter consumables for recharge of the EMU oxygen, the water tanks, and the battery.

ITAR restricted background on exploration space suit umbilical design requirements and expectations may be found at the following website (in cases where the solicitation requirements disagree with the references, the solicitation takes precedence.):

- Contract NNJ09T40C, Constellation Space Suit Systems ISS Umbilical Assembly, CSSS-T-002 Rev. DRAFT X-2, 7 July 2015. (http://sbir.gsfc.nasa.gov/SBIR/solicitations/2016/CSSS-T-002_LSS_CEI_ISS_Umbilical_Assembly_Specification.pdf)
- Contract NNJ09T40C, Constellation Space Suit Systems ISS Umbilical Assembly, Exploration EVA Space Suit Design Status Review, 26 August 2015. (http://sbir.gsfc.nasa.gov/SBIR/solicitations/2016/Umbilical_and_Connector_Section_CSSS_DSR_Day_2_PM.pptx)

H4.02 Trace Contaminant Control for Advanced Spacesuit Applications
Lead Center: JSC
Participating Center(s): MSFC

This subtopic is in search of a trace contaminant control (TCC) technology to remove trace contaminants in an advanced spacesuit atmosphere, specifically considering power, size, and removal capability. The advanced spacesuit portable life support system (PLSS) performs the functions required to keep an astronaut alive during an extravehicular activity (EVA) including maintaining thermal control, providing a pressurized oxygen (O_2) environment, and removing carbon dioxide (CO_2). The PLSS ventilation subsystem performs the transport and provides the conditioned O_2 to the suit for pressurization and astronaut breathing. It circulates O_2 through the ventilation loop using a fan and recycles the ventilation gas, removing CO_2 and providing humidity control. The ventilation subsystem is also responsible for removing trace contaminants from the spacesuit atmosphere. The International Space Station extravehicular mobility unit uses an activated charcoal bed inside the CO_2 removal bed (lithium hydroxide (LiOH) and metal oxide (MetOx) canisters). The charcoal in the MetOx canisters can be regenerated on-orbit. The selection of the rapid cycle amine (RCA) swingbed for CO_2 removal in the baseline advanced spacesuit PLSS has added a risk for removing trace contaminants. The trace contaminants in the PLSS ventilation subsystem and their predicted concentrations (mg/m^3) at the end of an 8-hour EVA without suit leakage include the following: acetaldehyde (0.181), acetone (0.301), ammonia (564), n-Butanol (1.13), carbon monoxide (74.4), ethyl alcohol (9.03), formaldehyde (0.902), furan (0.676), hydrogen (113), methyl alcohol (3.16), methane (1352), and Toulene (1.36). The predictions are based on EVA-specific generation rates.1 Based on these predictions ammonia and formaldehyde are the two contaminants most likely to exceed Spacecraft Maximum Allowable Concentration levels if no TCC device is in the PLSS ventilation loop. It would be beneficial for the technology to be regenerable such as vacuum swing regeneration. In particular, a vacuum-regenerable TCC device that can be regenerated in real time on the suit using a vacuum swing with 1 to 3 min of exposure would be optimum. Additional items for optimization include: reduction in expendables and incorporation into integrated CO_2 removal/reduction system. The desire is for the TCC system to be an immediate knock-down of inlet contaminants such as aldehydes which react irreversibly with the RCA sorbent. This will decrease the likelihood of losing capacity over the life of the system to these types of reactions.

Research done in Phase I of these efforts should focus on technical feasibility with an emphasis on hardware development that can be further expanded in a future Phase II award cycle. Phase II products must include a demonstration unit suitable for testing by NASA. Prototyping should be tailored to applications to ongoing HEO Mission Directorate missions and possible collaborative use in both the governmental and commercial manned spaceflight disciplines. Minimum deliverables at the end of Phase I are analysis and/or test reports, with priority given to functional hardware prototypes for further evaluation. Technical maturation plans should be submitted with Phase I submittals, as well as any expected commercial applications both internal and external to the manned spaceflight enterprise.

References:

- Paul, H., Jennings, M., and Waguespack, G., "Requirements and Sizing Investigation for Constellation Space Suit Portable Life Support System Trace Contaminant Control", 40th International Conference on Environmental Systems, Barcelona, Spain, July 2010. (http://sbir.gsfc.nasa.gov/SBIR/solicitations/2016/AIAA-2010-6065_TCC_CES_Paper_Paul-Jennings-Waguespack.pdf)
- James, J., "Spacecraft Maximum Allowable Concentrations for Airborne Contaminants," JSC-20584, Houston: NASA/Johnson Space Center, November 2008. (http://sbir.gsfc.nasa.gov/SBIR/solicitations/2016/Spacecraft_Maximum_Allowable_Concentrations_SMAC_JSC-20584.pdf)

H4.03 EVA Space Suit Power, Avionics, and Software Systems
Lead Center: JSC
Participating Center(s): GRC

Space suit power, avionics and software (PAS) advancements are needed to extend EVA capability on ISS beyond 2020, as well as future human space exploration missions. NASA is presently developing a space suit system called the Advanced Extravehicular Mobility Unit (AEMU). The AEMU PAS system is responsible for power supply and distribution for the overall EVA system, collecting and transferring several types of data to and from other mission assets, providing avionics hardware to perform numerous data display and in-suit processing functions, and furnishing information systems to supply data to enable crew members to perform their tasks with autonomy and efficiency. Current space suits are equipped with radio transmitters/receivers so that spacewalking astronauts can talk with ground controllers and/or other astronauts. The astronauts wear headsets with microphones and earphones. The transmitters/receivers are located in the backpacks worn by the astronauts only operate in the UHF band.

While a sufficient amount of radiation hardened electronics are available in areas such as serial processors, digital memory and Field Programmable Gate Arrays, certain ancillary electronic devices present a significant risk for the development of rad-hard spacesuit avionics. NASA is, therefore, seeking flight rated electronic devices needed to complement the existing inventory of flight rated parts so as to enable the creation of an advanced avionics suite for spacesuits. The suit and its corresponding avionics should be capable of being stowed inside a spacecraft outside the low-Earth orbit (LEO) environment for periods of up to 5 years (TBR). Devices should also be capable of supporting EVA sorties of at least 8 hours and total lifetime operational durations of at least 2300 hours (TBR) for a Mars surface mission. Assumptions may be made for inherent radiation shielding provided by the primary life-support system (PLSS) and possibly the power, avionics, and software (PAS) subsystem enclosure, but proposers are welcome to include shielding technologies at the board and individual part level to reduce the radiation requirements of the actual device. Devices should be immune to single event latch-up (SEL) for particles with Linear Energy Transfer (LET) values of at least 75 Mev-cm^2/mg. and maintain full functionality for total ionizing doses of at least 20 Krad (Si). Criticality 1 devices (life support) must be fully mitigated against single event errors (SEE) for all potential mission radiation environments, including solar flares. Lower criticality devices can be less tolerant of SEEs, but must still operate with acceptable error rates in all potential radiation environments. Power consumption should be no more than 2X similar COTS or mil-spec devices. Devices should be vacuum compatible and need to support conduction cooling. Need currently exists for a number of devices, as described below. However this list should not be considered to be exhaustive and proposals will be considered for other devices that are peculiar to a spacesuit avionics suite. Additionally, proposals are invited for simplified, low-cost and low-impact methods to adapt or test commercial or military-spec devices so as to yield a flight-rated part to the above levels. In order of priority, two key innovations are sought this round:

- *Safety Critical Switches and Controls* - Very low profile switches and controls for EVA Criticality 1 systems. Highly reliable and robust devices that provide traditional toggle switch, rotary dial, and linear slider control functionality in a very low profile package which permits higher packaging density compared to traditional solutions for vacuum space operations. Switches and controls must still be sized for easy operation with EVA gloves.
- *Wireless Communication* - Dual-band WLAN-class RF front-end module capable of supporting the SSCS (410 to 420 MHz) and the ISS External Wireless Communications system (5.25-5.35GHz). This module is expected to contain all RF components plus data converters. This module will interface with a baseband processing unit via high-speed digital interface. Consideration for supporting multiple antennas on the EWC band will be given, but this is not required. The front-end must be able to operate in the ISS environment.

Research done in Phase I of these efforts should focus on technical feasibility with an emphasis on hardware development that can be further expanded in a future Phase II award cycle. Phase II products must include a demonstration unit suitable for testing by NASA. Prototyping should be tailored to applications to ongoing HEO Mission Directorate missions and possible collaborative use in both the governmental and commercial manned spaceflight disciplines. Minimum deliverables at the end of Phase I are analysis and/or test reports, with priority given to functional hardware prototypes for further evaluation. Technical maturation plans should be submitted with Phase I submittals, as well as any expected commercial applications both internal and external to the manned spaceflight enterprise.

Topic: H5 Lightweight Structures and Materials

The SBIR topic area of Lightweight Structures and Materials centers on developing lightweight structures and advanced materials technologies for space exploration vehicles including launch vehicles, crewed vehicles and habitat systems, and in-space transfer vehicles.

Lightweight structures and advance materials have been identified as a critical need since the reduction of structural mass translates directly to additional up and down mass capability that would facilitate additional logistics capacity and increased science return for all missions. The technology drivers for exploration missions are:

- Lower mass.
- Improve efficient packaging of launch volume.
- Improve performance to reduce risk and extend life.
- Improve manufacturing and processing to reduce costs.

Because this topic covers a broad area of interests, subtopics are chosen to enhance and or fill gaps in the exploration technology development programs. These subtopics can include but are not limited to:

- Manufacturing processes for materials.
- Material improvements for metals, composites, ceramics, and fabrics.
- Innovative lightweight structures.
- Deployable structures.
- Extreme environment materials and structures.
- Multifunctional/multipurpose materials and structures.

This year the lightweight spacecraft materials and structures topic is seeking innovative technology for large deployable structures for smallsats, multifunctional materials and structures for integrated structural health monitoring, extreme temperature structures and in-space structural assembly. The specific needs and metrics of each of the focus areas of technology chosen for development are described in the subtopic descriptions.

Research awarded under this topic 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 full-scale demonstration unit for functional and environmental testing at the completion of the Phase II contract.

H5.01 Large Deployable Structures for Smallsats
Lead Center: LaRC
Participating Center(s): GRC, MSFC

This subtopic seeks deployable structures innovations in two areas for proposed lunar and deep-space missions:

- Large solar sails with at least 85 m^2 of deployed surface area for 6U cubesats.
- Large solar arrays with at least 200 W of power for 6U-12U cubesats or 600 W for 50-100 kg microsats.

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 for both capabilities (deployable solar sails and deployable solar arrays):

- 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.
- Load reduction, damping, and stiffening techniques.
- High-fidelity, functioning laboratory models.

Capability #1: Deployable Solar Sails

Solar sails provide propellant less in-space propulsion using reflected sunlight. Indefinite continuous thrust allows a wide range of advanced maneuvers including non-Keplerian orbits, efficient orbit changes, and extreme ultimate velocities. A near-term application of this technology is NASA's NEA Scout 6U cubesat missions. Larger and more capable solar sail systems are envisioned for future missions.

Square solar sails typically consist of four reflective triangular membranes supported by lightweight deployable booms, as well as mechanical sail actuation to assist attitude control. Specific innovations sought for 6U cubesat solar sails in this solicitation are: improved deployable boom technologies, novel sail designs and packaging concepts, and simpler or more-effective mechanical attitude control systems. Proposed improvements to the booms used on the LightSail mission (metallic Triangular Rollable and Collapsible (TRAC) booms) are of special interest.

Nominal solar sail requirements for 6U cubesats are:

- Deployed reflective surface area > 85 m^2 (>100 m^2 preferred).
- Stowed membrane volume < 10 cm x 10 cm x 20 cm.
- Sail membrane stress > 70 kPa.
- Minimum system deployed natural frequency > 0.1 Hz.
- Mission life > 3 years in deep space (< 2 AU from the Sun) including lunar vicinity.
- Deployed sail surface as flat as possible considering all thermal and mechanical loads and residual stresses.

Improvements to the deployable TRAC booms proposed for the NEA Scout solar sail should meet the following additional requirements:

- Deployed boom length: > 8 m (up to 10 m preferred).
- Stowed volume for all booms and deployment mechanisms < 5 cm x 10 cm x 20 cm.
- Boom buckling load > 3N.
- Mass of each boom < 0.25 kg (< 0.15 kg preferred).

Capability #2: Deployable Solar Arrays

Smallsats promise cost-effective solutions for diverse human spaceflight precursor missions using fuel-efficient solar electric propulsion (SEP). SEP thrust increases with electrical power, so larger solar arrays can shorten travel times and allow higher-power science and communications equipment. This subtopic seeks structures innovations for the next generation of smallsat solar arrays with at least 5x larger area than basic body-mounted solar cells or hinged pop-out panels. Scaling up electrical power for smallsats by > 5x will require game changing innovations. In particular, novel flexible-substrate solar array designs are sought that minimize structural mass and packaging volume while maximizing deployment reliability and deployed area, stiffness, strength, and longevity.
Nominal solar array requirements are:

- Beginning-of-life (BOL) power at 1 AU > 200 W for cubesats or > 600 W for microsats.
- Packaging efficiency > 50 kW/m^3 BOL.
- Recurring cost < $500/W.
- Deployment reliability > 0.999.
- Deployed stiffness > 0.5 Hz.
- Deployed strength > 0.05 g (all directions).
- Lifetime > 2 yrs.

Proposals should emphasize structural design innovations, not materials or photovoltaic innovations. Solar array designs that can be rapidly commercialized are of special interest.

For both capabilities, contractors should prove the feasibility of proposed innovations with suitable analyses and tests in Phase I. Significant hardware or software capabilities should be developed and demonstrated in Phase II. A Technology Readiness Level (TRL) at the end of Phase II of 3-4 or higher is desired.

References:

- (http://www.nasa.gov/sites/default/files/files/Small_Spacecraft_Technology_State_of_the_Art_2014.pdf).
- (http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140012882.pdf).
- (http://www.planetary.org/blogs/jason-davis/2014/20140610-lightsail-update-boom.html).

H5.02 Extreme Temperature Structures
Lead Center: LaRC
Participating Center(s): AFRC, MSFC

This subtopic seeks to develop innovative low cost and lightweight structures for cryogenic and elevated temperature environments. The storage of cryogenic propellants and the high temperature environment during atmospheric entry require advanced materials to provide low mass, affordable, and reliable solutions. The development of durable and affordable material systems is critical to technology advances and to enabling future launch and atmospheric entry vehicles. The subtopic focuses on two main areas: highly damage-tolerant composite materials for use in cryogenic storage applications and high temperature composite materials for hot structures applications. Proposals to each area will be considered separately.

Cryogenic Storage Applications

The focus of this area is to yield material polymeric composite systems and manufacturing processes which enable the capability to store and transfer cryogenic propellants (liquid oxygen and liquid hydrogen) to orbit. Operating temperature ranges for these fluids are -183° C to -253° C. Material systems and processes proposed should be sensitive to eventual scale up and manufacturability of end use hardware. Specific areas of interest include:

- Polymeric composite systems for applications in extreme cold environments such as storage vessels and ductwork for cryogenic fluids. Performance metrics for cryogenic applications include: temperature dependent properties (fracture toughness, strength, coefficient of thermal expansion), resistance to permeability and micro-cracking under cryogenic thermal and biaxial stress state cycling.
- Reliable hatch or access door sealing technique/mechanism for cryogenic polymeric composite structures. Concepts must address seal systems for both composite to composite and composite to metal applications.

Hot Structures

The focus of this area is the development of cost effective, environmentally durable and manufacturable material systems capable of operating at temperatures from 1200° C to 2000° C, while maintaining structural integrity. Significant reductions in vehicle weight can be achieved with the application of hot structures, which do not require structurally parasitic thermal protection systems. The desired material systems are lightweight structural composites that include continuous fibers. This area seeks innovative technologies in one or more of the following:

- Material systems with significant improvements of in-plane and thru the thickness mechanical properties, compared to current high temperature laminated composites, such as stitched or 3D woven fibrous preforms.
- Decreased processing time and increased consistency for high temperature composite materials.
- Improvement in potential reusability for multiple missions.

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.

Phase I Deliverables - Test coupons and characterization samples for demonstrating the proposed material product. Matrix of verification/characterization testing to be performed at the end of Phase II.

Phase II Deliverables - Test coupons and manufacturing demonstration unit for proposed material product. A full report of the material development process will be provided along with the results of the conducted verification matrix from Phase I. Opportunities and plans should also be identified and summarized for potential commercialization.

References:

- Anon, “Final Report of the X-33 Liquid Hydrogen Tank Test Investigation Team,” National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Huntsville, Alabama 35812, May 2000.
- 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).

H5.03 Multifunctional Materials and Structures: Integrated Structural Health Monitoring for Long Duration Habitats
Lead Center: LaRC
Participating Center(s): GRC, JSC, MSFC

Multifunctional and lightweight are critical attributes and technology themes required by deep space mission architectures. Multifunctional materials and structural systems will provide reductions in mass and volume for next generation vehicles. The NASA Technology Roadmap TA12, “Materials, Structures, Mechanical Systems, and Manufacturing” (http://www.nasa.gov/sites/default/files/atoms/files/2015_nasa_technology_roadmaps_ta_12_materials_structures_final.pdf), proposed Multifunctional Structures as one of their top 5 technical challenges, and the NRC review of the roadmap recommended it as the top priority in this area stating: “… To the extent that a structure can simultaneously perform additional functions, mission capability can be increased with decreased mass. Such multifunctional materials and structures will require new design analysis tools and might exhibit new failure modes; these should be understood for use in systems design and space systems operations.”

Some functional capabilities beyond structural that are in this multifunctional theme are insulating (thermal, acoustic, etc.), inflatable, protective (radiation and micrometeoroids and orbital debris), sensing, healing, in-situ inspectable (e.g., IVHM), actuating, integral cooling/heating, power generating (thermal-electric, photovoltaic, etc.), and so on.

Because of the broad scope possible in this SBIR subtopic, the intent is to vary its focus each year to address specific areas of multi-functionality:

- That have high payoff for a specific mission.
- That are broadly applicable to many missions.
- That could find broader applications outside of NASA which would allow for partnerships to leverage the development of these technologies.

For FY16, this SBIR subtopic seeks innovative, multifunctional approaches to integrating long-duration health monitoring capabilities within the range of candidate materials currently being investigated for space habitat long-duration mission concepts. These materials include, but are not limited to, thin-ply composites as well as the materials comprising the multiple soft-goods layers utilized in expandable space habitats, including the bladder, restraint and MMOD layers. Soft-goods materials, used in expandable habitats, may be packaged in an unloaded state for long periods of time prior to deployment, and then maintained at pressure for several years during a mission, while also being subjected to varying levels of thermal cycling. This creates a challenging set of conditions from which to predict the mechanical behavior of these structures over their operational life. NASA seeks the integration of robust, long-term sensing capabilities into the flexible materials (e.g., webbing, cordage, and woven fabrics) used in long-duration habitats, to provide health monitoring and evaluation of the structural integrity and properties of the multi-layer habitat structure throughout its mission life. The integration of the sensors would ideally be performed directly during manufacture; however, robust integration, post-fabrication, via non-destructive application, is also of interest. Ideally, the innovative sensing technology and integration approach should maintain the load-carrying capability or some other structural design requirement, and those technologies that enable weight reduction with similar or better structural performance when compared to traditional approaches will be considered. Sensing capabilities can include both the direct measurement of properties (strain, displacement, and load for example) and sensor fusion using multiple sensors to predict and locate critical damage areas and probable failure zones. The goal for long-duration space habitat design is fail-safe operation; providing monitoring and early prediction of failure onset via structural health monitoring and a benign, progressive failure architecture that allows for safe evacuation even at or after the first failure point.

In summary NASA seeks innovations in integrating structural health monitoring into materials for long-duration deep space habitats, including, but not limited to, state-of-the art thin-ply composites and soft-goods materials for expandable habitat structural concepts, during or after fabrication, to enable evaluation of structural properties and failure prediction over the duration of the habitat's operational life.

Contractors should prove the feasibility of proposed innovations using suitable analyses and small scale tests in Phase I. In Phase II, significant testing/fabrication or software capabilities should be developed and demonstrated. A Technology Readiness Level (TRL) at the end of Phase II of 3-4 or higher is desired.

H5.04 In-Space Structural Assembly
Lead Center: LaRC
Participating Center(s): ARC, JSC, KSC, MSFC

In-space assembly (ISA) of spacecraft systems has been proposed and demonstrated several times as way of assembling systems too large to fit into a single launch vehicle and enabling installation of orbital replacement units. The International Space Station and the repair missions of the Hubble Space Telescope are two good examples.

Efficient structural assembly in space, namely structures with low-mass and high-stiffness and strength, can be achieved by system level design that takes advantage of robotic assembly. For deep-space exploration, the key technology gaps for a robust ISA capability are the joining and unjoining technology (mechanical and electrical), design modularity, and the reuse of components. These technologies will enable a capability that makes future long duration vehicle systems more affordable than the current single-launch, single-use approach to space vehicle design.

The need for on-orbit repair/assembly/servicing are well documented Ref. 1-3. This subtopic seeks in-space assembly and structures manufacturing innovations in two areas of special interest for proposed deep-space space exploration missions:

- Reversible joining technology for structural components and modules.
- In-space and surface systems that recycle spent metallic and composite components to produce additive manufacturing feedstock. Design solutions must minimize mass, power, and complexity while meeting all other mission requirements including contamination control, load bearing strength and stiffness of the assemblage.

Capability #1: Reversible Joining Technology

The ability to join structural and spacecraft components in-space allows for the assembly of vehicles (perhaps aggregated from multiple launches) and for re-use of vehicle subsystems. The joining technology 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 capability seeks innovative joining technologies and capabilities for in-space assembly, disassembly, and re-use of deep-space exploration vehicle subsystems such as cargo tugs that use solar electric power for propulsion. Joining in-space of structural trusses that support multiple solar arrays for solar electric propulsion is one class of needed joining 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 shapes (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.

In particular, novel reversible joining systems for robotic operations are needed that minimize mass, energy and complexity while maximizing assembled stiffness, strength and stability.

Nominal joining applications are:

- Class 1: Structural Truss Joints.
    - Strength: > 0.4 g (Mars Extensible) in all degrees of freedom assuming a fixed joint with 1 meter rigid offset of a 100Kg point mass.
    - Power Transmission: > 5 kW.
    - Operating Temperature: -100° C to +100° C.
    - Assembly/Disassembly: > 20 times.
- 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/m^3.
    - Power Transmission: > 5 kW.
    - Data Transmission: 25 low voltage lines.
    - Temperature: -100° C to +100° C.
    - Assembly/Disassembly: > 20 times.

In Phase I, contractors should prove the feasibility of proposed innovations using suitable analyses and prototype tests. In Phase II, operational joining hardware for assembly and disassembly. Technology Readiness Level (TRL) at the end of Phase II is expected to be 3-4 or higher.

Capability #2: In-situ Surface Manufacturing

Sustainable extraterrestrial presence will require innovative approaches to lightweighting launch masses. The ability to manufacture structures onsite affords an alternative to carrying components of surface systems as part of the launch mass and volume. Additive manufacturing (AM) offers the flexibility to achieve this objective since it enables the conversion of various feedstocks into functional components, especially. Maximum benefits can be realized if the AM method can take advantage of resources available onsite, including both ISRU extracted planetary metals and discarded materials.

State of the art AM techniques can process material classes ranging from metals to plastics and ceramics. Typically, AM equipment use pristine forms of these material feedstocks. This manufacturing capability will permit the construction of various surface systems using feedstock carried as part of the launch and taking advantage of AM in this manner can contribute to the reduction of volume required to carry partly or fully assembled surface systems during launch. However, the impact of AM can be maximized if it is also able to utilize a broader suite of materials, especially those generated from repurposing objects/components required only for launch and transport to the exploration destination, in-space and surface presence. For example, metallic or composite parts from vehicles needed only for transit to the planetary surface, can be recycled to construct pressure vessels for life support and propulsion. The ability to repurpose what would otherwise be discarded materials and/or fabricate with processed extracted planetary materials (such as iron, aluminum, and silicon) takes full advantage of limited resources available to make sustained presence affordable. Further, automated AM offers a means to construct surface systems ahead of the arrival of humans.

Proposals are sought for additive manufacturing concepts that can enable manufacturing from extracted planetary materials and/or the recycling/repurposing of structural components from space vehicles to produce pressure vessels. This does not include the process of ISRU to extract the materials, just the use of the extracted materials in AM. (See H1.01 In-Situ Resource Utilization for processes to extract materials.) Of interest are the following:

Design concepts for AM approaches to accommodate feedstocks that are composites of various material types including but not limited to:

- Processing techniques to recycle and repurpose structural composites having thermoset matrices and carbon fiber reinforcement to yield AM feedstocks.
- Processing techniques to recycle and repurpose structural metallic vehicle components to yield AM feedstocks.
- Approaches to join additively manufactured components from disparate materials.
- Approaches to use minimal power in the manufacture of components.
- Mobile AM methods that operate on power generated from planetary surface resources.

Nominal manufacturing applications are:

- Class 1: Pressure vessels.
    - Size: > 0.25 m^3.
    - Strength: > 14.7 psi.
    - Operating Temperature: -100° C to +100° C.
- Class 2: Two-Dimensional Platform for Mobile Carrier.
    - Size: > 3 meter X 2 meter with thickness based on strength.
    - Strength: > 0.4 g (Mars) with 300 Kg mass uniformly distributed.
    - Operating Temperature: -100° C to +100° C.

In Phase I, contractors should prove the feasibility of proposed innovations using suitable analyses and prototype tests. In Phase II, prototype manufacturing systems capable of processing multiple material classes. Technology Readiness Level (TRL) at the end of Phase II is expected to be 3-4 or higher.

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.

Topic: H6 Autonomous and Robotic Systems

NASA invests in the development of autonomous systems, advanced avionics, and robotics technology capabilities for the purpose of enabling complex missions and technology demonstrations supporting the Human Exploration and Operations Mission Directorate (HEOMD). The software, avionics, and robotics elements requested within this topic are critical to enhancing human spaceflight system functionality. These elements increase autonomy and system reliability; reduce system vulnerability to extreme radiation and thermal environments; and support human exploration missions with robotic assistants, precursors and caretaker robots. As key and enabling technology areas, autonomous systems, avionics and robotics are applicable to broad areas of technology use, including heavy lift launch vehicle technologies, robotic precursor platforms, utilization of the International Space Station, and spacecraft technology demonstrations performed to enable complex or long duration space missions. All of these flight applications will require unique advances in autonomy, software, robotic technologies and avionics. The exploration of space requires the best of the nation's technical community to provide the technologies, engineering, and systems to enable human exploration beyond LEO, to visit Asteroids and the Moon, and to extend our reach to Mars.

NASA is investing in technologies and techniques geared towards advancing the state of the art of spacecraft systems through the utilization of the ISS as a technology test bed. For technologies that could benefit from demonstration on ISS, proposals should be written to indicate the intent to utilize ISS. 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.

H6.01 Robotic Systems - Mobility, Manipulation, and Human-System Interaction
Lead Center: JSC
Participating Center(s): ARC, JPL, KSC

The objective of this subtopic is to create autonomous systems and robotic technologies (hardware and software) to improve the human 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 (tele-operation to supervised autonomy), over multiple spatial ranges (shared-space, line-of-sight, on orbit, and interplanetary), and with a range of time-delay and communications bandwidth. Additionally, in order to build robotic systems that are cheaper, lighter, and more energy efficient than traditional devices based only on rigid assemblies, it is important to develop soft robotics technology for mobility and manipulation.

The software, avionics, and robotics elements requested within this topic are critical to increasing autonomy and system reliability; reducing system vulnerability to extreme radiation and thermal environments; and supporting human exploration missions with robotic assistants, precursors and caretaker robots. As key and enabling technology areas, autonomous systems, avionics, and soft robotics technologies are applicable to broad areas of technology use, including heavy lift launch vehicle technologies, robotic precursor platforms, utilization of the International Space Station, and spacecraft technology demonstrations performed to enable complex or long duration space missions. All of these flight applications will require unique advances in autonomy, software, robotic technologies and avionics. The exploration of space requires the best of the nation's technical community to provide the technologies, engineering, and systems to enable human exploration beyond LEO, to visit Asteroids and the Moon, and to extend our reach to Mars.

Proposals are sought to research and develop the following:

- *Mobility* - Subsystems to improve the transport of crew, instruments, and payloads on planetary surfaces, asteroids, and in-space. This includes: hazard detection sensors/perception; active suspension; grappling/anchoring; legged locomotion; robot navigation; infrastructure-free localization and sensors for deformable, flexible or active elastic mobility components.
- *Manipulation* - Subsystems to improve handling and maintenance of payloads and assets. This includes: tactile sensors; human-safe actuation active structures; dexterous grasping; modular “plug and play” mechanisms for deployment and setup; small/lightweight excavation devices; novel manipulation methods; and actuators and/or sensors for active tension control (including tendon-based manipulation and dynamic tensegrity).
- *Human-system interaction* - Subsystems that enable crew and ground controllers to better operate, monitor and supervise robots. This includes: robot user interfaces; automated performance monitoring; tactical planning software; real-time visualization/notification; software for situational awareness and modeling/simulation software for soft robotics (including design of highly compliant and/or underactuated dynamic systems).

H6.02 Requirements Management for Spacecraft Autonomy and Space Mission Automation
Lead Center: ARC

System and software requirements for autonomy have been difficult to define and test due to uncertainties in the environment in which autonomous systems might be deployed, the flexible yet safe interaction with in-situ humans that is needed, and the adaptability needed from an autonomous system for novel situations. Future human spaceflight missions will place crews and other assets at large distances and light-time delays from Earth that will need to act autonomously from mission control over significant time intervals in both nominal and emergency situations. Space missions have small crew sizes, and many mission concepts involve spacecraft and habitats that are only intermittently crewed, so automation through software will be a major portion of autonomous systems.

Proposals are solicited that provide novel methods and tools specifically targeted to defining and testing requirements for autonomy capabilities, including the definition of interactions and roles with in-situ humans. Proposals should encompass a subset of the following: methods and tools for autonomy requirement definition, refinement, verification of internal consistency, validation, and testing during subsequent development.

Proposals should compare their proposed methods and tools to conventional requirements management, and indicate why their methods and tools will result in requirements for autonomy with less ambiguity, fewer conflicts between different requirements, and more testable requirements - as compared to state of the art requirements methods. Proposals should provide metrics for measuring the quality of autonomy requirements resulting from their methods and tools compared to SOA. For example, in the aircraft industry today over half of system development errors originate during the requirements phase, while over 75% of system development errors are caught very late in development - typically in late phases of testing. This leads to high costs and development schedule overruns due to rework. Proposers should ground their proposed research by demonstrating methods and tools on plausible design reference missions involving autonomy.

Proposals should indicate how their methods and tools will bridge the gap between requirements definition and requirements-based testing, potentially including semi-automatic test generation suitable for the autonomy attributes of flexible response in uncertain environments with uncertain situations.

Proposals can draw upon a wide range of methods, including but not limited to ontology definition, uncertainty quantification, formal approaches to requirements engineering, symbolic methods for test generation from requirements, and techniques for requirements elicitation from stakeholders. Proposals that involve natural language as a medium for autonomy system and software requirements definition should describe how the natural language will be disambiguated in subsequent phases of system development.

H6.03 Spacecraft Autonomy and Space Mission Automation for Consumables
Lead Center: ARC
Participating Center(s): JPL, JSC

Future human spaceflight missions will place crew's at large distances and light-time delays from Earth, requiring novel capabilities for crews and ground to manage spacecraft consumables and renewables such as power, water, propellant and life support systems to prevent Loss of Mission (LOM) or Loss of Crew (LOC). This capability is necessary to reconfigure spacecraft, or replan missions, in response to events such as leaks or failures leading to unexpected expenditure of consumables coupled with lack of communications. If crews in the spacecraft must manage, plan and operate much of the mission themselves, NASA must migrate operations functionality from the flight control room to the vehicle for use by the crew. Migrating flight controller tools and procedures to the crew on-board the spacecraft would, even if technically possible, overburden the crew. Enabling these same monitoring, tracking, and management capabilities on-board the spacecraft for a small crew to use will require significant automation and decision support software. Required capabilities to enable future human spaceflight to distant destinations include:

- Enable on-board crew management of vehicle consumables that are currently flight controller responsibilities.
- Increase the onboard capability to detect and respond to unexpected consumables-management related events and faults without dependence on ground.
- Reduce up-front and recurring software costs to produce flight-critical software.
- Provide more efficient and cost effective ground based operations through automation of consumables management processes, and up-front and recurring mission operations software costs.

Necessary capabilities include:

- Peer-to-peer mission operations planning.
- Mixed initiative planning systems.
- Elicitation of mission planning constraints and preferences.
- Planning system software integration.

- Space Vehicle System Automation.
- Autonomous rendezvous and docking software.
- Integrated discrete and continuous control software.
- Long-duration high-reliability autonomous system.
- Power aware computing.
- Power Systems Autonomous Control.
- Vehicle Systems Automation.
- Crew Situational Awareness of Vehicle Automation.
- Contingency Management.

The emphasis of proposed efforts should focus primarily on software systems, but emphasize hardware and operating systems the proposed software will run on (e.g., processors, sensors), and proposals must demonstrate understanding of the consumables and dependent spacecraft systems that the software is intended to manage.

Proposals may reference existing fault management techniques, but this subtopic does not solicit development of fault management capability; proposers interested in developing these capabilities are referred to the relevant H6 topic area (H6.04). While Verification, Validation and Requirements of autonomous systems is also an important area, this subtopic does not solicit development of these technologies, proposers interested in developing these capabilities are referred to the relevant H6 topic area (H6.02).

Proposals must demonstrate mission operations cost reduction by use of standards, open source software, crew workload reduction, and/or decrease of software integration costs.

Proposals must demonstrate autonomy software cost reduction by use of standards, demonstration of capability especially on long-duration missions, system integration, and/or open source software.

H6.04 Integrating ISHM with Flight Avionics Architectures for Cyber-Physical Space Systems
Lead Center: ARC

This call for SBIR proposals is for technology development of integrated flight control systems for seamless integration of flight avionics with Integrated Systems Health Management (ISHM) systems. Flight avionics, with Integrated Modular Avionics (IMA) have well-defined Caution and Warning (CW) Fault Detection Isolation and Response (FDIR) alerting systems which in can in real-time detect, isolate and respond to single failures at a time. For each CW failure, a predefined mapping to a CW response procedure is defined. In this way when real time conditions occur, response can be almost immediate. However this approach suffers when more than one failure is present. Under multiple CW failures more than one CW response procedure is active. Which of the predefined procedures should you execute? A procedure execution deadlock can occur. Currently when procedure deadlock occurs a number of questions need to be addressed by flight/ground:

- At what step in each procedure should you execute first?
- Should procedure steps be removed /added?
- Should procedure steps be interleaved between procedures?
- Should an entirely new procedure by synthesized?

The determination of how to proceed from procedure deadlock under multiple failure scenarios is critically dependent upon the correct multiple failure diagnosis of the situation. ISHM supports this determination due to the fact that ISHM can extend traditional CW FDIR systems to utilize a systems view of the spacecraft which leverages all (or most) of the available sensors and command talk-back information. Whereas traditional CW FDIR logic are often small fragments of logic and code which utilize subsets of the sensors, and in general have no knowledge and/or context of the other FDIR algorithms, a global view allows for a global response but also brings additional challenges of determining that the data from all the sensors is consistent. It is also important to recognize that failure signatures/ propagation/fault masking can be the result of not only hardware but also the interaction of the myriad control loops and procedural behavior that is induced by the flight avionics. Another key aspect is to perform interpretation of fault data in the context of mission operations, and subsequent fault recovery consistent with current mission goals.

Additional challenges are also to devise methods to automatically develop the ISHM fault models from system descriptions such as the schematics, procedures, etc.

To date however seamless integration of ISHM systems with flight avionics CW FDIR systems has not matured to the level such that ISHM systems are trusted to support flight avionics systems in multiple failure high stress situations such as CW storms. Prior human-rated approaches have been proposed but not baselined for similar functional situations in both the Space Shuttle domain (Enhanced Caution and Warning (ECW) as part of the Cockpit Avionics Upgrade (CAU) program) as well as the International Space Station domain (ISS 24-hour autonomy mode). The challenge is to extend the lessons learned from these efforts to achieve program insertion. Such efforts will support both crewed as well as robotic missions, both near Earth as well as deep space missions. Support will be enabled under a variety of conditions including where:

- Communication time with Earth is insufficient and/or delayed.
- Communication bandwidth is insufficient.
- The complexity of analysis is beyond human comprehension.
- The reliance on a skeleton crew requires additional computational support.

Seamless integration can be defined through many dimensions. Several dimensions of interest are:

- Allow the operator the ability to select between a palette of ISHM modules.
- Allow the operator the ability to turn on/off the ISHM module.
- Real time support for flight avionics. At least one scenario should be defined which shows the operation of the flight avionics with and without ISHM.

In order to demonstrate a technology solution, proposed work should include as baseline, a representative set of hypothetical CW events, a FDIR procedure response for each CW event, and one or more scenarios where, with multiple CW events across subsystems, the set of applicable FDIR procedures deadlocks. The proposed work should then demonstrate how the procedure deadlock is resolved through the proposed technology solution which integrates ISHM with the flight avionics.

Topic: H7 Entry, Descent, and Landing

In order to explore other planets or return to Earth, NASA requires various technologies to facilitate entry, descent and landing. This topic, at this time, is supported by two subtopics.

The first subtopic calls for the development, modeling, testing, and monitoring of ablative thermal protection materials, high char yield adhesives and/or systems that will support planetary entry. NASA has been developing new ablative materials, some based on a 3-D woven reinforcement, either dry woven or impregnated, and some based on felt reinforcements. In order to develop heatshield systems from these materials, joining techniques are required. As new materials are developed, improved analytical tools are required to more accurately predict material properties and thermal response in entry conditions. Light weight, low power instrumentation systems for measuring the actual surface heating, in-depth temperatures, surface recession rates during testing and/or flight are required to verify the response of the materials and to monitor the health of flight hardware.

The second subtopic calls for the development of improved diagnostics for ground test facilities providing hypervelocity flows. As we try to understand the effects of hypersonic flow fields on entry vehicles, ground testing is often used to compare test data to predicted values. Improvements in diagnostic measurements in facilities such as NASA's high enthalpy facilities, which include the Electric Arc Shock Tube (EAST), Arc Jets, Ballistic Range, Hypersonic Materials Environmental Test System (HyMETS), and 8' High Temperature Tunnel (HTT) could provide data that will be used to validate and/or calibrate predictive modeling tools which are used to design and margin EDL requirements. This will reduce uncertainty in future mission planning.

H7.01 Ablative Thermal Protection Systems Technologies
Lead Center: ARC
Participating Center(s): GRC, JPL, JSC, LaRC

The technologies described below support the goal of developing advancements in polymers for bonding and/or gap-filling ablative materials, instrumentation systems, and analytical modeling for the higher performance Ablative Thermal Protection Systems (TPS) materials currently in development for future Exploration missions. The ablative TPS materials currently in development include felt or woven material precursors impregnated with polymers and/or additives to improve ablation and insulative performance, along with the block form of Avcoat ablator for MPCV.

Two classes of materials are currently in development for planetary aerocapture and entry. The first class is for a rigid mid L/D (lift to drag ratio) shaped vehicle with requirements to survive a dual heating exposure, with the first at heat fluxes of 400-500 W/cm^2 (primarily convective) and integrated heat loads of up to 55 kJ/cm^2, and the second at heat fluxes of 100-200 W/cm^2 and integrated heat loads of up to 25 kJ/cm^2. These materials or material systems are likely dual layer in nature, either bonded or integrally manufactured. The second class is for a deployable aerodynamic decelerator, required to survive a single or dual heating exposure, with the first (or single) pulse at heat fluxes of 50-150 W/cm^2 (primarily convective) and integrated heat loads of 10 kJ/cm^2, and the second pulse at heat fluxes of 30-50 W/cm^2 and heat loads of 5 kJ/cm^2. These materials are either flexible or deployable.

Also currently in development is a third class of materials, for higher velocity (>11.5 km/s) Earth return, with requirements to survive heat fluxes of 1500-2500 W/cm^2, with radiation contributing up to 75% of that flux, and integrated heat loads from 75-150 kJ/cm^2. These materials are currently based upon 3-D woven architectures.

Technologies sought are:

- The development of a high char yield, flexible polymer with high strain-to-failure for used in bonding and/or gap fills for tiles of advanced TPS for extreme entry conditions. While high char yield (comparable to phenolic) and high strain-to-failure (>1%) are key requirements, additional goals would include some or all of the following: high decomposition temperatures (comparable to phenolic or higher); room temperature cure preferred; manufactured in air (inert environment not required); stable at ambient conditions (not overly sensitive to moisture in cured or un-cured state); compatible with cured epoxy, phenolic, and/or cynate ester, extended out-time; and very low glass transition temperature to retain flexibility in space.
- Development of in-situ sensor systems including pressure sensors, heat flux sensors, surface recession diagnostics, and in-depth or structural interface thermal response measurement devices, for use on rigid and/or flexible ablative materials. Individual sensors can be proposed; however, instrumentation systems that include power, signal conditioning and data collection electronics are of particular interest. In-situ heat flux sensors and surface recession diagnostics tools are needed for flight systems to provide better traceability from the modeling and design tools to actual performance. The resultant data can lead to higher fidelity design tools, improved risk quantification, decreased heat shield mass, and increases in direct payload. The pressure sensors should be accurate to 0.5%, heat flux sensors should be accurate within 20%, surface recession diagnostic sensors should be accurate within 10%, and any temperature sensors should be accurate within 5% of actual values. These should require minimum mass, power, volume, and cost; MEMS-based, wireless, optical, acoustic, ultrasonic, and other minimally-intrusive methods are possible examples. All proposed systems should utilize low-cost, modular electronics that handle both digital and analog sensor inputs and could readily be qualified for the space environments of interest. Typical sensor frequencies are 1-10 Hz, with up to 200 channels of collected data. Consideration should be given to those sensors that will be applicable to multiple material systems.
- Advances are sought in ablation modeling, including radiation, convection, gas surface interactions, pyrolysis, coking, and charring for low and mid-density fiber based (woven or felt) ablative materials. There is a specific need for improved models for low- and mid-density as well as multi-layered charring ablators (with different chemical composition in each layer). The modeling efforts should include consideration of the non-equilibrium states of the pyrolysis gases and the surface thermochemistry, as well as the potential to couple the resulting models to a computational fluid dynamics solver.
- Advances are sought in modeling mechanical properties of 3-D woven materials. Tools that analyze and predict the effects of different fibers on the warp and fill directional properties that could help in fiber selection and weave design are sought.

Starting Technology Readiness Levels (TRL) of 2-3 or higher are sought.

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:

- *Advanced Polymer* - Polymer system with demonstration of desired char yields, along with a test plan to be executed in Phase II demonstrating its usability and compatibility with various NASA provided composite materials
- *Sensors* - Sensor system design, including electronics, with specified measurement performance, mass, power, and volume. Proposed test approach for Phase II that will demonstrate system performance in a relevant environment (arcjet or combined structural/thermal test). Plans should consider testing at the largest scale and highest fidelity that the Phase II funding constraints allow.
- *Ablator and Mechanical Modeling* - Software and architecture development plan, along with a validation test plan, to be executed in Phase II. The Phase I report should provide evidence that the mathematical approaches will improve the state-of-the-art.

Phase II Deliverables:

- *Advanced Polymer* - Aerothermal and structural testing to validate usability and compatibility of the polymer with various NASA provided composite materials
- *Sensors* - Working engineering model of a sensor system with the proposed performance characteristics. Full report of system development, architecture, and measurement performance, including data from completed test proposed in Phase I (TRL 4-5). Potential commercialization opportunities and plans should also be identified and summarized.
- *Ablator and Mechanical Modeling* - Prototype (Beta) software and results from the validation test cases.

H7.02 Diagnostic Tools for High Velocity Testing and Analysis
Lead Center: ARC

The company will develop diagnostics for analyzing ground tests in high enthalpy, high velocity flows used to replicate vehicle entry, descent and landing conditions. Diagnostics developed will be tested in NASA's high enthalpy facilities, which include the Electric Arc Shock Tube (EAST), Arc Jets, Ballistic Range, Hypersonic Materials Environmental Test System (HyMETS), and 8' High Temperature Tunnel (HTT).

Development of improved diagnostics for hypervelocity flows allows us to better understand the composition and thermochemsitry of our ground test facilities and are important for building ground-to-flight traceability. Characterizations in facilities may be used to validate and/or calibrate predictive modeling tools which are used to design and margin EDL requirements. This will reduce uncertainty in future mission planning.

Diagnostics of interest include measurement of temperature, velocity, electron number density, and information regarding byproducts of pyrolysis and ablation in CO_2 or air environments. Due to variation in facility operations, the diagnostics are required to obtain reasonable signals in test times down to approximately 4 μs with resolution on sub-μs time scales. Secondary methods of interest would relate to the detection of the shock front edge arrival to high accuracy (< 0.1 μs). Proposals should detail information such as detection limits, expected signal to noise ratios and data acquisition frequency. Data acquisition channels with up to 200 MHz sampling rate are available.

Deliverable will be in the form of a diagnostic hardware system that can be employed by NASA engineers/scientists in the test facility.

Topic: H8 High Efficiency Space Power

This topic solicits technology for power systems to be used for the human exploration of space. Power system needs consistent with human spaceflight include:

- Fuel cells compatible with methane-fueled landers, and electrolyzers and fuel cells compatible with materials extracted from lunar regolith and/or the Martian soil or atmosphere.
- Advanced battery cell technologies addressing NASA-unique environments and missions.
- Photovoltaic component and system technologies to power electric spacecraft and/or Mars surface systems.
- Thermal energy conversion.

Solid oxide technology is of interest for fuel cells and electrolyzers to enable:

- The operation of fuel cells using hydrocarbon reactants, including methane and fuels generated on-site at the Moon or Mars.
- Electrolysis systems capable of generating oxygen by electrolyzing CO_2 (from the Mars atmosphere, trash processing, life support, or volatiles released from soils), and/or water from either extraterrestrial soils, life support systems, or the byproduct of Sabatier processes. Both component and system level technologies are of interest.

Breakthrough battery cell technologies that far exceed the specific energy and energy density or temperature performance of state-of-the-art lithium-based cell technologies are sought to achieve NASA-unique energy storage goals for human missions to cis-lunar space and Mars. Applications include extravehicular activities, human-rated landers, and Mars ascent vehicles. The sub-topic solicitation describes the NASA-unique metrics being sought for new energy storage technologies.

Advanced photovoltaic (PV) power generation and enabling power system technologies are sought with improvements in power system performance (conversion efficiency, mass, stowed volume, etc.), mission operation capability, and reliability for PV power systems supporting NASA human exploration missions using solar electric propulsion (SEP) or on the surface of Mars. The sub-topic solicitation describes the specific metrics being sought for new photovoltaic technologies and systems.

H8.01 Thermal Energy Conversion
Lead Center: GRC
Participating Center(s): JPL, JSC, MSFC

NASA needs innovative technologies that convert thermal energy into electricity for space power generation on orbiting platforms, extraterrestrial surfaces, and space transportation vehicles. The thermal energy could be supplied by nuclear reactors, radioisotope heat sources, solar concentrators, chemical reactions, or as waste heat from other space systems. The focus of this subtopic is the energy conversion subsystem. Proposals are requested on thermal energy conversion approaches that offer high efficiency, low mass, high reliability, long life, and low cost. Candidate technologies include thermodynamic heat engines such as Stirling, Brayton, and Rankine as well as thermoelectric and thermionic devices. Ancillary components used to deliver heat (e.g., heat transport loops, heat pipes) to the energy conversion and reject waste heat (e.g., heat pipes, radiators) are also of interest.

The primary mission pull is providing electric power for human Mars surface missions that require kilowatts for remote science stations and rovers, or 10s of kilowatts for crew habitats and in-situ resource utilization plants. A secondary mission pull is providing electric power for Mars transportation vehicles that require 10s of kilowatts for crew life support and vehicle subsystems. The Mars missions may be preceded by human precursor missions to near earth objects, cis-lunar space, and the lunar surface during which the Mars technologies could be demonstrated. The anticipated heat source temperature ranges are 800 to 1300 K for nuclear, solar, and chemical sources and less than 400 to 500 K for waste heat. The expected operating lifetime ranges from several years to greater than 10 years.

The proposals should focus on energy conversion subsystems and components with a current technology readiness level of 2 or 3. The Phase I effort should include conceptual design with analytical or experimental proof-of-concept based on the expected operating environment and system interfaces (e.g., heat source, heat rejection). The Phase II effort should include development of breadboards or prototypes that can be operated at the contractor's facility to demonstrate functionality in a laboratory environment. If the contractor testing is successful, the hardware will be considered for integration into NASA ground tests and flight experiments with representative system interfaces and relevant operating environments. Upon completion of successful integrated system tests at NASA, Phase III projects would be pursued to infuse the technologies into flight projects.

H8.02 Solid Oxide Fuel Cells and Electrolyzers
Lead Center: GRC
Participating Center(s): JPL, JSC

Technologies are sought that improve the durability, efficiency, and reliability of solid oxide systems. Of particular interest are those technologies that 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 methane and fuels generated by processing lunar and Mars soils. Primary solid oxide components and systems of interest are:

- Solid oxide fuel cell, stack, materials and system development for operation on propellant grade direct methane in designs scalable to 1 to 3 kW at maturity. Strong preference for high power density configurations.
- Cell and stack development capable of Mars atmosphere electrolysis should consider feasibility at 0.4 to 0.8 kg/hr O_2; scalable to 2 to 3.5 kg/hr O_2 at maturity. CO_2 electrolysis or co-electrolysis designs must have demonstrated capability of withstanding 15 psid in Phase I with pathway to up to 50 psid in Phase II.

Proposed technologies should demonstrate the following characteristics:

- The developed systems are expected to operate as specified after at least 20 thermal cycles during Phase I and greater than 70 thermal cycles for Phase II. The heat up rate must be stated in the proposal.
- The developed systems are expected to operate with less than five percent degradation after at least 500 hours of steady state operation on propellant-grade methane and oxygen. Operation for 2500 hours and less than five percent degradation is expected of a mature system.
- Fuel reforming must be water neutral. Integrated systems that minimize components and complexity are favored.
- Minimal cooling is available for power applications. Some cooling in the final application will be provided by means of conduction through the stack to a radiator exposed to space or other company proposed solution that minimizes resources required.
- Minimal power (heating plus electrolysis) required for CO_2 electrolysis applications.
- Demonstrate electrolysis of the following input gases: 100% CO_2, Mars atmosphere mixture (95.7% CO_2, 2.7% N_2, 1.6% Ar), 100% water vapor, and 0.7 to 1.6:1 CO_2:H_2O mass ratio. A final test using pure CO_2 of 500 hours (or stopping at 40% voltage degradation) is required. Description of technical path to achieve up to 11,000 hrs for human missions is requested.

H8.03 Advanced Photovoltaic Systems
Lead Center: GRC
Participating Center(s): JSC

Advanced photovoltaic (PV) power generation and enabling power system technologies are sought with improvements in power system performance (conversion efficiency, mass, stowed volume, etc.), mission operation capability, and reliability for PV power systems supporting NASA human exploration missions. Power levels may cover ranges of 25-250 kWe to MegaWatt-class systems. Component technologies and array concept designs are sought that can address all or parts of the following: improved efficiency (>30% cell conversion efficiency at Air Mass zero), cost (50% reduction compared to state-of-the-art (SOA) through modularization, automated manufacturing, and reduced material costs), improved reliability, reduced mass (50% reduction compared to SOA designs), reduced stowed volume (designs capable of accommodating 100kW power levels within a single launch), high array bus voltages (> 250 V), and long-lived, reliable operation within the expected space environment (i.e., high radiation environments, both high and low temperature and light intensity extremes, planetary surface dust conditions, electric propulsion plume impingement erosion, and minimal arcing/degradation due to interactions with the space plasma). The technologies being sought should enable or enhance the ability to provide low-cost, low mass, and higher efficiency solar power systems that support high power Solar Electric Propulsion (SEP), high radiation/extreme environments, and Mars surface NASA missions. Areas of particular emphasis include:

- Advanced PV blanket and component technology with designs that support very high power and high voltage (> 250 V) applications.
- Array structures and blankets optimized for Mars surface gravity and maximum wind loading conditions while still preserving the low mass, low stowed volume, high reliability, and possible retraction/redeployment capabilities.
- Array/blanket designs capable of operating in high dust environments.
- PV blanket, component technology, and arrays optimized for extreme environment conditions (high radiation, low/high temperature extremes, exposure to SEP plume environments, etc.).
- PV module/component technologies that emphasize low mass and cost reduction (via materials, fabrication, and reduced testing).
- Improvements to solar cell efficiency consistent with low cost, high volume fabrication techniques that are applicable to HEOMD missions.
- Automated/modular fabrication methods for PV panels/modules on flexible blankets (includes cell laydown, interconnects, shielding and high voltage operation mitigation techniques).

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

H8.04 Advanced Next Generation Batteries
Lead Center: GRC
Participating Center(s): JPL, JSC

Breakthrough battery cell technologies that far exceed the specific energy and energy density or temperature performance of state-of-the-art lithium-based cell technologies are required to achieve far-term energy storage goals for human and robotic missions to the moon, Near Earth Orbit, Venus, and Mars. NASA is seeking innovative, advanced electrochemical cell and battery technologies that can aggressively address requirements for these future missions. Proposed chemistries and components must meet performance goals while simultaneously delivering a high level of safety. Components and systems that can enable one of the following sets of cell-level performance goals (simultaneously, within the same system) are sought for specific missions:

- Extravehicular Activities. 450 Wh/kg, 1000-1500 Wh/L, >100 full cycles, >5 year calendar life, up to C/5 rate capability, operation at 0 to 40° C, retention of at least 90% of room temperature capacity during operation at 0°C, and tolerant to electrical and mechanical abuse (i.e., abuse does not result in fire or thermal runaway).
- Human Lunar and Mars Landers and Rovers. 300-375 Wh/kg, 1000-1500 Wh/L, up to 2000 full cycles, >10 year calendar life, >C/2 rate capability, operation at -60 to 30°C, and retention of at least 80% of room temperature capacity during operation at -60° C.
- Mars Ascent Vehicle - Quiescent capability. >250-300 Wh/kg, 1000-1500 Wh/L, few cycles, >15 year shelf life after activation and very limited cycling, and C-rate capability. Extremely high reliability and very low irreversible capacity loss required after 15 year quiescent period. Calendar life and reliable operation after quiescent period are paramount.

Offerors may propose to develop a single or multiple components, or a full cell system. Phase I proposals shall include quantitative analysis, scientific evidence, and technical rationale that clearly demonstrates how the proposed component or components will meet or contribute to the cell performance goals by the end of a Phase II effort. If a single component(s) is proposed rather than full cells, the Offeror shall also include in their justification of the proposed technology the performance that other advanced cell components must achieve in order to meet the claimed cell-level goals. Additionally, Phase I proposals shall describe the technical path that will be followed to achieve the claimed goals. Where possible, laboratory scale prototype hardware should be proposed as deliverables to NASA in Phase I.

Phase I Deliverables - Laboratory scale prototype hardware.

Phase II Deliverables - Incremental hardware deliverables and breadboard demonstration.

Topic: H9 Space Communications and Navigation

Space Communication and Navigation (SCaN) technologies support all NASA space missions with the development of new capabilities and services that make our missions possible. Communication links are the lifelines that provide the command, telemetry, science data transfers, and navigation support to our spacecraft. Advancement in communication and navigation technology will allow future missions to implement new and more capable science instruments, greatly enhance human missions beyond Earth orbit, and enable entirely new mission concepts. NASA's communication and navigation capability is based on the premise that communications shall enable and not constrain missions. This topic supports development of technologies to fundamentally change the paradigm of communications and navigation. They include greatly increased data rates via optical communications; cognition in Software Defined Radios (SDR); advanced guidance, control, and navigation; and advanced RF systems. For more details, see: (http://www.nasa.gov/scan).

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 [1]:

- >100 gigabit/s cis-lunar (Earth or lunar orbit to ground).
- >10 gigabit/s Earth-sun L1 and L2.
- >1 gigabit/s per A.U.-squared deep space.
- >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):

- *Low-mass large apertures for high-EIRP laser transceivers [2]* - 30 to 100 cm diameter laser communications telescopes massing less than 65 kg/square-meter with wavefront errors less than 1/25th of a wavelength at 1550 nm and a cumulative wavefront error and transmission loss of <3dB in the far field that can survive direct sun-pointing. Operational range of -20° C to +50° C without active thermal control is desired.
- *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 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 100 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. Highly efficient (>20% DC-to-optical, including support electronics) and space qualifiable (including resilience to photo-darkening) multi-watt Erbium Doped Fiber Amplifier with high gain bandwidth (> 30nm, 0.5 dB flatness) concepts will also be considered. Detailed description of approaches to achieve the stated efficiency is a must.
- *Waveform signal processing technologies [3]* - **CCSDS White Book, "High Photon Efficiency Optical Communications -- Coding & Modulation," March 2015**, http://www.nasa.gov/directorates/heo/scan/engineering/datastandards/index.html - 100 Mb/s and higher hardware/firmware implementation of the coding and synchronization layer of the proposed Consultative Committee for Space Data Systems (CCSDS) high-photon-efficiency optical signaling waveform, including

transmitter and receiver functions. Supported features are to include CCSDS Transfer Frame ingestion and slicing; attached frame sync markers; CRC; serially concatenated convolutional coding with accumulate pulse position modulation (SCPPM), including a constraint length 3 convolutional code of rates 1/3, 1/2, and 2/3, code interleaver, accumulator, and PPM of orders 4, 8, ..., 256; randomizer; 1 s channel interleaver; codeblock sync marker repeat/spreader, and guard slot insertion.

- *Large aperture ground receiver subsystem technologies [4]* - Demonstrate innovative subsystem technologies for >10 m diameter ground receiver 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. Also desired are cryogenic optical filters for operation at 40K with noise equivalent bandwidths of a few nm in the 1550 nm spectral region, transmission losses < 0.25 dB, clear aperture >35 mm, and acceptance angle >40 milliradians with out-of-band rejection of >65 dB from 0.4 to 5 microns.
- *Superconducting magnesium diboride (MgB_2) thin films for ground receiver detectors [5]* - 5 to 20 nm thick MgB_2 films with critical temperature Tc > 35 K and critical current density Jc > 5 MA / cm^2 at 20 K The preferred substrates are SiC, Sapphire or MgO. The substrate size should be at least 4 in^2. There is also strong interest in MgB_2 films deposited on buffered Si wafers. The MgB_2 films should be passivated with SiO_2 or Au.
- *Cryogenic read-out electronics for large format superconducting nanowire arrays [6]* - 64 to 1024 channel DC coupled amplifier arrays for mounting onto a 40K cryocooler stage with 50 to 110 Ohm input impedance, <0.5 dB noise figure, DC to >4 GHz bandwidth, >40 dB gain, <1 dB compression with -47 dBm input, < 5 ps additive jitter, and less than 20 mW per channel power dissipation; strongly desired is an integrated per-channel leading-edge detect discriminator with LVDS-compatible output signal levels. Also of great interest is development of an read-out integrated circuit for direct bump-bonding to superconducting nanowire arrays operating in the 1 to 3 K range, with <0.5 dB noise figure, DC to >4 GHz bandwidth, >20 dB gain, <1 dB compression with -47 dBm input, < 5 ps additive jitter, and less than 1 mW per channel power dissipation.
- *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.

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.

References:

- [1] - (http://ssed.gsfc.nasa.gov/IPM/PDF/1010.pdf).
- [2] - W. Farr, W, et al. “Overview and Design of the DOT Flight Laser Transceiver,” IPN Progress Report 42-185, (2011).
- [3] - CCSDS White Book, "High Photon Efficiency Optical Communications -- Coding & Modulation," March 2015.
- [4] - Birnbaum, K., et al., “DOT Ground Laser Receiver: Overview and Major Trades,” IPN Progress Report 42-182, (2010).
- [5] - Wolak, M. A. et al., IEEE Trans. Appl. Supercond. 25, 1-5 (2015).
- [6] - Dauler, E., et al., “Review of Superconducting Nanowire Single-Photon Detector System Design Options and Demonstrated Performance.” Opt. Eng 53 (2014).
- [7] - Biswas, A., et al., “Future Planetary Optical Access Links”, 2011 International Conference on Space Optical Systems and Applications.

H9.02 Advanced Space Communication Systems
Lead Center: GRC
Participating Center(s): GSFC, JPL

NASA's future systems require increased levels of adaptive, cognitive, and autonomous system technologies to improve mission communication capabilities 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. These goals are further described in the TA05 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems Roadmap, Sections 5.1, 5.2, 5.3 and 5.5.

Over the past 10 years software defined radio platforms and their applications have emerged and demonstrated the applicability of reconfigurable platforms and applications to space missions. This solicitation seeks advancements in cognitive and automation communication systems, networks, waveforms and components. 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 improve the communications capabilities and situation for the mission. Cognitive systems naturally lead to advanced multi-function RF platforms; platforms that serve more than one user or function and are reconfigurable, on-demand, either autonomously or by the user for arbitrary applications. NASA can leverage these systems, techniques, hardware, algorithms and waveforms for use in space applications to maximize science data return, enable substantial efficiencies, reduce operations costs, or adapt to unplanned scenarios. While much interest in cognitive radio in other domains focuses on dynamic spectrum access, this subtopic is primarily interested in much broader ways to apply cognition and automation. Areas of interest to develop and/or demonstrate are as follows:

- *System wide intelligence* – While much of the current research often describes negotiations and improvements between two radio nodes, the subtopic seeks solutions to understand system wide 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, and automated link planning and scheduling to optimize data throughput and reduce operations costs. Capabilities may include interference mitigation, maximizing data throughput and efficiency, and intelligent network routing (best route) and disruptive tolerant networking over cognitive links. The focus here is on a cognitive understanding of, and adaptation to, temporally or spatially non-contiguous communications paths.
- *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. STRS based 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.).
- *Flexible and adaptive hardware systems* - Signal processing platforms, wideband and multi-band adaptive front ends for RF (particularly at S-, X-, and Ka-bands) or optical communications, and other intelligent electronics that advance or enable flexible, cognitive, and intelligent operations. 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
- *Autonomous Ka-band and/or optical communications antenna pointing* - Future mission spacecraft in low Earth orbit may need to access both shared relay satellites in geosynchronous orbit (GEO) and direct to

ground stations via Ka-band (25.5-27.0 GHz) and/or optical (1550 nm) communications for high capacity data return. To maximize the use of this capacity, user spacecraft will need to point autonomously and communicate on a coordinated, non-interfering basis along with other spacecraft using these same space- and ground-based assets. Included here are electronically steered antennas, especially at Ka-Band. Applications include large, high-performance electronically-steered 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.

For all technologies, Phase I will emphasize research aspects for technical feasibility, clear and achievable benefits (e.g., 2x-5x increase in throughput, 25-50% reduction in bandwidth, 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 hardware or software product for NASA. Proposals should demonstrate and explain how and where cognitive and automation technologies could be applied to NASA space systems and be discussed in the proposal.

Phase I Deliverables - Feasibility study and concept of operations of the research topic, including simulations and measurements, proving 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). 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). Opportunities and plans should also be identified and summarized for potential commercialization or NASA infusion.

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/documents/detail/3315910).

H9.03 Flight Dynamics and Navigation Systems
Lead Center: GSFC
Participating Center(s): GRC, JPL

NASA is investing in the advancement of software algorithm/stools, systems, and devices to enhance and extend its capabilities for providing position, attitude, and velocity estimates of its spacecraft as well as improve navigation, guidance and control functions to these same spacecraft. Efforts must demonstrate significant risk or cost reduction, significant performance benefit, or enabling capability.

Proposals can support mission engineering activities at any stage of development from the concept-phase/pre-formulation through operations and disposal. Applications in low Earth orbit, lunar, and deep space are in scope for this sub-topic. Proposals that could lead to the replacement of the Goddard Trajectory Determination System (GTDS), or leverage state-of-the-art capabilities already developed by NASA such as the General Mission Analysis Tool (http://sourceforge.net/projects/gmat/), 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/) are especially 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.

In particular, this solicitation is primarily focused on NASA's needs in the following focused areas:

Guidance and Control

- Advanced optimal control methodologies for chemical and electric space flight guidance and control systems.
- Numerical methods and solvers for robust targeting, and non-linear, constrained optimization problems.

- Applications of advanced dynamical theories to space mission design and analysis, in the context of unstable orbital trajectories in the vicinity of small bodies and libration points.
- Advanced guidance and control techniques that support autonomous, on-board applications.

Navigation

- Applications of cutting-edge estimation techniques to spaceflight navigation problems.
- Applications of estimation techniques that have an expanded state vector (beyond position, velocity, and/or attitude components) or that employ data fusion.
- 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.
- Advanced time and frequency keeping and dissemination

Software

- Addition of novel guidance, navigation, and control improvements to existing NASA software that is either freely available via NASA Open Source Agreements, or that is licensed by the proposer.
- Interface improvements, tool modularization, APIs, workflow improvements, and cross platform interfaces for software that is either freely available via NASA Open Source Agreements, or that is licensed by the proposer that provide significant cost or performance benefits

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.

With the exception listed below for heritage software modifications, 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. For efforts that extend or improve existing NASA software tools, the TRL of the deliverable shall be consistent with the TRL of the heritage software. Note, for some existing software systems (see list above) this requires delivery at TRL 8. Final software, test plans, test results, and documentation shall be delivered to NASA.

Topic: H10 Ground 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 topic seeks innovative concepts and solutions for both addressing long-term ground processing and test complex operational challenges and driving down the cost of government and commercial access to space. Technology infusion and optimization of existing and future operational programs, while concurrently maintaining continued operations, are paramount for cost effectiveness, safety assurance, and supportability.

A key aspect of NASA's approach to long term sustainability and affordability is to make test, processing and launch infrastructure available to commercial and other government entities, thereby distributing the fixed cost burden among multiple users and reducing the cost of access to space for the United States.

Unlike previous work focusing on a single kind of launch vehicle such as the Saturn V rocket or the Space Shuttle, NASA is preparing common infrastructure to support several different kinds of spacecraft and rockets that are in development. Products and systems devised at a NASA center could be used at other launch sites on earth and eventually on other planets or moons.

H10.01 Improved Test and Launch Operations via Interface Design
Lead Center: KSC
Participating Center(s): SSC

This subtopic seeks to improve ground and surface processing in both the operational and test environments through improved interface design concepts. 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 an interface that connects it to the adjacent hardware which includes flight critical seals or connectors and other components. The impact of these interface-driven 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.

The interfaces between payloads, boosters and ground/surface support equipment have historically been drivers of numerous delays and unplanned work prior to launch. The developmental impact of interface design and requirements development includes extensive design labor and validation for any new integrated launch system. Finally, the historical trend of having unique interface types for different launch systems has hampered recent efforts to establish a multi-user capability for existing launch infrastructure.

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 flight hardware and drive down the cost of government and commercial access to space.

Standardization of interfaces used during testing or launch processing also provides eventual benefits to autonomous servicing, a key space technology for future missions. Future in-space and surface servicing of multiple spacecraft/user types such as satellites becomes more feasible if a common interface approach can be developed and widely adopted. Technologies sought for interface design are grouped in the following two focus areas:

Physical Interfaces

- Modular architectures of expandable surface systems that minimize the adverse impact of interface connections.
    - Interfaces suitable for modular, reliable, cryogenic propellant liquefaction architectures that enable incremental system approaches for increasing capacities as needed.
    - Dust-tolerant interface approaches that drive highly reliable and/or autonomous connections.
- Development of earth based analog test hardware to test and validate these surface system interface concepts (module equipment interfaces and/or surface to vehicle interfaces).
    - Connector technologies including ports, disconnects or couplers that enable standardization across the industry for the transfer of cryogenic and storable propellants or other servicing fluids, power, and/or data for Governmental and Commercial launch providers and/or future surface system analog testing.
    - Interface concepts that simplify or standardize future Interface Requirements Documents (IRDs) or enable increased use of off-the-shelf hardware for future flight and exploration support systems.
    - Solutions that promote standardization of key payload to launch vehicle and subsystem interface standards to reduce the cost associated with analysis, design, configure, integration, and preparation of space systems for launch and reusability through standard servicing interfaces.
    - Novel concepts for adaptation of common interface architectures from relevant industries and the analysis and development required to adapt them to space and exploration architectures. Adaptation should include providing the relevant certification planning required for acceptance by government and industry.

Software/Data Interfaces

- Concepts for embedded intelligence within interfaces that include software attributes to enhance the usage of interface data for tasks such as self-testing, diagnostics, configuration verification and/or management of the interface.

- Concepts for the use of industry standards and/or open source software to reduce or eliminate the need for dedicated interfaces by more efficiently managing system configurations. Software addressable interfaces conducting fault isolation and recovery, and decrease of software integration costs.
- Interface concepts that simplify or standardize future Interface Requirements Documents (IRDs) or enable increased use of off-the-shelf hardware for future flight and exploration support systems.

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 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.

H10.02 Advanced Propulsion Systems Ground Test Technology
Lead Center: SSC
Participating Center(s): KSC

Rocket propulsion development is enabled by rigorous ground testing in order 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.

In particular, technology needs includes producing large quantities of hot hydrogen, and develop 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.
- Improved capability for monitoring environmental conditions for ground and launch facilities supporting test and launch operations. Instrumentation should provide a remote sensing capability to measure atmospheric 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 multiple times an hour in both cloudy and clear environments.
- Improved capability for cryogenic leak and fire detection to support ground test or launch operations.
- Non-instrusive instrumentation for measuring rocket engine plume velocities including a volumetric assessment of plume extent, volume and turbulence.

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.

Topic: H11 Radiation Protection

The SBIR Topic area of Radiation Protection focuses on the development of 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. All space radiation environments in which humans may travel in the foreseeable future are considered, including geosynchronous orbit (GEO), Moon, Mars, and the Asteroids. Advances are needed in mitigation schema for the next generation of exploration vehicles and structures technologies to protect humans from the hazards of space radiation during NASA missions. As NASA continues to form plans for long duration exploration, it has become clear that the ability to mitigate the risks posed to crews by the space radiation environment is of central importance. Advanced computer codes are needed to model and predict the transport of radiation through materials and subsystems, as well as to predict the effects of radiation on the physiological performance, health, and well-being of humans in space radiation environments.

A number of codes and computational packages currently exist that can be used to assess the transport of the diverse particle and energy spectra of the space environment through shielding materials. However, using these transport codes on geometry represented by complex CAD models requires considerable human intervention. Computational tools that automate vehicle ray tracing for use with the NASA-developed HZETRN space radiation transport code are needed to enable vehicle dose mapping and a larger vehicle optimization capability. Tools that enable the use of Monte-Carlo transport codes with native CAD geometry could also make it possible to perform radiation analyses for space architectures using multiple transport codes. Research under this topic should be conducted to demonstrate technical feasibility during Phase I and show a path forward to Phase II software demonstration. Phase I deliverables are alpha-tested computer codes. Phase II deliverables are beta-tested computer codes.

H11.01 Radiation Shielding Technologies - Transport Codes
Lead Center: LaRC
Participating Center(s): 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 2016 solicitation, the special interest is in advanced space radiation transport codes. Mid-TRL (3 to 5) 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. A number of codes and computational packages currently exist that can be used to assess the transport of the diverse particle and energy spectra of the space environment through shielding materials. However, using these transport codes on geometry represented by complex CAD models requires considerable human intervention. Computational tools that automate vehicle ray tracing for use with the NASA-developed HZETRN space radiation transport code are needed to enable vehicle dose mapping and a larger vehicle optimization capability.
- Tools that enable the use of Monte-Carlo transport codes with native CAD geometry could also make it possible to perform radiation analyses for space architectures using multiple transport codes.
- Phase I deliverables are alpha-tested computer codes.
- Phase II deliverables are beta-tested computer codes.

For additional information, please see the following link: (http://www.nasa.gov/pdf/500436main_TA06-ID_rev6a_NRC_wTASR.pdf).

Topic: H12 Human Research and Health Maintenance

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 exploration 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 and Performance.
- Exploration Medical Capability.
- Space Human Factors and Habitability.
- Space Radiation.
- ISS Medical Projects.

Each HRP Element addresses a subset of the risks, with ISS Medical Projects responsible for the implementation of the research on various space and ground analog platforms. The HRP subtopics in this year's solicitation address risks from the Behavioral Health and Performance, Exploration Medical Capability, and Space Human Factors and Habitability Elements.

NASA is investing in technologies and techniques geared towards advancing the state of the art of spacecraft systems through the utilization of the ISS as a technology test bed. For technologies that could benefit from demonstration on ISS, proposals should be written to indicate the intent to utilize ISS. 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.

H12.01 Task Analysis Visualization and Data Management Tool
Lead Center: JSC
Participating Center(s): ARC

Task analysis (TA) is a method within the Human-Centered Design process that represents tasks as sequences or concurring steps and actions that are necessary to accomplish goals. It is used to understand and document the sequence of tasks, steps, and the relationship among these in order to indicate how the user or uses performing them. Furthermore, most major NASA programs, such as Orion, call for TA in the verification process. The output of the TA is a Master Task List (MTL) that feeds into design, models, and databases. Designers use the MTL to design systems, subsystems, and components to accommodate crew tasks. Operations personnel use the MTL for operations concepts and crew procedures development. This solicitation invites proposals intending to develop methods and technologies to manage and visualize TA information.

Although recognized as a critical function in design, task analysis is often erroneously overlooked until final design phases when hardware, system, and software designs are too costly to change. It is essential that task analysis be conducted as early in the design process as possible. Task analysis should be conducted iteratively and should be frequently evaluated throughout the design and development process to allow for proper verification of crew task and system design. Furthermore, task analysis should be performed to identify the “critical” tasks, i.e., those tasks that are necessary to successfully accomplish operations and mission objectives. Function allocation is also an important part of task analysis: deciding whether a particular function will be accomplished by the human or the system, or by some combination of humans and systems.

Task analyses for long-duration missions will result in a complex structure of tasks and sub-tasks. Master task lists can contain thousands of tasks that have complex temporal and sequential relations among them that need to be visualized. In order to use the results of a complex task analysis efficiently, there is a need for a robust visualization tool that helps with overviewing, sorting, and interpreting the results. Available commercial tools are not able to deal with the complexity of long-duration mission task analysis data due to the following limitations: cannot easily show simultaneous tasks and tasks performed by multiple operators, difficult to track changes, difficult to search for tasks, few/no summary options, and few/no file export options.

The tool should improve task design and system design by relating tasks and sequences of tasks in an efficient way, making the data more usable and ultimately improving overall design.

Phase I Deliverables - Conceptual prototype of a task analysis data management and visualization tool and final report detailing the conceptual prototype and software development plan including feature and display requirements.

Phase II Deliverables - Completed, usability-tested software tool along with the source code, user's guide, and final report on the development and testing of the tool.

H12.02 Passive Vital Sign Monitoring
Lead Center: ARC
Participating Center(s): JSC

Human exploration missions beyond low earth orbit (LEO) require physiologic monitoring of the crew. These highly mass, volume, and power constrained missions require significant leveraging of resources by all vehicle subsystems. To date, research and development resources involving physiologic monitoring have been allocated to crew worn devices to measure these physiologic parameters. NASA recognizes that there are numerous worn devices that provide monitoring, but all of these devices still require mass, volume, power, and crew time to operate. The exploration vehicle, however, will already provide a variety of technologies that could potentially be used to extrapolate human physiologic data in a more passive and continuous manner that does not require additional mass, volume, power, and crew time to operate. Examples of technology embedded within the vehicle include, but are not limited to, high quality video and audio, wireless networks, radio frequency identification, and other electromagnetic (EM) sources/detectors.

NASA requires new technologies that will exploit vehicle infrastructure to passively and continuously monitor the crew's physiologic parameters. NASA is amenable to improving existing vehicle technologies to extract crew data, but also for incorporating novel and innovative technologies that could be added to the vehicle or the crew. Examples of technology developments can include, but are not limited to, heart and respiration rate detection via HD video, temperature detection via infrared camera, or circadian rhythm phase detection via automated urine analysis. Some of the parameters that would be desirable for monitoring include:

- Heart Rate.
- Oxygen Saturation Level.
- Respiration Rate.
- Blood Pressure (diastolic/systolic).
- Core and/or Skin Temperature.
- Urinary 6-sulfatoxymelatonin.

A list of anticipated medical conditions that would require monitoring can be found on the Exploration Medical Condition list (EMCL), which may be found on NASA's Human Research Wiki: (https://humanresearchwiki.jsc.nasa.gov/index.php?title=ExMC).

Phase I Deliverables - Conceptual prototype of a monitoring device/algorithm and final report detailing the conceptual prototype and hardware/software development plans.

Phase II Deliverables - Completed monitoring device/algorithm, and final report on the development, testing, and validation of the tool.

H12.03 Novel Imaging Technologies for Space Medicine
Lead Center: GRC
Participating Center(s): JSC

NASA is seeking novel medical imaging techniques in two areas: software-based ultrasound and portable x-ray.

Software-Based Ultrasound

Ultrasound has been, and will continue to be for the foreseeable future, NASA's workhorse modality for internal imaging in space. Ultrasound's smaller footprint, lower power consumption and lower emissions across the electromagnetic spectrum make it particularly well-suited for space medicine. Ultrasound also provides additional medically useful capabilities outside the realm of imaging, such as quantitative ultrasound diagnostic techniques, and therapeutic techniques that utilize the energy in the ultrasound signal itself. NASA's commitment to ultrasound has led to the development of the Flexible Ultrasound System (FUS), which is a software-based, state of the art clinical scanner specially adapted to support the development of novel research in ultrasound. The FUS may be thought of as an "ultrasound development platform". It features software-based beam forming, scanning and receiving on up to 192 channels, dual-probe operation, high power support, and full access to the radio frequency (RF) data. Developers using the FUS may implement their algorithms and techniques in an Application Programming Interface (API) that supports both Matlab and C++.

The ground-based demonstration of the FUS will begin in April of 2016 and will potentially last for several years. NASA requires novel ultrasound-based diagnostic and therapeutic techniques for diagnosing and/or treating conditions on the Exploration Medical Condition List (EMCL), which can be found on NASA's Human Research Wiki at – (https://humanresearchwiki.jsc.nasa.gov/index.php?title=ExMC).

NASA is amenable to improving existing uses of ultrasound for both diagnostic and therapeutic purposes, but also for completely novel and innovative uses of ultrasound for diagnosis or treatment of any conditions on the EMCL. These novel techniques, which can include both hardware and software, should be developed with integration onto the FUS in mind, either by direct development on a system loaned to the developer by NASA or by porting the application from another system to the FUS at a later stage in the grant. Current examples of FUS integration include novel probe and algorithm development to quantify bone density and efforts to move/break up renal stones.

Portable X-Ray

Although ultrasound remains NASA's workhorse modality for internal imaging of body parts on spaceflight missions, there are gaps in ultrasound's ability to diagnose certain medical conditions that might arise during spaceflight, particularly to deep space destinations. Ultrasound is not as well suited to diagnosing dental conditions and certain musculoskeletal (MSK) injuries as traditional radiographic (x-ray) techniques. A set of limiting factors have precluded the use of x-ray devices on-orbit. These limitations include the relatively higher volumetric footprint, higher power requirements and higher electromagnetic (EM) emissions (particularly ionizing radiation, both in terms of dosage delivered to the crew and stray emissions) of x-ray devices and other imaging devices.

NASA needs new technology developments to overcome these limitations and ensure the diagnosis of dental and MSK conditions are more compatible with human spaceflight. NASA is amenable to improvements in existing x-ray devices and/or other novel and innovative imaging technologies. Example technology developments include, but are not limited to, those leading to more efficient x-ray sources, more sensitive detector technologies, improving image quality, reducing delivered EM dosage, and expanding the usefulness of handheld portable x-ray devices and other imaging devices to address dental and MSK conditions. A complete list of dental and MSK conditions can be found on the Exploration Medical Condition list (EMCL), which may be found on NASA's Human Research Wiki - (https://humanresearchwiki.jsc.nasa.gov/index.php?title=ExMC).

Proposals should address one of the two aforementioned technology areas.

The expected deliverables for Phase I for the software-based ultrasound are:

- Conceptual prototype of a novel device/algorithm.
- Final report detailing the conceptual prototype and hardware/software development plans.

The expected deliverables for Phase II are:

- Completed FUS device/algorithm.
- Integrated testing on FUS platform.
- Final report on the development, testing, and validation of the tool.

The expected deliverables for Phase I for the portable x-ray are:

- Conceptual prototype of an imaging device.
- Final report detailing the conceptual prototype and hardware/software development plans.

The expected deliverables for Phase II are:

- Completed imaging device.
- Final report on the development and testing of the tool.

Topic: H13 Non-Destructive Evaluation (NDE)

Future manned space missions will require technologies that enable detection and monitoring of the space flight vehicles during deep space missions. Development of these systems will also benefit the safety of current missions such as the International Space Station and Aerospace as a whole. Technologies sought under this SBIR Topic can be defined as advanced sensors, sensor systems, sensor techniques or software that enhance or expand NASA's Nondestructive Evaluation (NDE) and NDE modeling capabilities beyond the current State of the Art.

Sensors and Sensor systems sought under this topic can include but are not limited to techniques that include the development of 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. Advanced processing and displays are needed to reduce the complexity of operations for astronaut crews who need to make important assessments quickly. Examples of structural components that will require sensor and sensor systems are multi-wall pressure vessels, batteries, thermal tile, thermal blankets, micrometeoroid shielding, International Space Station (ISS) Radiators or aerospace structural components.

Technologies sought under the modeling SBIR 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. Simulation 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. Techniques sought include advanced material-energy interaction simulation in 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. NDE/SHM techniques for simulation can include ultrasonic, laser, micro-wave, terahertz, eddy current, infra-red, backscatter X-Ray, X-ray computed tomography and fiber optic.

H13.01 NDE Simulation and Analysis
Lead Center: LaRC
Participating Center(s): ARC, JSC

Technologies sought under this SBIR 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. Simulation 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.

Techniques sought include advanced material-energy interaction simulation in 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. 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 all systems will have high resolution high volume data. Modeling efforts should be physics based and account for changes in energy interaction due to material aging 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.

H13.02 NDE Sensors
Lead Center: LaRC
Participating Center(s): ARC, GRC, JSC, KSC

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 measureable 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.

Topic: H14 International Space Station (ISS) Demonstration & Development of Improved Exploration Technologies and Increased ISS Utilization

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 as a test bed for development of improved space exploration technologies; 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.
- Conducting technology development and demonstrations to reduce cost and prove required capabilities for future human exploration.
- Developing exploration precursor robotic missions to multiple destinations to cost-effectively scout human exploration targets.
- Developing communication and navigation technologies.
- Enabling U.S. commercial spaceflight opportunities.

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.

NASA is investing in technologies and techniques geared towards advancing the state of the art of spacecraft systems through the utilization of the ISS as a technology test bed. For technologies that could benefit from demonstration on ISS, proposals should be written to indicate the intent to utilize ISS. 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.

H14.01 International Space Station (ISS) Utilization
Lead Center: JSC
Participating Center(s): ARC, GRC, JPL, KSC, 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 examples:

- Providing additional on-orbit analytical tools. Development of instruments for on-orbit analysis of plants, cells, small mammals and model organisms including Drosophila, C. elegans, and yeast. Instruments to support studies of bone and muscle loss, multi-generational species studies and cell and plant tissue are desired. Providing flight qualified hardware that is similar to commonly used tools in biological and material science laboratories could allow for an increased capacity of on-orbit analysis thereby reducing the number of samples which must be returned to Earth.
- Instruments that can be used as infrared 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.
- Innovative technologies and flight projects that can enable significant terrestrial applications from microgravity development or in-space manufacturing and lead to private sector and/or government agency product development within a number of discipline areas, including biotechnology, medical applications, material sciences, electronics, and pharmaceuticals. This includes modifications to existing flight instruments as well as the development of novel flight hardware for deployment on the ISS.

For the above, research should be conducted to demonstrate technical feasibility and prototype hardware development during Phase I and show a path toward Phase II hardware and software demonstration and delivering an engineering development unit or software package for NASA testing at the completion of the Phase II contract that could be turned into a proof-of-concept system which can be demonstrated in flight.

Phase I Deliverables - Written report detailing evidence of demonstrated prototype technology in the laboratory or in a relevant environment and stating the future path toward hardware and software demonstration on orbit. Bench or lab-level demonstrations are desirable. The technology concept at the end of Phase I should be at a TRL of 3-6.

Phase II Deliverables - Emphasis should be placed on developing and demonstrating hardware and/or software prototype that can be demonstrated on orbit (TRL 8), or in some cases under simulated flight conditions. The proposal shall outline a path showing how the technology could be developed into space-worthy systems. The contract should deliver an engineering development unit for functional and environmental testing at the completion of the Phase II contract. The technology at the end of Phase II should be at a TRL of 6-7.

9.1.3 SCIENCE

NASA leads the nation on a great journey of discovery, seeking new knowledge and understanding of our planet Earth, our Sun and solar system, and the universe out to its farthest reaches and back to its earliest moments of existence. NASA's Science Mission Directorate (SMD) and the nation's science community use space observatories to conduct scientific studies of the Earth from space, to visit and return samples from other bodies in the solar system, and to peer out into our Galaxy and beyond.

NASA's science program seeks answers to profound questions that touch us all:

- How are Earth's climate and the environment changing?
- How and why does the Sun vary and affect Earth and the rest of the solar system?
- How do planets and life originate?
- How does the universe work, and what are the origin and destiny of the universe?
- Are we alone?

For more information on SMD, visit - (http://science.nasa.gov/).

The following topics and subtopics seek to develop technology to enable science missions in support of these strategic objectives.

Topic: S1 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://solarsystem.nasa.gov/2013decadal/index.cfm).
- Earth Science – (http://science.nasa.gov/earth-science/decadal-surveys/).
- Heliophysics the 2009 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. The following subtopics are concomitant with these objectives and are organized by technology.

S1.01 Lidar Remote Sensing Technologies
Lead Center: LaRC
Participating Center(s): GSFC, JPL

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 2016 SBIR Program, NASA is soliciting the component and subsystem technologies described below.

- Compact and rugged single-frequency continuous-wave and pulsed lasers operating between 0.28-ìm and 2.05-ìm wavelengths suitable for lidar. Specific wavelengths are of interest to match absorption lines or atmospheric transmission: 0.28 to 0.32-ìm (ozone absorption), 0.45 to 0.49-ìm(transmission through ocean water), 0.532-ìm, 0.817 to 0.830-ìm (water lines), 1.0-ìm, 1.57-ìm (CO_2 line), 1.65-ìm (methane line), and 2.05-ìm (CO_2 line). For wavelengths associated with an absorption line, tunability on the order tens of nanometers is desired. 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 8-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-ìm to 2.05-ìm. Specific wavelengths of interest are listed above in the bullet above. 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-ìm wavelength, consisting of the detection device, complete Dewar/cooling systems, and associated amplifiers. General requirements are: large single-element active detection diameter (>200 micron), 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 at a fraction of the power, mass, and cost of the Mercury Laser Altimeter (i.e., less than 7.4kg, 17W, and 28x28x26cm). The technologies 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.
- Narrow linewidth and frequency stable laser transmitter at 780-nm wavelength for development of low-cost, compact, and eye-safe high spectral resolution lidar (HSRL) for ground-based profile measurements of aerosol and cloud intensive and extensive properties. Desired specifications include pulse energy of 5 to 20-mJ, pulse repetition rate of 1 to 10-kHz, wavelength near 780-nm coincident with rubidium vapor line, linewidth < 10-MHz, spectral purity > 99.9%, and wavelength tunabilty of at least 0.5-nm around central wavelength.

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

NASA employs active (radar) and passive (radiometer) 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) sounders to G-band (160 GHz) radars for measuring precipitation and clouds, for planetary landing, upper atmospheric monitoring, 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 these future radar and radiometer missions and applications. The areas of interest for this call are listed below.

Single Pole Double Throw Switch with the following specifications:

- Frequency: 183 GHz, 325 GHz, or 380 GHz.
- Bandwidth: > 15 GHz.
- Insertion Loss: < 2 dB.

- Isolation: > 15 dB.

Calibration of sub-mm wave radiometers is limited in large part to external sources due to the lack of suitable switches for internal calibration. This increases the mass and cost of these instruments. A SPDT switch at 180 or 340 GHz will significantly reduce the cost and complexity of radiometers at these frequencies.

NEW: GaN Schottky diode technology for ultra-high power local oscillator power sources

This includes the development of GaN epi-structures on Si or SiC substrates suitable for millimeter-wave operations (SOA electron mobility >1000 $cm^2/V \cdot s$ for 5E16 to 1E17 cm-3 epi doping levels, and discrete GaN Schottky diodes (power handling capabilities > 200 mW/diode).

Technology for compact Dual Frequency (Ka and W-band) quasi-optical radar front end

W-band (94 GHz +/- 50 MHz):

- Single Polarization Tx, Dual Polarization Rx using a quasioptical duplexer such as a faraday rotator.

Ka-band (35.5 GHz +/- 100 MHz):

- Dual Polarization Tx and Rx.
- Shared beam waist with W-band.
- Waveguide duplexer and OMT okay.

The Decadal Survey ACE mission calls for a dual-frequency (Ka/W-band) radar for observation of clouds and light precipitation from space. Recently a similar but more compact and low cost radar is considered for operation on the International Space Station (ISS). Compared to traditional ferrite material based radar Tx/Rx front-end, quasi-optical front-end offers significantly low loss and high power handling capability, which have direct impact on radar performance. A compact dual-frequency and dual-polarization quasi-optical radar front-end has not been developed and is in critical need for ISS, ACE and suborbital airborne radars.

Interconnection technologies to enable highly integrated, low loss distribution networks that integrate power splitters, couplers, filters, and/or isolators in a compact package

Technologies are sought that integrate X, Ku, and Ka-bands transmit/receive modules with antenna arrays and/or LO distribution networks for F- and/or G-band receiver arrays.

Dual-frequency (Ka/W-band), dual polarization compact quasi-optical front-end for cloud radars.

- Freq: 35.5 GHz ± 100MHz.
- 94 GHz ± 100MHz.
- Loss: < 0.5 dB.
- Polarization Isolation: > 30 dB.
- Polarization: V and H.

640 GHz Heterodyne Polarimeter with I, Q, U Channels

Current 640 GHz polarimetric radiometers are either unsuitably large for space in terms of Mass/Volume/Power, or are direct-detection instruments that lack the ability to reject ozone emission contamination by selectively filtering the signal in the IF stages. This technology would help enable polarimetric measurements to provide microphysical parameterization of ice clouds applicable to ACE.

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

NASA requires a low power, low mass, low volume, and low data rate RFI mitigating receiver back end that can be incorporated into existing and future radiometer designs. The system should be able to channelize up to 1 GHz with 16 sub bands and be able to identify RFI contamination using tools such as kurtosis.

Compact 10+ Watt W-band transceiver including:

- SSPA, LNA, Circulator, and receiver protection switches.
- Mixer and 2 GHz Band-Pass Filter.
- 10-Watt SSPA, <1 dB transmit loss, 7 dB Rx Noise Figure.
- Approximately 3.5” x 3.5” x 4” dimensions.

NEW: Compact, highly integrated technologies enabling Altimetry/Velocimetry for space qualified radars

- Frequency: C-band to K-band.
- 0.2% range and 1% velocity accuracies.
- Operating range 6000m to 0 m.
- Compact antenna development.
- Integrated digital backend.
- Highly integrated MMIC for radar systems/subsystems.
- < 3kg and 1U (10 x 10 x 3 cm^3) for electronics.

Deployable 1-D Parabolic Antenna

- At least 2 m x 2 m in dimensions.
- Operable up to Ka-band (35.5 GHz).

Deployable 1-D parabolic antenna technology at Ka-band will allow higher gain and better spatial resolution for future flight precipitation measurement missions.

Technology for low-power, rad-tolerant broad band spectrometer back ends for microwave radiometers

Includes - digitizers with 20 Gsps, 20 GHz bandwidth, 4 or more bit and simple interface to FPGA; ASIC implementations of polyphase spectrometer digital signal processing with ~1 watt/GHz. Current FPGA based spectrometers require ~10 W/GHz and are not flight qualifiable. High speed digitizers exist but have poorly designed output interfaces. Specifically designed ASICs could reduce this power by a factor of 10.

A compact, broadband (6-12 GHz or 10-30 GHz), low insertion loss isolator

- < 0.3 insertion loss.
- 20 dB input and output return loss.

The isolator should be compatible with either microstrip or CPW for ease of transition with the rest of the system.

Ka-band Power Amplifier for CubeSats

- F = 35.7 GHz +/- 200MHz.
- Volume: <1U (10 x10 x10 cm^3).
- Psat >32W.
- Gain > 35 dB.
- PAE > 20%.
- Pulsed, 12% duty cycle.
- Current state of the art amplifiers are limited to 7W at < 15% efficiencies.

Development of on-wafer high frequency probes above 300 GHz for cryogenic temperatures

Passive or active cooled space missions will benefit from early performance characterization and selection at operating temperatures. The conventional test on individual packaged components is expensive and time consuming.

Advanced Deployable Antennas for CubeSats

- F = 35.7 GHz +/- 200MHz capable of 1D scanning.
- F = 94.05 GHz ± 50MHz.
- Aperture size = 2 m.
- Gain > 48dB @36GHz.
- Sidelobe ratio > 20dB.
- Stowed volume: <2.5U (25 x 10 x 10 cm^3).
- Polarization: Linear.

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

NASA requires low insertion loss solutions to the challenges of developing stable radiometers and spectrometers operating above 100 GHz that employ LNA based receiver front ends. This includes noise diodes with ENR>10dBm and with better than ≤ 0.01 dB/°C thermal stability when integrated with a proper electrical circuit, Dicke switches with better than 30 dB isolation, phase modulators, and low loss isolators along with fully integrated state-of-art receiver systems operating at room and cryogenic temperatures.

NEW: Wideband Antenna Technologies for GPRs

- Conformal / planar.
- 0.1 - 3 GHz bandwidth.
- Separate tx/rx with high isolation (> 30 dB).

S1.03 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/).

Development of un-cooled or cooled infrared detectors (hybridized or designed to be hybridized to an appropriate read-out integrated circuit) with NE”T<20mK, QE>30% and dark currents <1.5x10-6 A/cm^2 in the 5-14 ¼m 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.

New or improved technologies leading to measurement of trace atmospheric species (e.g., CO, CH_4, N_2O) or broadband energy balance in the IR and far-IR from geostationary and low-Earth orbital platforms. Of particular interest are new direct, nanowire or heterodyne detector technologies made using high temperature superconducting films (YBCO, MgB_2) or engineered semiconductor materials, especially 2-Dimensional Electron Gas (2-DEG) and Quantum Wells (QW) that operate at temperatures achieved by standard 1 or 2 stage flight qualified cryocoolers and do not require cooling to liquid helium temperatures. 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.

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 >8bit ADC at >500MHz sampling rate that channelizes into 1000 readout tones each with >5kHz of bandwidth. This type of readout would be used for photometers and spectrometers for astrophysics focal planes, and earth or planetary remote sensing instruments.

Development of new or improved large-format focal plane array Readout Integrated Circuit (ROIC) architectures to provide advanced detection features for overcoming existing limitations for low background astronomical applications. The main limitations of existing source-follower unit cells include potential image persistence and interpixel capacitance induced crosstalk. These limitations have complicated the use of these ROICs in a number of past missions, and will likely be even more constraining as detector performance improves. An improvement of a factor of 2 or more over current state-of-the-art would be of interest. Ideally, this would be done without compromising any good characteristics, but even in the case of a modest degradation in some parameters (like noise), the new features may prove to be superior for some applications.

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 the '1-inch' die level but should be do-able at the 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.

S1.04 Detector Technologies for UV, X-Ray, Gamma-Ray and Cosmic-Ray Instruments
Lead Center: GSFC
Participating Center(s): JPL, MSFC

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

The proposed efforts must be directly linked to a requirement for a NASA mission. These include Explorers, Discovery, Cosmic Origins, Physics of the Cosmos, 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).
- Specific mission pages:
  - 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).
  - X-ray Astrophysics - (http://sites.nationalacademies.org/bpa/BPA_049810).

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, ATALAST 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 GEOCape, 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.
- 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.

S1.05 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 conversion surfaces for the conversion of Energetic Neutral Atoms (ENAs) to ions for increasing the sensitivity of low energy ENA instruments.
    - 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 the Art: The efficiency of present SOA conversion surfaces is 1-2%. This is quite low and results to low sensitivities. An efficiency increase to 10% will lead to increased sensitivity by a factor of x 5 to 10 and /or smaller instruments sizes / resources.
    - Importance: Very High – Critical need for next generation low energy ENA instruments.
- Very low energy threshold < 5eV particle detectors for direct neutral particle detection.
    - Science Traceability: Explorer missions, Decadal survey missions IMAP, MEDICI, DYNAMICS, DRIVE Initiative, DISCOVERY and CubeSat/Smallsat missions.
    - Need Horizon: 1 to 3 years.
    - State of the Art: SOA solid state detectors have an energy threshold for particle detection of ~1keV. Although this problem can be overcome in charged particle detection with pre acceleration, it poses a severe limitation in direct neutral particle. New detectors with low energy threshold will enable a whole new class of instruments and improve existing instruments.
    - Importance: Very High – Critical need for next generation direct neutral instruments.
- UV filters that greatly attenuate UV Ly radiation but let particles freely pass through. Enabling technology for direct particle detection.
    - 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 the Art: Particle detectors are very sensitive to UV light. The commonly used technology for direct particle detection is very thin foil the attenuate UV light but at the same time pose an energy threshold / scatter particles. A possible micro porous type of detector that greatly attenuates UV but let particles pass through will greatly improve current instruments.
- Importance: Very High – Critical need for next generation particle instruments.

- 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.
- Strong, lightweight, thin, rigid, compactly stowed electric field booms possibly using composite materials that deploy sensors (including internal harness) to distances of 10 m or more
  - Explorer missions, DRIVE Initiative, CubeSat/Smallsat missions.
  - Need Horizon: 1 to 3 years, 3 to 5 years.
  - Particle detectors are very sensitive to UV light. The commonly used technology for direct particle detection is very thin foil the attenuate UV light but at the same time pose an energy threshold / scatter particles. A possible micro porous type of detector that greatly attenuates UV but let particles pass through will greatly improve current instruments.
  - Importance: Very High for future Cubesat and SmallSat stand alone and constellation missions.

S1.06 In-Situ Sensors and Sensor Systems for Lunar and Planetary Science
Lead Center: JPL
Participating Center(s): ARC, GRC, GSFC, JSC, MSFC

This subtopic solicits development of advanced instrument technologies and components suitable for deployment on 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 Councils, Vision and Voyages for Planetary Science in the Decade 2013-2022 (http://solarsystem.nasa.gov/2013decadal/). Technologies that support NASAs 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 technologies. Orbital sensors and technologies that can provide significant improvements over previous orbital 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.
- *Europa & Io* - 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) for candidate instruments on proposed missions such as Europa Clipper and Io Volcano.

- *Titan* - 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). 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, air sampling mechanisms for mass analyzers, and aerosol detectors are also solicited.
- *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. Also, 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.). Specifically, advancements geared towards instruments that enable elemental or mineralogy analysis (such as high-sensitivity X-ray and UV-fluorescence spectrometers, UV/fluorescence flash lamp/camera systems, scanning electron microscopy with chemical analysis capability, time-of-flight 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.
- *Saturn, Uranus and Neptune* - Technologies are sought for 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* - This solicitation seeks 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 UV-fluorescence spectrometers, UV/fluorescence flash lamp/camera systems, scanning electron microscopy with chemical analysis capability, time-of-flight 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 are sought. 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.

S1.07 Airborne Measurement Systems
Lead Center: GSFC
Participating Center(s): ARC, GRC, JPL, KSC, LaRC, MSFC, SSC

Measurement system miniaturization and/or increased performance is needed to support for NASA's airborne science missions, particularly those utilizing the Global Hawk, SIERRA-class, Dragon Eye or other unmanned aircraft. The subject airborne instruments are intended as calibration/validation systems for space-based measurements, or to provide local measurements not available from space-based instruments. Linkages to other subtopics such as S3.04 Unmanned Aircraft and Sounding Rocket Technologies are encouraged. Complete instrument systems are desired, including features such as remote/unattended operation and data acquisition, low power consumption, and minimum size and weight. Desired sensors include:

- High accuracy and precision atmospheric measurements of Nitrous Oxide, Ammonia, Sulfur Dioxide, Dimethyl Sulfide, Carbonyl Sulfide and Formaldehyde, with significant improvements over the current state-of-the-art, such as measurement speed, resolution, or system weight/volume.
- Preconcentration instruments for the measurement of the isotopic composition of atmospherically relevant trace gases (CO_2, CH_4, O_3, Ozone depleting substances and isotopomer, etc.) in are using optical, mass-spectrometric, and other types of detection. Proposals are invited for the development of versatile preconcentration instrumentation that initially can be used with a range of measurement instrumentation as well as for field and laboratory applications.
- Spectrally resolved absorption and extinction of atmospheric aerosols (0.1 to 10 micron).
- Multiphase Precipitation (0.1 mm to 20 mm with 5 % accuracy in three dimensions).
- Size distribution, phase, and asymmetry of atmospheric aerosols and cloud particles (0.1 micron to 200 micron with 10% accuracy).
- Three-dimensional wind measurement (1 mps accuracy/resolution at 10 Hz sampling).

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 PIXIE (Primordial Inflation Explorer). The topic areas are as follows:

Cryocooler Systems and Components

- *Miniaturized/Efficient Cryocooler Systems* - Cryocooler systems viable for application on SmallSat space platforms are sought. Present state of the art capabilities demonstrate approximately 0.4W of cooling capacity at 77K provided an input power of 5W. Contemporary system mass is on the order of 400 grams. Desired performance specifications for cryocoolers sought include a cooling capability on the order of 0.2W at temperatures spanning 30K - 80K. Desired masses and input powers will be < 400 grams and < 5W respectively. Component level improvements are also desirable.
- *Low Temperature/Input Power Cooling Systems* - Low temperature/Input Power Cooling systems are sought for application on future Planetary missions that require performance in space environments that have limited access to power. Contemporary cooling systems are incapable of providing cooling loads as high as 0.2W at 30K while rejecting heat to an ambient environment of approximately 150K. Cooling systems providing cooling capacities of approximately 0.3W at 35K with heat rejection capability to temperature sinks at 150 K or lower are of interest. Component level improvements are also desirable.
- *High Capacity/Efficiency Cryocooler Systems* - High Capacity/Efficiency cryocoolers are of interest for use on future science missions. State of the art high capacity cryocooler systems have demonstrated cooling capabilities spanning 0.3W - 1W with a load temperature of 20K and < 0.3 W at 10K. High Capacity cryocoolers are available at low to mid TRL levels for both Pulse Tube (e.g., 5W cooling capacity at 20K) and Turbo Brayton (e.g., cooling capacity of 20W at 20K) configurations. Desired cryocooler systems will provide cold tip operational temperatures spanning 10K to 20K with a cooling capacity of > 4W at 20K or more than 0.3 W at 10 K. Very low vibration systems with these capabilities are desirable. Component level improvements that increase overall efficiency are also desirable.

Sub-Kelvin Cooling Systems

- *Magnetic Cooling Systems* - State of the art sub-Kelvin temperature control architectures that use magnetic cooling consist of ADR (Adiabatic Demagnetization Refrigeration) systems. The Astro-H FM (Flight Model) ADR represents the state of the art in ADR system and component level technologies for space application. Future missions requiring cooling to sub-Kelvin levels will look to use new and improved ADR systems. AMRR (Active Magnetic Regenerative Refrigeration) systems are a related magnetic cooling technology that requires system and component level development in order to attain sub-Kelvin cooling levels. Improvements at the component level may lead to better overall system performance and increased hold times at target temperatures. Both of these are highly advantageous and desirable to future science missions. Specific components sought include:

- Low current superconducting magnets (3-4 Tesla at temperatures > 15K).
- Heat Switches (including optimization of current designs, such as low thermal conductivity heat switch shells)
- High cooling power density magnetocaloric materials, especially single crystals with volume > 20 cm^3.
- Active/Passive magnetic shielding (for use with 3-4 Tesla magnets).
- 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.

Topic: S2 Advanced Telescope Systems

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-degrees Kelvin. 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): GSFC, JPL

This subtopic solicits solutions 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.

Please note: an emphasis regarding mirror systems is the mirror substrate support structure. The Technical Challenges contains information on specific technologies which need developing for each area.

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.

This subtopic matures technologies needed to affordably manufacture, test or operate complete mirror systems or telescope assemblies. Traditionally, this subtopic matured technology from TRL3 to TRL4. Now, there is an additional opportunity to propose in Phase II for an effort larger than a traditional Phase II for the purpose of maturing demonstrated component level technologies (TRL4) to demonstrated system level technologies (TRL6) by using them to manufacture complete telescope systems. A requirement of this option is that there must be an identified NASA program that will fly the developed new technology system.

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.

Introduction

The 2010 National Academy Astro2010 Decadal Report specifically identified large light-weight mirrors as a key technology needed to enable potential Extreme Ultraviolet (EUV), Ultraviolet/Optical (UV/O) and Infrared (IR) to Far-IR missions.

The 2012 National Academy report “NASA Space Technology Roadmaps and Priorities” states that one of the top technical challenges in which NASA should invest over the next five years is developing a new generation of larger effective aperture, lower-cost astronomical telescopes that enable the discovery of habitable planets, facilitate advances in solar physics, and enable the study of faint structures around bright objects.
Finally, NASA is developing a heavy lift space launch system (SLS) with an 8 to 10 meter fairing and 40 to 50 mt capacity to SE-L2. SLS will enable extremely large space telescopes, such as 12 to 30 meter class segmented primary mirrors for UV/optical or infrared wavelengths.

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. Specifically needed for a potential UVO mission are normal incidence 4-meter (or larger) diameter mirrors with 5 nm RMS surface figure error; and, active or passive alignment and control of normal-incidence imaging systems to achieve 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 performance requirement requires ultra-stable mirror support structures. Finally, specifically needed for potential IR/Far-IR missions are normal incidence 8-meter (or larger) diameter mirrors with cryo-deformations < 100 nm rms.

In all cases, the most important metric for an advanced optical system (after performance) 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 $\$1M/m^2$.

Development is required to fabricate components and systems to achieve the following Metrics:

- Areal Cost < $\$500K/m^2$ (for UV/Optical).
- Areal Cost < $\$100K/m^2$ (for Infrared).
- Monolithic - 1 to 8 meters.
- Segmented > 4 meters (total aperture).
- Wavefront Figure < 5 nm RMS (for UV/Optical).
- Cryo-deformation < 100 nm RMS (for Infrared).
- Slope < 0.1 micro-radian (for EUV).
- Wavefront Stability < 10 pm/10 min (for Coronagraphy).
- Actuator Resolution < 1 nm rms (UV/Optical).

Finally, also needed is ability to fully characterize surface errors and predict optical performance.

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, Visible, and IR 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 for wide range of wavelengths from X-Ray to IR (X-Ray, EUV, Visible, and IR).
- Free-form Optics design, fabrication, and metrology for CubeSat, SmallSat and Visible Nulling Coronagraph (VNC).

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 to 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 visible nulling coronagraph.

In a nutshell, a successful proposal demonstrates a low-cost ability to address NASAs science mission needs and technical challenges specified under each category of Technical Challenges.

Introduction

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, Visible, and IR Telescopes

The optical coating technology is a mission-enabling feature that determines 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 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 each wavelength are desired as:

The Optical Coating Metrics

- 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 200 nm and depositable onto a < 2 meter mirror substrate.
    - UVOIR Metrics:
    - Broadband reflectivity > 60% and uniform polarization from 90 nm to 2500 nm and depositable onto 2, 4, and 6 meter mirror 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 ~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.

Topic: S3 Spacecraft and Platform Subsystems

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. 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.

Innovations for 2016 are sought in the areas of:

- Command and Data Handling, and Instrument Electronics
- Power Generation and Conversion
- Propulsion Systems for Robotic Science Missions
- Power Electronics and Management, and Energy Storage
- Unmanned Aircraft and Sounding Rocket Technologies
- Thermal Control Systems
- Guidance, Navigation and Control
- Terrestrial and Planetary Balloons

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 2009 - 2030" (http://sec.gsfc.nasa.gov/2009_Roadmap.pdf).
- The 2011 Planetary Science Decadal Survey was released March 2011. This decadal survey is considering technology needs - (http://www.nap.edu/catalog/13117/vision-and-voyages-for-planetary-science-in-the-decade-2013-2022).

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.

S3.02 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/multimedia/download-detail.cfm?DL_ID=742). Future spacecraft and constellations of spacecraft will have high-precision propulsion requirements, usually in volume- and power-limited envelopes.

This subtopic seeks innovations to meet SMD propulsion in chemical and electric propulsion systems related to sample return missions to Mars, small bodies (like asteroids, comets, and Near-Earth Objects), outer planet moons, and Venus. Additional electric propulsion technology innovations are also sought to enable low cost systems for Discovery class missions, and low-power, nuclear electric propulsion (NEP) missions. 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.

Advanced Electric Propulsion Components

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:

- High thrust-to-power ion thruster component or system technologies. Key characteristics include:
    - Power < 14 kW.
    - T/P > SOA Hall Effect Thrusters at comparable specific impulse ranging from 1500-3000 seconds.
    - Lifetimes > 10,000 hours.
    - Thruster components including, but not limited to, advanced cathodes, rf devices, advanced grids, lower-cost components.
    - 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.
    - Instrumentation and support equipment that will enable or improve ground testing of electric propulsion power processor units.

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 small satellite missions flown are often selected for concept or component demonstration activities as the primary objectives. Opportunities are anticipated to select future small satellite missions based on application goals (i.e., science return). However, several technology limitations prevent high value science from low-cost small 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,
- RF devices,
- Improved operational life over SOA propulsion systems, and
- 1U sized solar electric ionized gas propulsion unit with delta V of 1-8 km/s for 6U CubeSat, and a clear plan for demonstrated constellation station keeping capability for 6 months in LEO.

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

Note to Proposer - Topics under the Human Exploration and Operations Directorate also addresses advanced propulsion. Proposals more aligned with exploration mission requirements should be proposed in H2.

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

NASA's science vision (http://science.nasa.gov/media/medialibrary/2014/05/02/2014_Science_Plan-0501_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 (http://science.nasa.gov/media/medialibrary/2014/04/18/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, radiation tolerance, 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

NASA's 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 show 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 radiation hardened power electronics, especially tolerant of single event upsets, 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.

Also, in order to maximize functional capability for Earth Observations, operate higher performance instruments and deliver significantly better data and imagery from a small spacecraft, more capable power systems are needed. NASA is interested in a power system (stretch goal of 100w) that can be integrated into a cubesat or nanosat for this purpose. The power system package must be restricted to 6U or 3U volume, and the design should minimize orientation restrictions. The system should be capable of operating for a minimum of 6 months in LEO.

SMD's In-space Propulsion Technology, Radioisotope Power Systems and Cubesat/Nanosat programs are direct customers of this subtopic.

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
- Radiation hardened (single event effects), 1200 V (or greater) MOSFETs and high speed diodes for high voltage space missions (300 V average, 600 V peak).
- 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.
- Cubesat/nanosat power systems up to 100 watts

Patent 6,461,944, Methods for growth of relatively large step-free SiC crystal surfaces Neudeck, et al., October 8, 2002.

A method for growing arrays of large-area device-size films of step-free (i.e., atomically flat) SiC surfaces for semiconductor electronic device applications is disclosed. This method utilizes a lateral growth process that better overcomes the effect of extended defects in the seed crystal substrate that limited the obtainable step-free area achievable by prior art processes. The step-free SiC surface is particularly suited for the heteroepitaxial growth of 3C (cubic) SiC, AlN, and GaN films used for the fabrication of both surface-sensitive devices (i.e., surface channel field effect transistors such as HEMT's and MOSFET's) as well as high-electric field devices (pn diodes and other solid-state power switching devices) that are sensitive to extended crystal defects.

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.

S3.04 Unmanned Aircraft and Sounding Rocket Technologies
Lead Center: GSFC
Participating Center(s): AFRC, ARC, GRC, JPL, LaRC

Unmanned Aircraft Systems Technologies

Breakthrough technologies are sought that will enhance performance and utility of NASA's Airborne Science fleet with unmanned aircraft systems (UAS). Novel instrumented platforms or innovative subsystems suitable for addressing specific Earth science research goals are desired. Relevant NASA and FAA requirements must be addressed. Potential concepts include:

- Long endurance (~1 month) small UAS for miniature (~2 lb) instrument packages scalable to larger platforms.
- Fuel cell propulsion and high efficiency airframes for high altitude/long endurance (HALE, target ~50 kft, 2 days endurance with 50 lb payload).
- Harsh environment flight (e.g., for volcanic eruptions, fires) including high density altitude (20 kft asl), high turbulence, high temperature (300 to 500° C), significant icing, or corrosive environments.
- Novel flight management approaches such as dynamic soaring, autonomous mission planning, terrain following, or autonomously linking aircraft.
- Small UAS for in-situ cloud measurements.
- Guided dropsondes.
- Airspace monitoring system for small UAS operations.
- Over-the-horizon communications systems with increased bandwidth.

Sounding Rocket Technologies

The NASA Sounding Rockets Program provides low-cost, sub-orbital access to space in support of space and Earth sciences research. NASA utilizes a variety of vehicle systems comprised of surplus and commercially available rocket motors, capable of lofting scientific payloads of up to 1300lbs, to altitudes from 100km to 1500km. NASA launches sounding rocket vehicles worldwide, from both land-based and water-based ranges, based on the science needs to study phenomenon in specific locations. Of particular interest are systems that will enable water recovery of payloads from high altitude flights from locations such as launch ranges at Wallops Island VA or Andoya, Norway. New telemetry approaches are also encouraged. Specific elements may include:

- High speed decelerators.
- Steerable high altitude parachute systems.
- Water recovery aids such as floatation devices, location systems, and robotic capabilities.
- Ruggedized over-the-horizon telemetry systems with increased bandwidth.
- Constellation communication for sub-to-main payload data telemetry
- 10 to 50 MB/s for primary data, 1 to 2 MB/s for sub payloads, ~30 cubic inches (without antenna), with C or S band desired

S3.05 Guidance, Navigation and Control
Lead Center: GSFC
Participating Center(s): ARC, JPL

NASA seeks innovative, ground breaking, and high impact developments in spacecraft guidance, navigation, and control technologies in support of future science and exploration mission requirements. This subtopic covers the technologies enabling significant performance improvements over the state of the art in the areas of spacecraft attitude determination and control, spacecraft absolute and relative orbit and attitude navigation, pointing control, and SmallSat/CubeSat technologies.

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 all spacecraft platform sizes will be considered. Special considerations will be given to emerging technologies applicable to SmallSat/CubeSat class spacecraft if they are technology leaps and mission enabling.

Advances in the following areas are sought:

- *Spacecraft Attitude Determination and Control Systems* - Sensors and actuators that enable milli-arcsecond class pointing 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 technologies that can be used to enable other areas within this subtopic apply.
- *SmallSat/CubeSat Technologies* - Lightweight, low power, compact sensors and actuators that push the state-of-the-art for SmallSat/CubeSat attitude and orbit controls capabilities. Arcsecond-level pointing performance, non-propulsive orbit control, and radiation hardening technologies apply. NASA would like to utilize SmallSat/CubeSat technologies on missions beyond LEO therefore special considerations would be given to proposals addressing those needs.

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.

S3.06 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 three key areas:

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.

UV Protection Technologies

Innovative, economic, and applicable processes or materials to protect the balloon flight train subsystems and the balloon components are needed. Long duration balloon missions on the order of 100 days will expose the balloon flight train subsystems such as the parachute, and the balloon components such as the high strength tendons, to the harmful effects of UV exposure. The impact may lead to shorter duration missions and/or severe damage to the science payloads. Innovative concepts are need for the protection of these subsystems or components to eliminate or minimize these adverse UV effects. The proposed innovative concepts shall be economic and practical. It shall be easy to implement with no major impact on balloon design, fabrication, packaging, or launch operations.

Planetary Balloons

Innovations in materials, structures, and systems concepts have enabled the lifetime of Titan and Venus buoyant vehicles to play an expanding role in NASA's future Solar System Exploration Program. Balloons are expected to carry scientific payloads at Titan and Venus that will perform in-situ investigations of their atmospheres and near surface environments. Both Titan and Venus feature extreme environments that significantly impact the design of balloons for those two worlds and efficient use of energy is critical.

Proposals are sought in the following areas:

Floating Platforms for Venus (New)
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 vehicles at altitudes of between 30 and 45 km for periods in excess of five years. Concepts that use ammonia or water as a source of buoyancy as well as conventional light gases hydrogen and helium should be considered. A primary focus should be on the design of the flotation device and the materials for achieving long duration operation. The temperature at 45 km is roughly 110° C; at 30 km it is about 225° C. 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.

Altitude and Positional Control for Titan Aerial Vehicles (NEW)
NASA is interested in Titan aerial vehicles that can both change altitude and also execute controlled movements in latitude and longitude in order to target surface locations of interest. Innovative concepts are sought that can minimize the use of scarce power resources and can achieve controlled motions in latitude under all anticipated atmosphere conditions and in longitude for parts of the Titan year. The targeted capabilities for the system are as follows: altitude range between the surface and 15 km, system mass of payload, power and communications systems of 100 kg; average power usage for horizontal and vertical mobility of less than 50 watts. It is expected that a Phase I effort will consist of a complete system-level design and a proof-of-concept experiment on one or more key components.

S3.07 Thermal Control Systems
Lead Center: GSFC
Participating Center(s): ARC, GRC, 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:

- Components of advanced small spacecraft such as CubeSat/SmallSat will have very small masses (i.e., small thermal capacitance), and their temperatures are highly sensitive to variations in the component power output and spacecraft environmental temperature. Advanced thermal devices capable of maintaining components within their specified temperature ranges are needed. 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; d) thermal coatings with low absorptance, high emmittance, and good electrical conductivity; and e) a miniature pumped fluid loop system that is lightweight, provides radiator turndown, and consumes minimal power (< 2W).
- 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, especially for miniature thermal systems for CubeSat/SmallSat applications. 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.
- Missions with high sink temperatures require temperature lifting devices in order to dissipate the heat. Some advanced devices having long life, high efficiency are sought for, including absorption/adsorption systems, advanced TECs, etc. The use of heat lift devices can also reduce the radiator area, hence realizing mass and volume savings.

- Current analysis for ablation analysis of re-entry vehicles utilizes various computer codes for predicting the following individual phenomena: aeroheating, ablation, thermal response behind the bond line, thermal radiation, and structural response to thermal and pressure environments. The interfaces between each code lead to potential errors, inaccuracy, and huge computer run time. What is needed is a single code that evaluates the trajectory or input conditions, predicts aeroheating over the surface, does an integrated ablation-thermal analysis, and then uses that thermal and pressure gradient to do a full structural analysis. Even better would be a link back to the aeroheating prediction code to revise the aeroheating based on shape change from structural analysis and ablation.
- New techniques for measuring the internal pressure of arcjet test samples are sought. Modern ablation codes such as FEAR and CHAR solve the Darcy flow equations to track both the internal pyrolysis gas pressure and mass flow. However, there is currently no data available to validate the internal pressure calculations due to a lack of a reliable and accurate measurement system. The internal pressure calculation becomes even more important when analyzing flexible thermal protection system materials which are highly porous.

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.

S3.08 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 NASA’s 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.

S3.09 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 2016 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:

- *Spaceflight Multicore Middleware* - Current and emerging spaceflight processors are leveraging multi-core architectures to satisfy the ever increasing onboard processing demands. These architectures can provide increased processing bandwidth, power efficiency, and fault tolerance for onboard processing applications. However, these advantages come at the cost of increased hardware and software complexity. As software development is a major cost driver for missions, this increased complexity has the potential to significantly increase cost for future NASA missions. To address this risk, this subtopic solicits

Spaceflight Multicore Middleware technology providing machine management for multicore processing devices. This middleware software layer shall primarily reside between the application layer and the operating system, with extensions into and below the OS as necessary, to provide intelligent resource, fault, and power management. By providing these functions, application software can be largely agnostic to underlying hardware, thereby reducing cost and complexity. It is desired that the middleware software support multiple processor architectures. Examples include, but not limited to, ARM, Freescale, Tilera, and LEON, and those that support a number of cores ranging from 2-32.

- *Advanced Spaceflight Memory* - As spaceflight processor technology advances to provide increased bandwidth, power efficiency, and flexibility, advanced spaceflight memory devices are needed to fully leverage these improvements. This subtopic solicits technologies enabling power efficient, high performance volatile spaceflight memory incorporating high speed, fault tolerant, serial interfaces, internal EDAC, power and fault management, and 2.5/3D manufacturing processes enabling implementation of miniaturized, highly-reliable fault tolerant systems.
- *Point-of-Load Power Converters* - Emerging spaceflight processors require multiple supply voltages, and multiple switched services for many of these voltages. Using currently available point-of-load power converters, an unacceptably large portion of future spaceflight computer boards will need to be dedicated for these devices. To address this concern, this subtopic solicits technologies enabling miniaturized spaceflight point-of-load power conversion and switching.
- *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.

This subtopic also solicits technologies enabling the use of COTS micropower/ultra-low power computing devices in highly reliable spacecraft avionics systems.

Topic: S4 Robotic Exploration Technologies

NASA is pursuing technologies to enable robotic exploration of the Solar System including its planets, their moons, and small bodies. NASA has a development program that includes technologies for the atmospheric entry, descent, and landing, mobility systems, extreme environments technology, sample acquisition and preparation for in-situ experiments, and in-situ planetary science instruments. Robotic exploration missions that are planned include a Europa Jupiter System mission, Titan Saturn System mission, Venus In-Situ Explorer, sample return from Comet or Asteroid and lunar south polar basin and continued Mars exploration missions launching every 26 months including a network lander mission, an Astrobiology Field Laboratory, a Mars Sample Return mission and other rover missions. Numerous new technologies will be required to enable such ambitious missions. The solicitation for in-situ planetary instruments can be found in the in-situ instruments section of this solicitation. See URL: (http://solarsystem.nasa.gov/missions/index.cfm) for mission information. See URL: (http://mars.jpl.nasa.gov/programmissions/technology/) for additional information on Mars Exploration technologies.

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).

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.

NASA also seeks low-mass (on the order of the density of the fabric itself), fabric-and/or-fiber-embedded sensors and time-synchronized, distributed data collection systems (preferably less than 30 grams total) to measure the time history of load/stress/strain distributed across large (30+ meters), trailing-body deployable decelerator technologies such as parachutes and ballutes. The distributed sensors and data collection systems must be self-powered and capable of being pressure-packed into a compressed mortar canister installation package and stored for up to 1 year or more. All sensors and data collection packages in the distributed system are to record time-stamped peak sensor values and time histories, with time-stamp accuracies not to exceed 4 milliseconds relative to a central vehicle data collection system using IRIG and GPS technology for time-stamping and synchronization. Packages must survive the parachute deployment and inflation events and if data is stored locally on the individual devices, survive recovery from the ocean after many hours of immersion in seawater.

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.

S4.02 Robotic Mobility, Manipulation and Sampling
Lead Center: JPL
Participating Center(s): AFRC, ARC, GSFC, JSC

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 (both rocky and icy).

Mobility technologies are needed to enable access to steep and rough terrain for planetary bodies where gravity dominates, such as the Moon and Mars. 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 in micro-gravity environments 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.

Contamination control and planetary protection are important considerations for sample acquisition and handling technologies. Contamination may include Earth-source contaminants produced by the sampling tool, handling system, or deposited on the sampling location from another source on the rover or spacecraft. Cleaning to Sterility technologies are needed that will be compatible with spacecraft materials and processes. Surface cleaning validation methods are needed that can be used routinely to quantify trace amounts (~ng/cm^2) of organic contamination and submicron particle (~100nm size) contamination. Priority will be given to cleaning and sterilization methods that have potential for in-situ applications.

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 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.
- Cleaning to sterility technologies that will be compatible with spacecraft materials and processes.
- Surface cleaning validation technology to quantify trace amount (~ng/cm^2) of organic contamination and submicron particle (~100nm size) contamination.
- Sample handling technologies that minimize cross contamination and preserve mechanical integrity of samples.

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.

Topic: S5 Information Technologies

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 on 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.

As a result, solutions that involve the following must clearly explain how they would work in the NASA environment:

- Technologies involving elements operating outside of the NASA supercomputing firewall.
- Embarrassingly parallel computations.
- Technologies that require significant application re-engineering.

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.

Specific technology areas of interest:

- *Efficient Computing* - In spite of the rapidly increasing capability and efficiency of supercomputers, NASA's HEC facilities cannot purchase, power, and cool sufficient HEC resources to satisfy all user demands. This subtopic element seeks dramatically more efficient and effective supercomputing approaches in terms of their ability to supply increased HEC capability or capacity per dollar and/or per Watt for real NASA applications. Examples include: novel computational accelerators and architectures; cloud supercomputing with high performance interconnects (e.g., InfiniBand); enhanced visualization technologies; improved algorithms for key codes; power-aware "Green" computing technologies and techniques; and approaches to effectively manage and utilize many-core processors including algorithmic changes, compiler techniques and runtime systems.
- *User Productivity Environments* - The user interface to a supercomputer is typically a command line in a text window. This subtopic element seeks more intuitive, intelligent, user-customizable, and integrated interfaces to supercomputing resources, enabling users to more completely leverage the power of HEC to increase their productivity. Such an interface could enhance many essential supercomputing tasks: accessing and managing resources, training, getting services, developing and porting codes (e.g., debugging and performance analysis), running computations, managing files and data, analyzing and visualizing results, transmitting data, collaborating, etc.
- *Ultra-Scale Computing* - Over the next decade, the HEC community faces great challenges in enabling its users to effectively exploit next-generation supercomputers featuring massive concurrency to the tune of millions of cores. To overcome these challenges, this subtopic element seeks ultra-scale computing technologies that enable resiliency/fault-tolerance in extreme-scale (unreliable) systems both at job startup and during execution. Also of interest are system and software co-design methodologies, to achieve performance and efficiency synergies. Finally, tools are sought that facilitate verification and validation of ultra-scale applications and systems.

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

The NASA Applied Sciences Program (http://nasascience.nasa.gov/earth-science/applied-sciences) seeks innovative and unique approaches to increase the utilization and extend the benefit of Earth Science research data to better meet societal needs. One area of interest is new decision support tools and systems for a variety of ecological applications such as managing coastal environments, natural resources or responding to natural disasters.

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. Similar to Eclipse, this subtopic will create an open-source DST development framework that enables components from multiple providers to be seamlessly integrated. This subtopic will also create software components that plug into the framework and open source tools that help users create new components. The components will provide functionality ranging from basic operations, such as retrieval of data meeting user-specified criteria from online repositories and visualization, to sophisticated data processing and analysis algorithms, such as atmospheric correction, data fusion, computational model interfaces, and machine learning based quality control.

To expedite DST development and deployment by knowledgeable users, this subtopic seeks an open source graphical workflow tool, similar to Labview or Simulink, which enables well informed users to quickly create a functional DST from a catalog of software components. Ultimately, a more sophisticated graphical workflow development tool, similar to MIT's Scratch would enforce functionally, but not necessarily logically, "correct by construction" rules that would enable a broad population of people to successfully create DSTs. Open source and commercial components, as well as services, will be available through an online "store" similar to iTunes or Google Play.

The framework, components and resulting DSTs should be able to run in a commercial cloud such as Amazon EC2 or Google Compute Engine. Cloud enabled components and DSTs, those that can intelligently take advantage of flexible computing resources for processing, analysis, visualization, optimization, etc. are highly desired.

Ideally, users should be able to create, configure deploy DSTs, and view outputs such as status, reports, alerts, plots, maps, etc. via desktop computers (Windows 7 and OS X) as well as tablet and smart phones running recent versions of Android (4.0 and later) and iOS (5.0 and later). An HTML5 web application in a standards compliant browser, such as Chrome, can provide the required level of interoperability and capability. Due to serious security issues, Java and Flash based approaches will not be considered.

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:

- The MERRA2 reanalysis data set is approximately 400 TB.
- 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, and infrastructure to enable high performance analytics across large observational and model data sets. *Proposals should be in alignment with existing and/or future NASA science programs,* and the reuse of existing NASA assets is strongly encouraged.

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 and methods for high performance analytics that scale to extremely large data sets – of specific interest are the following:
    - Techniques for 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.).
- Methods to enable in-situ, data proximal, parallel data analytics that will accelerate the access, analysis, and distribution of large Science datasets.
    - Potential use of open source data analytic tools (such as Hadoop, MapReduce, Spark, etc.) to accelerate analytics.
    - 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.

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

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

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

Specific objectives are to:

- Improve the ability to predict FM system complexity and estimate development and operations costs.
- Enable cost-effective FM design architectures and operations.

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

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

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

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

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

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

9.1.5 Space Technology

The Space Technology Mission Directorate (STMD) enables a new class of missions by drawing on talent from the NASA workforce, academia, small businesses, and the broader space enterprise to deliver innovative solutions that dramatically improve technological capabilities for NASA and the Nation. The rapid development and infusion of new technologies and capabilities are critical components to advancing the Nation's future in space. These activities fuel an emerging aerospace economy and build upon the space technology needs of other government agencies, as well as the overall aerospace enterprise. NASA supports these objectives and contributes to the demands of larger national technology goals by investing in Space Technology.

Using a broad investment strategy, NASA's Space Technology investments address the identified range of technology areas found in NASA's Space Technology Roadmaps as prioritized by the National Academies. Under the direction of STMD, NASA funds the development of pioneering technologies that will increase the Nation's capability to perform space science, operate in space, and enable deep space exploration. Significant progress in technology areas such as in-space power systems, solar electric propulsion, radiation protection, next generation life-support, human robotic systems, cryogenic fluid handling, and entry, descent and landing capabilities, are essential for future science and human exploration missions. Developing these solutions will stimulate the growth of the Nation’s innovation economy by enabling new technology sectors in areas such as robotics, advanced manufacturing, and synthetic biology.

SBIR and STTR continue to support early-stage research and mid-TRL development performed by small businesses through competitively awarded contracts. These programs produce innovations for both Government and commercial applications. SBIR and STTR provide the high-technology small business sector with opportunities to develop technology for NASA, as well as commercialize those technologies to provide goods and services that address other national needs based on the products of NASA innovation.

Topic: Z1 Power & Energy Storage

The Advanced Space Power and Energy Storage Systems topic area will focus on technologies that generate power and/or store energy within the space environment. Functional areas, sub-topics, of interest include:

High Power/Voltage Electronics

NASA is seeking performance improvements to Power Management and Distribution (PMAD) systems through increases to the operating voltages and temperatures of these electrical components. Although many parts 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/high temperature components 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.

Z1.01 High Power/Voltage Electronics
Lead Center: GSFC
Participating Center(s): GRC, LaRC

NASA is seeking performance improvements to Power Management and Distribution (PMAD) systems through increases to the operating voltages and temperatures of these electrical components. Although many parts 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/high temperature components 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. Such performance improvements are necessary if NASA is to realize several operational concepts such as very high power Solar Electric Propulsion (SEP) that undergird their future mission architectures. For example, SEP is a key technology supporting NASA's deep space asteroid retrieval mission. This SEP mission requires total power on the order of 50 kW with a thruster power processing unit that steps up voltages to 700 V or more. These parameters are not truly negotiable and in turn dictate certain design choices for current and voltage regulation across the system. Given the space qualified electronic parts available today, system engineers are frequently required to make sub-optimal design choices. In a simplistic but specific realization, higher voltage parts allow power generation at higher voltages on the arrays themselves, this higher voltage allows for the same power to be transferred at lower current thereby reducing cable mass at the system level. At a more general level within the PMAD architecture, the use of presently available parts forces design choices that end in lower operating efficiency and increased heat generation within the electronic system, which in turn drive overall system mass.

The premise of this solicitation is that there have been recent improvements to semi-conductor devices at the material level, e.g., SiC and GaN, which have enabled higher efficiency, voltage and temperature regimes for parts and systems working terrestrially. However the first generation devices have proven unsatisfactory for use in space applications due to radiation-induced early failures after exposure to heavy-ion fluences of concern to most space missions. Further research and development effort must be accomplished to fully understand the failure mechanisms within devices made of these advanced materials and iterative design cycles must then be conducted to develop components that have the performance characteristics required for future NASA missions.

The types of components coming under this topic include:

- Semiconductor switches, e.g., the design of Wide Band Gap semiconductors such as switches and diodes using GaN or SiC, with minimum voltage and current ratings of 1200 V and 12 A.
- Switch driver diodes.
- High temperature capacitors.
- Interconnection wires for switchgears.
- Associated control electronics.

This solicitation topic seeks proposals that address each of the following points:

- Analysis and research into the failure modes related to heavy-ion radiation exposure, as well as high temperature operation of GaN and SiC devices.
- Design and development of “next-generation” components.

It is important to note that technologies of interest to NASA under this topic must not simply provide an incremental improvement as the solution but must have the potential to significantly improve upon device operating points, thermal range, heavy-ion single-event effect tolerance, and the mass and volume characteristics. Proposals submitted in response to this topic must state the initial component state of the art and justify the expected final performance metrics.

Target performance levels include:

- Radiation hardness:
    - 300 krad(Si) total ionizing dose tolerance, and
    - For vertical-field power devices: No heavy-ion induced permanent destructive effects upon irradiation 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 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).
- Thermal range: 150 °C or greater junction temperature.

Topic: Z2 Thermal Management

NASA is seeking unique solutions for mid-temperature thermal control technologies that will facilitate a low mass highly reliable thermal control system for an exploration vehicle. Future human spacecraft will require more sophisticated thermal control systems that can operate in severe environments ranging from full sun to deep space and can dissipate a wide range of heat loads. Planetary systems (both human and robotic) need to minimize mass and maximize performance to enable more science payloads, and face complications from dust and regolith in many locations, and from the Mars atmosphere. The systems must perform their function while using fewer of the limited spacecraft mass, volume and power resources while increasing the reliability of these components. Furthermore, as human missions require longer extravehicular activities, the need for a closed loop, mass efficient thermal control system is needed for the EVA Suit. NASA's Technology Roadmaps 6 and 14 cover many of the defined key performance parameters sought through this SBIR. The following technical areas seek to cover the gaps outlined through this solicitation:

- Variable Heat Rejection Technologies.
- Advanced-Closed Loop EVA Thermal Control.
- Highly Efficient, Low Pour Point Thermal Control Fluids.
- Advanced Heat Exchangers.

Z2.01 Active Thermal Control Systems for Space Exploration
Lead Center: JSC
Participating Center(s): GRC, GSFC, JPL, MSFC

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Variable Heat Rejection Technologies

As NASA moves beyond low earth orbit, exploration vehicles that must accommodate various mission scenarios find a need for variable heat rejection. A vehicle may need to operate in severe environments ranging from full sun to deep space while managing a wide range waste energy rejection including active and dormant phases. Heat rejection systems and/or radiators that can operate at low fractions of their design heat load in the cold environments that are required for deep space missions. Room temperature thermal control systems are sought that are sized for full sun yet are able to maintain set point control and operate stably at 25% of their design heat load in a deep space (0 K) environment. This variation in heat rejection is often described as a turn-down ratio. NASA Technology Roadmap Area 14 outlines a turn down goal of 6 to 1 by a thermal control system operating at the scale of kilowatts of waste energy removal. Solutions for variable heat rejection may include the use of novel thermal control fluids, advanced radiator technologies, and/or variable conductance.

Advanced-Closed Loop EVA Thermal Control

NASA has evolved space suit technology beyond the Extravehicular Mobility Unit (EMU) state of the art for exploration missions. However, the latest iteration of the portable life support system includes the use of a Suit Water Membrane Evaporator to facilitate the rejection of waste energy produced by the suit, which still vents water vapor like the EMU sublimators. Longer duration extra vehicular activities and systems that do not impact the environment of Mars are needed, including a closed loop, non-venting EVA thermal control system capable of working in the Martian atmosphere. The solicitation seeks novel approaches to close the thermal control system of the Suit so that minimal to no consumables are used for rejection of waste energy. Approaches may include, but are not limited to, novel radiative approaches, desiccant systems to reclaim evaporants, etc. Examples of such technologies and goals are outlined in NASA's Technology Roadmap Area 06.

Highly Efficient, Low Pour Point Thermal Control Fluids

Most if not all space vehicles have the need for a thermal control fluid that does not freeze at relatively low temperatures. These fluids with low pour points come with decreased thermal performance, causing an increase in system mass to the thermal control system. This scenario was apparent with JPL’s Mars Science Laboratory as well as the Orion Vehicle. Vehicles subjected to the environments of deep space through transit scenarios to the Moon and Mars especially need a highly efficient thermal control fluid with low pour point. Ideally, this new thermal control fluid would have a pour point near -110°C with thermal physical properties near water. Furthermore, for use in human systems, this thermal control fluid would have low toxicity, flammability, and vapor pressures for use in a habitable volume.

Advanced Heat Exchangers

Air/liquid, liquid/liquid, coldplates, and phase change material heat exchangers are at the core of any thermal control system for a vehicle. Advances in manufacturing may yield a considerable mass savings over the current state of the art heat exchangers. Furthermore, lightweight non-venting phase change heat exchangers are sought to ameliorate the environmental transients that would be seen in planetary (Martian or Lunar) orbit. Heat exchangers that have minimal structural mass and good thermal performance are sought. Furthermore, the use of phase change materials that have a transition temperature between 8°-12°C with heat of fusions above 200 kJ/kg are needed. The goal is a ratio exceeding 2/3 phase change material mass and 1/3 structural mass. Condensing heat exchangers (air/liquid heat exchangers) are deemed to be a critical component of a closed loop environmental control life support system. The need for highly reliable condensing heat exchangers that do not contaminate due to microbial growth and do not impact the water processing system of an ECLSS system due to coatings on the HX is of high need for future human systems. Finally, advances in the aforementioned heat exchangers are expected to utilize new materials and manufacturing techniques over conventional brazing processes used today. NASA's Technology Roadmap Area 14 details various points of interest for these heat exchangers.

Topic: Z3 Advanced Manufacturing

NASA is using several manufacturing processes supporting the Space Launch System to create structures with superior mechanical properties and increased reliability. Advancing the state of the art for advanced metallic materials and processes will continue to be a critical technology to build more efficient space vehicles with less expensive materials.

This topic seeks to develop new and innovative materials and manufacturing processes (both additive and subtractive) for lightweight and/or multifunctional metallic components and structures for NASA and related applications. Technologies that can enable joining of new or dissimilar materials, as well as significantly reduce costs, increase production rates, and improve weld quality should be considered.

Technologies should result in components with minimal or no machining; Technologies should provide novel techniques for producing high-strength components and joints that are highly free of defects. Emphasis on reduced structural mass, improves processing lead-time, and minimizes touch labor and final assembly steps, resulting in increased capability, reliability and reduced cost.

Z3.01 Advanced Metallic Materials and Processes Innovation
Lead Center: MSFC
Participating Center(s): JPL, LaRC

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This subtopic seeks innovative processes and development of metallic material systems. The emphasis is on solid state welding practices including but not limited to: ultrasonic, thermal, and friction stir welding; new concepts for built- up structure approaches for lightweight structural panel applications, advanced near-net shaping, additive manufacturing processes; advanced coating technologies for wear and environmental resistance; functionally-graded (gradient alloy) materials that exhibit superior performance exceeding that of the individual constituent alloys. Technologies should result in components with minimal or no machining.

Proposals are sought in the following areas:

- Joining new materials: technologies that enable welding on a wide range of alloys and a wide range of thicknesses, including high-strength, temperature-resistant materials (such as titanium alloys, Inconel/Nickel-Based alloys, steels, and copper), metal-matrix composites, and other materials previously considered unweldable.
- Joining of complex geometries: technologies that enable welding of complex curvature joints or other types of structure variations that increase manufacturing possibilities.

- Development and prototyping technologies for fabricating gradient alloy (functionally graded) or amorphous (bulk metallic glass) materials for solid state welding processes, near- net shape, and additive manufacturing processes.

Responses should identify key performance parameters and TRL advancement in terms of quantifiable benefits to address specific areas including but not limited to the following: reduced structural mass, increased structural efficiency, improved processing lead-time, minimized touch labor and final assembly steps, increased reliability and reduced cost. Scale-up and transition to aerospace hardware and products should also be addressed.

Topic: Z4 Lightweight Structures and Materials

The Lightweight Materials, Structures, and Advanced Manufacturing/Assembly SBIR topic area will focus on technologies that will enable mass reduction, improved performance, lower cost and scalability of the material and structural systems that will be critical to NASA's space exploration and science missions. As NASA strives to explore deeper into space than ever before, improvements in all of these areas will be critical. For example, mass reduction is an ever-present goal in the development of space-exploration systems. Reductions in structural mass can either enable additional payload to be launched to orbit or reduce the mass of the payload that must be returned to Earth or landed on another planetary surface. Application areas for the material, structural, and manufacturing/assembly technologies developed under this SBIR topic include launch and crew vehicles, in-space transportation elements, habitation and crew-transfer systems, surface systems, and other systems used for space exploration.

Since this topic area has a broad range of interest, subtopics are selected by the Space Technology Mission Directorate to enhance and/or fill gaps in the exploration technology development programs and to complement other mission directorate topic areas. Advances in composite, metallic, and ceramic material systems are of interest in this topic, as are advances in the associated manufacturing methods for these various material systems. Significant advances can be realized by improvements in material formulation through improvements in the capabilities to manufacture and assemble large-scale structural components. Therefore, subtopics of interest will include but will not be limited to nanomaterial and nanostructures development, advanced metallic materials and processes development, and large-scale polymer matrix composite structures, materials, and manufacturing technologies. Other sub-topic areas may be added as required to address specific agency needs.

The subtopic of interest for FY16 addresses joining techniques and designs for large segmented polymer matrix composite (PMC) structures. The intent of this specific focus is to address needs for large composite hardware applications for programs such as SLS as well as future composite structure applications for exploration such as habitat, transit vehicles and surface systems. Joining technologies (bonded or mechanical) to enable 5 – 9 m diameter composite structures will be of interest, as will new concepts for lightweight separation joints. The specific needs and metrics of this focus area is described in the subtopic description.

Research awarded under this topic should be conducted to demonstrate technical feasibility (proof of concept) during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a full-scale demonstration unit for functional and environmental testing at the completion of the Phase II contract.

References:

- (http://www.nasa.gov/directorates/spacetech/home/index.html).

Z4.01 Joining for Large-Scale Polymer Matrix Composite (PMC) Structures
Lead Center: MSFC
Participating Center(s): GSFC, LaRC

The subtopic area for Large-Scale Polymer Matrix Composite (PMC) Structures and Materials concentrates on developing lightweight structures, using advanced materials technologies and new manufacturing processes. The objective of the subtopic is to advance technology readiness levels of PMC materials and manufacturing for launch vehicles and in-space applications resulting in structures having affordable, reliable, and predictable performance. A key to better understanding predictable performance and faster qualification of components includes integrating the analytical tools between the materials and manufacturing process.

This subtopic will focus efforts on innovative low cost, light weight, high reliability composite joint concepts/techniques to enable the fabrication of complex geometry and/or large composite structures (5 to 9 meter) diameter by 10 meters long. The specific area of interest is focused on:

- Novel concepts for joining (mechanical or bonded) large and/or complex segmented PMC structures together are of interest. Useful concepts can consider metallic-to-composite and composite-to-composite material interfaces. Examples of joints of interest include, but are not limited to, longitudinal and circumferential joint configurations for launch vehicle structures. In addition, cylinder to cylinder, and cylinder to frustum/conical ("Y" shaped) designs are of interest.
- Innovative joint designs with integrated sensing for the purposes of assisting with qualification of the joint design and interrogation of the joint during use to assess its performance and capability are also of interest.
- For bonded structure, novel, reproducible, and scalable surface treatments, bonding methods and techniques for very large structure, and novel adhesives are of interest as well as techniques to verify bond quality and predict/validate strength. Useful concepts can consider metallic-to-composite and composite-to-composite bond interfaces.
- New concepts for lightweight separation joints, both longitudinal and circumferential designs.

Concepts must consider end-to-end process evaluation with considerations to modeling of the joint/joining process and to full-size scale-up factors which will limit autoclave and oven access for joint cures (if needed). Concepts that are amenable to in-situ and/or on-orbit implementation are also of interest. Research should be conducted to demonstrate novel approaches, technical feasibility, and basic performance characterization for large-scale PMC structures and joint concepts during Phase I, and show a path toward a Phase II design allowables and prototype demonstration. Emphasis should be on demonstrable manufacturing technology that can be scaled up for very large structures.

References:

- Kirsch, M. T., “Composite Crew Module: Primary Structure,” (http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20110020665.pdf).
- Tenney, D. R. et al., “NASA Composite Materials Development: Lessons Learned and Future Challenges,” (http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20090037429.pdf).

Topic: Z5 Robotics and Autonomous Systems

One of NASA’s strategic goals is to extend and sustain human activities across the solar system. With time delays and potentially sparse communications back to earth, astronauts will face the daunting task of operating and maintaining numerous systems that might unexpectedly break or may even be required to perform life-saving surgery without support from the earth based operators. The augmented reality (AR) technology holds the promise to reduce crew reliance of ground and paper procedure support in a deep-space human spaceflight missions.

NASA invests in the development of autonomous systems, advanced avionics, augmented reality and robotics technology capabilities for the purpose of enabling complex missions and technology demonstrations supporting the Science, Technology Mission Directorate (STMD). The software, avionics, and robotics elements requested within this topic are critical to enhancing human spaceflight system functionality. These elements increase autonomy and system reliability; reduce system vulnerability to extreme radiation and thermal environments; and support human exploration missions with robotic assistants, precursors and caretaker robots. As key and enabling technology areas, autonomous systems, avionics, augmented reality and robotics are applicable to broad areas of technology use, including heavy lift launch vehicle technologies, robotic precursor platforms, utilization of the International Space Station, and spacecraft technology demonstrations performed to enable complex or long duration space missions. All of these flight applications will require unique advances in autonomy, software, augmented reality, robotic technologies and avionics. The exploration of space requires the best of the nation's technical community to provide the technologies, engineering, and systems to enable human exploration beyond LEO, to visit Asteroids and the Moon, and to extend our reach to Mars.

Z5.01 Augmented Reality
Lead Center: JSC
Participating Center(s): JPL, KSC

One of NASA's strategic goals is to extend and sustain human activities across the solar system. With time delays and potentially sparse communications back to earth, astronauts will face the daunting task of operating and maintaining numerous systems that might unexpectedly break or may even be required to perform life-saving surgery without support from the earth based operators. The augmented reality (AR) technology holds the promise to reduce crew reliance of ground and paper procedure support in a deep-space human spaceflight missions.

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

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

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

Proposal are sought to address the following Technology Areas:

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

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

Topic: Z6 Wireless Technology

Wireless sensor networks can effectively support an array of sensors able to measure structural properties, the heat profile for thermal protection, impact detection for orbital debris and other functions requiring distributed sensors. Moreover, embeddable passive wireless sensors can greatly increase the capabilities of the sensing and telemetry portion of a spacecraft. This would be relevant to any of the ascent and landing systems needed for planetary exploration as part of the spacecraft or mission support systems. Of particular interest is the capability of adding sensors at a low cost - enabling better Integrated Health Management and Spacecraft Autonomy functions, which depend upon better sensing of spacecraft state and environment. If developed under STMD, the resulting technology has high potential for infusion into SMD and HEOMD Programs leading to more effective ascent vehicles, better spacecraft management, new entry, descent and landing systems and future planetary exploration systems.

Z6.01 Wireless Technology
Lead Center: ARC
Participating Center(s): GRC, JSC, MSFC, SSC

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While wireless sensors have been slowly improved, tested and deployed on earth, their extension to aerospace has not occurred. The technology itself does not limit such extension, but rather traditional methods using wired interconnects have proven adequate for most vehicles and missions. However, there are major advantages conferred by wireless technology for aerospace avionics that make adoption favorable.

Wireless technology

- Reduces the mass and volume of spacecraft by eliminating large heavy cable runs. This is particularly useful for small satellites, where internal volume is often highly constrained particularly for subsystem cables and connectors. This would enable smaller and lighter spacecraft.
- Can transfer data across pressure interfaces, into remote locations where it is difficult to run cables and onto movable structures where cables are at risk of failure.
- Provides less intrusive measurement and health monitoring capability by enabling sensors within fuel tanks and pipes and across pressure interfaces without breaching the structure.
- Supports late additions or mission enhancements by significantly limiting changes to vehicle structure and data paths.
- Functions despite structural failures that can break physical wires such as those caused by micrometeorite impacts or connector contamination, thereby creating heterogeneous redundancy for critical systems that improve reliability and safety.
- Supports dynamic reconfiguration of networks and components, enabling robust response to faults or changes in operating mode.

In time, wireless interconnects and interaction methods could largely supplant (or perhaps more importantly, complement) wired methods. Consider the adoption of mobile computing devices, which rely on purely wireless interfaces for communication, printing and even peripheral connection. Such advantages can apply to spacecraft, distributed sensor networks and even distributed instruments and planetary surface exploration systems.

Specifically, this subtopic solicits the following technologies:

- Low power, low mass, and small volume components, where sensor/actuator modules are less than 20 grams in mass and less than 1 cc in volume. Of particular interest are highly scalable systems for measurement and data acquisition where total subsystem mass would be under 1 Kg and would operate under 3 W of power.
- Components capable of surviving and operating in aerospace environments requiring tolerance to extreme temperatures, shock and vibration, and radiation effects that exist for satellites, launch vehicles, planetary and space habitats, deep space exploration systems and landing/re-entry systems.

- Techniques that decrease reliance upon batteries or eliminate the need for charging and battery replacement, including novel approaches for electromagnetic energy harvesting, generating and storage methods; including capacitive, hybrid and acoustic power harvesting technologies.
- Wireless technology, protocols, architectures and software systems that support redundant networks that can dynamically reconfigure to reestablish connectivity and function after temporary interruptions or component failures, including internal fault detection capability.

The major NASA and commercialization thrust for wireless technology would be its maturation for use in aviation and space. The end product of this SBIR subtopic is likely to be a series of demonstrations of capability of interest to NASA Programs for Phase III maturation. Significant commercial opportunities for these products are available in the existing aerospace market, particularly for aviation.

9.2 STTR

The STTR Program Solicitation topics correspond to strategic technology research areas of interest to NASA. The subtopics reflect NASA's current highest priority technology thrusts being worked through each of its ten Centers.

Topic: T1 Launch Propulsion Systems

Launch Propulsion Systems reflects a staged development of critical technologies that include both “pull” technologies that are driven by known short- or long-term agency mission milestones, as well as “push” technologies that generate new performance or mission capabilities over the next 20 to 25 years. While solid and liquid propulsion systems are reaching the theoretical limits of efficiency, they have known operational and cost challenges while continuing to meet critical national needs. Improvements in these launch propulsion systems and their ancillary systems will help maintain the nation’s historic leadership role in space launch capability. Newer technologies like air-breathing launch propulsion, unconventional, and other propulsion technologies and systems, while low in TRL, can radically transform the nation’s space operations and mission capabilities and can keep the nation’s aerospace industrial base on the leading edge of launch technologies.

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.

Topic: T2 In-Space Propulsion Technologies

Reserved for future Solicitations.

Topic: T3 Space Power and Energy Storage

Space Power and Energy Storage is divided into four technology areas: power generation, energy storage, power management and distribution, and cross cutting technologies. NASA has many unique needs for space power and energy storage technologies that require special technology solutions due to extreme environmental conditions. These missions would all benefit from advanced technologies that provide more robust power systems with lower mass.

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

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, transforming and disseminating naturally occurring and artificially induced energy from multiple environments into usable power is critical toward supporting future power generation systems. This subtopic addresses the potential for deriving power from the environment for; local or remote consumption, inundating structures or environments with energy, transmission, distribution, regulation, and storage of said energies. 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.

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 Self-Powered, Ultra-Miniature Devices
Lead Center: MSFC
Participating Center(s): GSFC, SSC

As the Human Exploration and Operations (HEOMD) Mission Directorate seeks technologies in support of NASA space operations related to human exploration in Space, development of technologies that address efficient energy usage and storage are considered to be of utmost importance. Development of a range of self-powered devices that maximize the safety and reliability of extended missions can only enhance human space flight capabilities in support of human and robotic exploration programs.

Suggested research appropriate for small colleges and universities, are development of Self-Powered Exploration Devices (SPED), and Miniature Ultra-power Storage Technologies (MUST). The SPED objective is to run a small self-powered mobile device around a small table-top, low-friction track using electrical energy generated by elements of the environment, with no stored power at the start. The energy source can be vibrational, acoustic, biological, chemical, thermal, solar, or any physical characteristic from the natural environment that can generate energy for storage or immediate use. The MUST objective is to run a small device continuously, from environmentally generated power, for an extended period of time, using a miniature capacitor, or battery, technology. A long running device is the objective.

These tasks are suitable for small academic institutions where probable long technology development time trajectories and low levels of focused technology development effort are ideally accommodating for students to mature to convergence with concurrently maturing respective technologies. The SPED and MUST technologies are designed to merge into a “Game Changing” Development (TRL 3-5) of Smart Dust Motes, partnering with a larger university already making advances in the field.

“Smart Dust Motes” are millimeter-scale self-contained micro-electromechanical devices (MEMS) that include sensors, computational ability, bi-directional wireless communications technology and a power supply. Size development as of about 2007, Hitachi, are tiny dust particle devices with dimensions of about 0.05 x 0.05 mm. This aggregate development, sensing/bi-directional wireless communication, hence “swarming”, is biomimetic. Potential future partnership possibilities are companies and institutions interested in low-bandwidth, low-power wireless mesh networks that transmit data using radio signals.

Finally, DARPA researchers pioneered the area of Dust Motes since the early ‘90s. Top research universities such as Berkeley, MIT, Stanford, etc., have also been active in this field, involving MEMS and the most recent advances in digital circuitry and wireless communication since inception of the idea. The challenges for Smart Dust are to create a package that includes all the elements needed to perform sensory measurements, while also being able to communicate back to a base station to process the data. The “Smart Dust Mote”, which could contain micro-fabricated sensors, optical receivers, passive and active optical transmitters, signal-processing and control circuitry, and power sources, in a MEMS device, is very highly advanced already, relative to someone just getting started. SPED/MUST research is ideal for smaller colleges and universities to gain experience in these areas. This positions them to participate in ultimate Dust Mote development ideal for a partnership arrangement.

Interested NASA directorates are, e.g., HEOMD, and STMD.

Topic: T4 Robotics, Tele-Robotics and Autonomous Systems

The topic for Robotics, Tele-Robotics and Autonomous Systems, consists of seven technology subareas: Sensing and Perception; Mobility; Manipulation; Human-Systems Integration; Autonomy; Autonomous Rendezvous and Docking (AR&D); and Robotics, Tele-Robotics and Autonomous Systems Engineering. Robotics, Tele-Robotics and Autonomous Systems supports NASA space missions with the development of new capabilities, and can extend the reach of human and robotic exploration through a combination of dexterous robotics, better human/robotic interfaces, improved mobility systems, and greater sensing and perception. The Robotics, Tele-Robotics and Autonomous Systems topics focuses on several key issues for the future of robotics and autonomy: enhancing or exceeding human performance in sensing, piloting, driving, manipulating, and rendezvous and docking; development of cooperative and safe human interfaces to form human-robot teams; and improvements in autonomy to make human crews independent from Earth and make robotic missions more capable.

T4.01 Dynamic Servoelastic (DSE) Network Control, Modeling and Optimization
Lead Center: AFRC
Participating Center(s): JPL, LaRC

This subtopic addresses advanced control-oriented techniques for dynamic servoelastic (DSE) terrestrial, planetary, and space environment flight systems using distributed network sensor and control systems. Methods include modeling, simulation, optimization and stabilization of DSE systems to actively and/or adaptively control structural dynamic geometry/topology, vibration, atmospheric and intraspace disturbances, static/dynamic loads, and other structural dynamic objectives for enhanced dynamic servoelastic performance and stability characteristics.

- DSE control for performance enhancements while minimizing dynamic interaction.
- Flexible aircraft and spacecraft stabilization and performance optimization.
- Modeling and system identification of distributed DSE dynamics.
- Sensor/actuator developments and modeling for distributed DSE control.
- Uncertainty modeling of complex DSE system behavior and interactions.
- Distributed networked sensing and control for vehicle shape, vibration, and load control.

This subtopic also addresses capabilities enabling design solutions for performance and environmental challenges of future air and space vehicles. Research in revolutionary aerospace configurations include lighter and more flexible materials, improved propulsion systems, and advanced concepts for high lift/performance and drag/energy reduction. This subtopic targets efficiency and environmental compatibilities requiring performance challenges and novel control-oriented techniques for aero-servoelastic considerations which are gaining prevalence in advanced aerospace flight vehicles, atmospheric and extra-terrestrial.

Technical elements for the Phase I proposals may also include:

- Mission/maneuver adaptivity with dissipative optimal energy-force distribution.
- Data-driven multi-objective DSE control with physics-based sensing.
- Robust sensing-control-communication networks for sensor-based distributed control.
- Compressive information-based sensing and information structures.
- Evolving systems as applied to self-assembling and robotic maneuvering.
- Scalable and evolvable information networks with layering architectures.
- Modular architectures for distributed autonomous aerospace systems.
- Multi-objective, multi-level control and estimation architectures.
- Distributed multi-vehicle dynamics analysis and visualization with complex simulations.
- Reduced order modeling capable of substructure coupling of nonlinear materials.

Development of distributed sensory-driven control-oriented DSE systems is solicited to enable future flight vehicle concepts and designs that manage structural dynamic uncertainty on a vehicle's overall performance. Proposals should assist in revolutionizing improvements in performance to empower a new generation of air and space vehicles to meet the challenges of terrestrial and commercial space concerns with novel concepts and technology developments in systems analysis, integration and evaluation. Higher performance measures include energy efficiency to reduce fuel burn and operability technologies that enable information network decompositions that have different characteristics in efficiency, robustness, and asymmetry of information and control with tradeoff between computation and communication.

Advanced mission applicability in Phase II should show the ability of aerospace GN&C systems to achieve mission objectives as a function of GN&C sensor performance, vehicle actuation/power/energy, and the ability to jointly design them as onboard-capable, real-time computing platforms with applicable environmental effects and robust guidance algorithms. Goals are to:

- Provide capabilities that would enable new projects/missions that are not currently feasible.
- Impact multiple missions in NASA space operations and science, earth science, and aeronautics.
- Be influential across aerospace and non-aerospace disciplines with dynamic interactions.

State of the Art

This subtopic will:

- Provide capabilities that would enable new projects and missions that are not currently feasible, using distributed sensing and controls for network processing.

- Impact multiple missions in NASA space operations and science, earth science, and aeronautics.
- Be influential across aerospace and non-aerospace disciplines with dynamic interactions.

Potential technical impacts are:

- Vehicle energy efficiency with passive/active dissipativity for control and dynamic stability with extreme power constraints.
- Weight minimization through dynamic servoelastic control.
- Mission adaptivity and robustness with real-time, consensus-coordinated control dealing with computation, communication, and dynamics.

New technologies proposed should have the potential to impact the following NASA missions:

- Data availability for science missions.
- Mission planning.
- Autonomous rendezvous/docking technology.
- Environmental monitoring for human habitation.

Apart from NASA missions, the aeronautics technology could be adapted for development and use in autonomous operation of wind/ocean energy and smart space power grid systems in dynamic environments. There are number of advantages to exploring this subtopic technology:

- Increase in autonomy and fuel efficiency of coordinated robotic vehicles and sub-components.
- Improved science, atmospheric, and reconnaissance data.
- Cost, risk and reliability of flight vehicles for a terrestrial, planetary, or space mission.
- Inter-networks with improved dynamic behavior.

Potential technical impacts are:

- Vehicle energy efficiency with passive/active dissipativity for control and dynamic stability with extreme power constraints.
- Weight minimization through dynamic servoelastic control.
- Mission adaptivity and robustness with real-time, consensus-coordinated control dealing with computation, communication, and dynamics.

T4.02 Regolith Resources Robotics - R³
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 due to radiation exposure limits (Asteroids, Mar's Moons & NEO's). Communications latencies of greater than 40 minutes at Asteroids mandate autonomous robotics applications. Proposals are sought which provide solutions for the following space resource related technology area:

Asteroid Resource Prospecting and Characterization

The first step towards using resources derived from small bodies in space, such as water, volatiles, metals and organic compounds is to visit the Near Earth Object (NEO) target body and prospect it with sample acquisition devices and subsequently do characterization of these samples. Proposals are sought for innovative resource prospecting mission concepts and associated technology demonstrations such as autonomous small marsupial free flier prospector spacecraft that can sample an asteroid, comet or Mars moon and transport the sample back to a locally orbiting spacecraft with an associated suite of characterization instruments for analysis.

Proposals are sought for innovative resource prospecting mission concepts, technology development, and demonstrations.

Technologies include sample acquisition methods and devices, regolith anchoring methods, autonomous conops, sub-surface access, excavation, specialized sensors, dust lofting mitigation, perception in dusty environments, mobility methods, surveying, remote sample characterization, geodetic mapping, replenishing and transferring robotic commodities such as propellants, electric power, data transfer, pneumatics and robust interfaces for commodity transfer.

Future prospecting missions include:

- Water/Ice on Mars, Mars moons or Earth's Moon.
- Micro-gravity Near Earth Object (NEO) operations to prospect/sample surface resources.
- Lava tubes/shadowed crater cold traps on planetary surfaces to characterize volatiles accumulation.

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).

Topic: T5 Communication and Navigation

Communications and Navigation Systems, consists of six technology subareas: optical communication and navigation; radio frequency communication; internetworking; position, navigation and timing; integrated technologies; and revolutionary concepts. Communication links are the lifelines to spacecraft, providing commanding, telemetry, and science data transfers as well as navigation support. Therefore, the Communications and Navigation Systems Technology Area supports all NASA space missions. Advancement in communication and navigation technology will allow future missions to implement new and more capable science instruments, greatly enhance human missions beyond Earth orbit, and enable entirely new mission concepts.

T5.01 Autonomous Ka-band Spacecraft Terminals
Lead Center: GRC
Participating Center(s): GSFC

This subtopic focuses on the ability of small spacecraft to autonomously connect and communicate with other approved spacecraft, relays, and ground terminals in a manner that ensures compliance with NASA communications and software defined radio standards, access protocols, and frequency spectrum constraints. Innovations are sought to increase the autonomy, flexibility and performance of Ka-band spacecraft terminals while reducing their cost, size, mass, power consumption and thermal and vibrational impact on user spacecraft. Advances in compact directional antennas, flexible software defined radios (SDR) or software transceivers (SDT), and autonomous communications terminal operations will enable small spacecraft to establish communications with existing and emerging NASA space relays and ground terminals, as well as other approved spacecraft within the network. Automation embedded into the user terminals will help ensure efficient use of all available Ka-band communications capacity and mitigate potential for interference.

Background

Future missions will need higher data rates, more opportunities to transmit and receive data, lower communications burden on the spacecraft, and flexibility and automation where practicable to reduce human intervention. To reduce life-cycle development cost and schedule, NASA missions are trending toward smaller spacecraft and clusters of spacecraft to accomplish mission objectives. Autonomous communications operations in Ka-band frequencies will enable higher data rates, better utilization of existing and emerging NASA and commercial infrastructure, increase instantaneous use of available relay and ground network capacity, mitigate potential for interference.

Programmatic Relevance

NASA's Space Communications and Navigation (SCaN) Program has been deploying Ka-band service capabilities into near Earth relays and near Earth and deep space ground terminal infrastructure to enable NASA missions to help reduce congestion in lower frequency bands. This migration also leverages significant commercial investments in Ka-band communications technologies over the past two decades. However, the lack of innovative, commercially sourced low-cost, autonomous user terminals has hindered mission movement into Ka-band with the exception of a few custom, one-of-a-kind, mission specific terminals. Compliance with SCaN's Space Network (SN) and Near Earth Network (NEN) User Guides and NASA Space Telecommunications Radio Systems (STRS) standards will enable new missions based on small spacecraft and clusters of spacecraft to operate with high performance and lower cost than one-of-a-kind solutions. Compact, agile Ka-band antennas will enable uplinks, crosslinks and downlinks with a wide range of space and ground assets. Enabling cost-effective operations especially for small spacecraft in NASA's Ka-band frequency spectrum allocations will help ease congestion in current bands (e.g., UHF/VHF, S-band, X-bands and unregulated spectrum), and enable higher data rates and a higher return on NASA and commercial investments in Ka-band geostationary relays and ground terminals.

Technology Advancement Goals

Proposed advancements are encouraged in, but are not limited to, any or several of the following capabilities. Autonomous integrated terminals: Agility across and compliance with NASA Ka-band space-space and space-ground frequency spectrum allocations autonomous pointing, tracking, and communications with known or discovered relay, ground and/or proximity assets; autonomous optimization of data throughput based on predicted or sensed link conditions; flexible use of antenna and transceiver gains to cover a range of operating conditions; minimal impact on user spacecraft; cost-effective implementation; clear path to space qualifiable implementation. SDTs: NASA STRS compliant implementation; NASA space and ground infrastructure compliant; variable and/or adaptive coded modulation and data rates; autonomous link margin optimization; compact, low-mass, power efficient. Ka-band Antennas: electronically steered, scanned or switched directional beams; potential for multiple simultaneous beams; isoflux beams for space-ground links; hemispherical or omni coverage for proximity and non-directional conditions; small size or compact deployable; low mass, low power consumption; low cost.

Research Institution (RI)/Small Business (SB) Collaboration Goals:

The goals of this collaborative effort are to:

- Select practical advancements from a range of autonomous operations technologies, SDT approaches, and innovative antenna concepts; and
- Refine, integrate and demonstrate the potential of those advancements in response to the unique needs and practical constraints of small spacecraft operating within NASA's Ka-band space and ground infrastructure.

Collaboration between the RI and SB should allow for rapid TRL advancement into practical autonomous communications terminals that are flexible and commercially realizable.

Topic: T6 Human Health, Life Support and Habitation Systems

Human Health, Life Support and Habitation Systems, includes technologies necessary for supporting human health and survival during space exploration missions and consists of five technology subareas: environmental control and life support systems and habitation systems; extravehicular activity systems; human health and performance; environmental monitoring, safety, and emergency response; and radiation. These missions can be short suborbital missions, extended microgravity missions, or missions to various destinations, and they experience what can generally be referred to as “extreme environments” including reduced gravity, high radiation and UV exposure, reduced pressures, and micrometeoroids and/or orbital debris.

T6.01 Space Suit Environmental Protection Garment Materials and Technologies
Lead Center: JSC

Pressure garments designed for long-duration exploration missions require new Environmental Protection Garments (EPGs) to address the environments and use conditions to which they will be subjected. The EPG on the Apollo A7LB spacesuit was required to only tolerate a few days of working in a dusty environment whereas the surface mission on Mars will last for up to 500 days with routine EVAs.

An EPG is a lay-up of materials that protect the inner layers (bladder and restraint) of the pressure garment. Environmental protection functions of the EPG include protection from: thermal extremes; secondary ejecta; cuts and punctures; abrasion and wear from dust; durability with respect to cycle fatigue and radiation exposure; and resistance to chemical corrosion. The layers of the EPG work together as a system to address all of these functions.

To date, very limited effort has been focused on developing the EPG. If new materials are required it is anticipated that a development effort of up to 10 years may be necessary to reach TRL 6, making EPG technology a schedule driver for exploration. Materials that are immediately applicable will be offered to the ISS space EMU subsystem manager for potential incorporation.

The challenges being addressed with this call include dust mitigation, cut and puncture resistance, and cycle life:

- *Dust Mitigation* - Dust mitigation can be addressed on one or both of two fronts: dust repellant (keep dust from penetrating) and dust resistance (dust doesn’t degrade performance). Protection from both lunar and Martian regolith and from the full range of particle sizes of the regolith is of interest. Materials that are resistant to the potentially corrosive chemical products resulting from Mars regolith combining with oxygen and/or water vapor. Unique methods of fabrication and of design to limit the intrusion of dust at breaks between sections of the EPG (such as between the lower arm and shoulder sections of the EPG) are included.
- *Cut and punctures* - Current ISS EMU materials have proven susceptible to cuts from sharp edges on hand rails. Exploration suits will be handling rocks, dirty tools, and other abrasive and rough surfaces.
- *Durability* - EPGs will see hundreds of thousands to millions of cycles as the joints of the space flex as crewmembers walk, grasp, and use tools. Materials need to be highly durable to withstand the cycles of joint flexion in the thermal, dust and radiation environments on planetary surfaces.

Additionally, the goal of the EPGs design is to improve performance on all fronts. When the ISS EMU glove design was changed to increase durability against sharp edges, its mobility was reduced. The EPG dust mitigation, for example, that protects the suit bladder from dust will also have minimal impact (less than 10%) on suit range of motion and torque.

This call seeks innovative materials and creative approaches for both individual layers of the EPG as well as full EPG lay-ups, as well as, EPG system level dust mitigation approaches.

Research done in Phase I of these efforts should focus on technical feasibility with an emphasis on hardware development that can be further expanded in a future Phase II award cycle. Phase II products must include a demonstration unit suitable for testing by NASA. Prototyping should be tailored to applications to ongoing HEO Mission Directorate missions and possible collaborative use in both the governmental and commercial manned spaceflight disciplines. Minimum deliverables at the end of Phase I are analysis and/or test reports, with priority given to functional hardware prototypes for further evaluation. Technical maturation plans should be submitted with Phase I submittals, as well as any expected commercial applications both internal and external to the manned spaceflight enterprise.

T6.02 Space Radiation Storms: Monitoring, Forecasting and Impact Analysis
Lead Center: GSFC

Radiation hazards constitute one of the most serious risks to future human and robotic missions beyond Low-Earth Orbit, and particularly to long-duration, long-distance space missions. The main contributors to space radiation are Galactic Cosmic Rays (GCRs) and Solar Particle Events (SPEs). The latter is the more unpredictable of the two and is associated with most energetic solar eruptions: flares and coronal mass ejections; at the same time, SPEs are capable of inducing acute and profound effects on humans and on spacecraft components. The goal of the current opportunity is to help address the challenges by focusing on investigations that can potentially lead to longer-range (2-3 days) forecasting of SPEs (or at least an improved all-clear SPE forecasting capability), as well as those which couple radiation environment models with engineering models of radiation effects so that single-event effects on specific hardware and instruments can be predicted.

State of the Art

Many questions regarding space radiation have yet to be answered, and numerous challenges remain, such as improving the forecasting capability of the dynamic radiation environment (particularly SPEs), coupling the radiation environment models with engineering models of radiation effects on specific instruments or spacecraft hardware, and achieving a quantitative measure of human or space assets' response to radiation storms.

What is the compelling need for this Subtopic?

Penetrating particle radiation from SPEs adversely affect aircraft avionics, communication and navigation, and potentially the health of airline crews and passengers on polar flights. SPEs also constitute major hazards for astronauts performing EVAs (Extra-Vehicular Activities) on board the International Space Station (ISS). Characterizing and predicting the dynamic variation of the radiation environment is a crucial capability, enabling personnel to take preventive measures to mitigate the potential risks, and facilitating adoption of the proper mitigation strategy. STMD/NASA/NARP/National: Identified as an NRC High Priority Technology Area.

T6.03 Sustainability in Space
Lead Center: JSC

Survival in remote locations such as another planet requires conservation, smart utilization and reuse of resources and resilience, especially in the event of a failed resupply ship. Closed loop living systems such as this are also important for Earth as world population grows and natural resources decrease. This STTR subtopic seeks to advance the state-of-the-art for spacecraft habitats by "closing the loop" on materials needed to sustain life and provide energy on exploration missions, while simultaneously reducing the environmental impact of aerospace processes. Air, water and waste all need to be regenerated with highly reliable systems to reduce or eliminate the need to launch more materials into space as missions become longer. Energy for life support and other systems can also be obtained from renewable energy sources or waste streams. Many current cleaning, manufacturing and testing processes for spacecraft also create an environmental burden that could be mitigated by new technologies. All these "green" technologies will improve sustainability in space and on Earth.

Technical innovation and unique approaches are solicited for the development of new technologies that will lower mission cost and environmental impact by conserving resources and closing the materials loop. This will enable self-sufficiency and thus longer space exploration missions. Also, technologies that conserve resources or reduce negative impact during spacecraft development are solicited to improve sustainability at NASA. Real world demonstration of the technologies should be emphasized, even in Phase I. Many areas of research are possible, but preference will be given to those that address gaps in the following areas and lead to early applications and dual use partnerships:

- *Waste Water Treatment and Reuse* - Reuse/recycling of waste water from gray and black water sources with minimal mass, power, volume and expendables is needed. A particular challenge is treatment of urine to prevent odor and fouling of systems without the use of hazardous chemicals. NASA would like to extract nearly 100% of the water from any brine that may be created by a primary processor. Easy regeneration of filter and resin elements is desirable to reduce expendables.
- *Waste Processing* – Technologies for stabilization, safening, recycling or creation of energy or useful products from feces or trash are sought. Proposed technologies must take into account relevant factors for space exploration such as resource scarcity, planetary protection and human factors.
- *Renewable Energy and use of Waste Heat* – Solar and other renewable energy technologies that apply to "closing the loop" in space and on Earth are sought. This could include high efficiency and regenerative fuel cell technologies and technologies that combine waste and water treatment with energy production. Also included are technologies that make use of waste heat from one process for another purpose.
- *Greener Ground Processing* – Many aerospace processes require chemicals that are not environmentally friendly or result in lots of waste. NASA seeks technologies that will significantly reduce environmental impacts for NASA as well as others who use similar processes. Technologies are sought that: reduce or eliminate solvent waste from precision cleaning and validation processes; improve particle removal efficiency when cleaning with supercritical fluids; combine multi step processes (such as metal cleaning and passivation) into one step with reduction of waste.

T6.04 Closed-Loop Living System for Deep-Space ECLSS with Immediate Applications for a Sustainable Planet
Lead Center: ARC

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 limited availability of resources. The parallel with earth planetary resources management is ideal as the world population grows and resources and infrastructure availability decreases. We expect that technologies developed for closed loop living systems will be immediately available and applicable to provide 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, 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 mostly based on the thermodynamics laws of the conservation of mass and energy. We expect to maximize the conservation so that only a minimal amount of resources needs to be taken on a deep space mission.

Innovations are sought to enable:

- Transfer of deep space exploration technologies to earth applications.
- Development of integrated self-sustainable systems.
- Development of the most effective processes to allow for closed loop living applications.
- Application to so-called "off-the-grid" habitation in remote areas where infrastructure is inexistent.

Potential deliverables may include a demo of ECLSS concept(s) with clear applications to earth, enhanced control techniques of multiple life support subsystems (e.g., environment, water recovery, power usage, etc.), or prototype hardware and/or software to enable sustainability.

Topic: T7 Human Exploration Destination Systems

Human Exploration Destination Systems, includes six technology subareas: in-situ resource utilization, sustainability and supportability, advanced human mobility systems, advanced habitat systems, missions operations and safety, and cross cutting technologies. The technologies included here are necessary for supporting human operations and scientific research during space exploration missions, both in transit and on surfaces. Technology areas in this topic should be considered enabling systems, rather than competing discrete technologies, all of which are required for mission success.

T7.01 Synthetic/Engineering Biology for NASA Applications
Lead Center: ARC

Synthetic Biology (SB) provides a unique opportunity to engineer organisms that reliably perform necessary functions for future exploration activities. NASA is interested in harnessing this emerging field to create technological advances that will benefit both future spaceflight and surface missions in a variety of enabling areas. Proposals must use a biologically-based approach, such as synthetic biology, to engineer novel biologically-based (or inspired) functions that significantly exceed current biological capabilities. Proposed projects should focus on using microorganisms in novel ways that enable ISRU, with a particular focus on resource acquisition and/or utilization or feedstock production to enable ISM. NASA's ISM program has the desire to be able to manufacture materials, parts and/or structures utilizing feedstock generated from renewable biology-based resources. Available in-situ resources may include crew and spacecraft by-products or resources found on planetary surfaces. Products of interest might include, but are not limited to, various metals, bioplastics, biocements, and other biomaterials. Applications that concurrently support more reliable and efficient life support systems during the acquisition and utilization of in-situ resources or the production of feedstock are highly desirable. Proposals should address how systems and technologies will reduce the required launch-mass and dependence on consumables, resupply, and energy and should identify how such technologies provide advantages over physico-chemical systems. 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. There is strong potential for the Phase I effort continuing to a Phase II STTR demonstration to compare ground to microgravity data (obtained via parabolic and/or ISS flight demonstration).

Topic: T8 Science Instruments, Observatories and Sensor Systems

Science Instruments, Observatories, and Sensor Systems addresses technologies that are primarily of interest for missions sponsored by NASA's Science Mission Directorate and are primarily relevant to space research in Earth science, heliophysics, planetary science, and astrophysics. This topic consists of three Level 2 technology subareas:

- Remote sensing instruments/sensors.
- Observatories.
- In-situ instruments/sensors.

T8.01 Technologies for Planetary Compositional Analysis and Mapping
Lead Center: JPL

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

Council's, 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 Obama's 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.

T8.03 Detection technologies for extant or extinct life for use on robotic missions
Lead Center: ARC

One of the biggest questions that NASA is chartered to address, is "Are we alone?" NASA desires to extend the search for existing or past life on non-terrestrial bodies. Leveraging work done on extreme environment ecologies and related fields, technologies are sought that can detect and/or quantify pre-biotic compounds (amino acids, polymers) or unique molecules (organic biomarkers including certain chiral compounds, polypeptides/proteins, lipids, nucleic acid polymers) that may be evidence of living processes. These sensors or instruments should eventually be compatible with small spacecraft, rovers, or small penetrator platforms.

Efforts within this initial STTR activity are to identify potential detection approaches and system architectures that demonstrate a pathway forward for inclusion on future robotic missions. A number of research institutions have capabilities in the supporting technologies that will be critical to detecting life, including research systems deployed in extreme environments, in addition to a large number of laboratory bench techniques that may be adapted to robotic platforms. The industrial partner will be crucial not only in commercializing the technology, but developing it and maturing it towards application on robotic missions. These robotic missions may employ in-situ measurements, or may also use remote sensing methods.

Topic: T9 Entry, Descent and Landing Systems

Entry, Descent, and Landing, consists of four sub-technology areas:

- Aeroassist and entry.
- Descent.
- Landing.
- Vehicle systems technology.

Entry, Descent and Landing (EDL) is a critical technology that enables many of NASA's landmark missions, including Earth reentry, Moon landings, and robotic landings on Mars. The EDL topic defines entry as the phase from arrival through hypersonic flight, with descent being defined as hypersonic flight to the terminal phase of landing, and landing being from terminal descent to the final touchdown. EDL technologies can involve all three of these mission phases, or just one or two of them.

T9.01 Navigation and Hazard Avoidance Sensor Technologies
Lead Center: LaRC
Participating Center(s): JSC

Missions to solar systems bodies must meet increasingly ambitious objectives requiring new or improved capabilities such as: "precision surface-relative navigation", "automatic rendezvous and capture", "well-controlled soft landing", "precision landing", and "hazard avoidance". Robotic missions to the Moon and Mars demand landing at pre-designated sites of high scientific value near hazardous terrain features, such as craters, slopes, and rocks. Missions aimed at paving the path for colonization of the Moon and human landing on Mars need to execute onboard hazard detection and precision maneuvering to ensure safe landing near previously deployed assets. Asteroid missions require precision rendezvous, identification of the landing or sampling site location, and navigation to the highly dynamic object that may be tumbling at a fast rate. NASA seeks sensor technologies enabling these missions to solar system bodies. The same sensor or sensor component technologies can also benefit space operations such as satellite servicing and optical communication.

Sensor and sensor component technologies are sought for providing measurement of vehicle relative proximity and velocity, bearings, and high resolution 3-dimensional images during the approach to the targeted body. Also of interest are sensors capable of measuring atmospheric winds and density for aiding navigation and guidance of landing vehicles in general and large hypersonic decelerators in particular. The proposals should target advanced sensor technologies for eventual space utilization. Phase I research should demonstrate the 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 an aircraft platform or rocket-power terrestrial test vehicles. The component and sensor system technologies being sought include but limited to the following list:

- Highly sensitive Flash lidar camera including 2-D detector array, associated readout integrated circuit (ROIC), and drive/control electronics. Operational wavelength range 1.06-1.54 micron, the camera shall be capable of providing image frames greater than 60k pixels at 20 Hz with better than 3 cm range precision.
- Very compact and rugged laser transmitter operating in the 1.0 µm – 1.6 µm wavelength range with an output pulse energy of 30 mJ to 60 mJ, pulse width of about 6 nsec, and repetition rate of 20 Hz to 50 Hz suitable for flash lidars. The proposed laser must show path in maturing for operation in space environment.
- Non-mechanical laser beam steering devices capable of 2-axis pointing over +/- 25 degrees angle.
- Novel lightweight transmit and receive optical systems for 3-D flash lidar, Doppler lidar, or laser altimeter with aperture size from 5 cm to 10 cm suitable for operation in space environment.
- Space-qualifiable compact and rugged single-frequency CW laser systems operating at 1.55 micron wavelength region. Proposed lasers must be able to generate at least 5 W of power with less than 5 KHz linewidth over a tunable range of about 50 nm. Systems must be highly wavelength stable and come with full supporting electronic systems for thermal and power control. The lasers must be developed with space environment considerations and demonstrate a clear path to space.

Topic: T10 Nanotechnology

Reserved for future Solicitations.

Topic: T11 Modeling, Simulation, Information Technology and Processing

Modeling, Simulation, Information Technology and Processing consists of four technology subareas, including computing, modeling, simulation, and information processing. NASA’s ability to make engineering breakthroughs and scientific discoveries is limited not only by human, robotic, and remotely sensed observation, but also by the ability to transport data and transform the data into scientific and engineering knowledge through sophisticated needs. With data volumes exponentially increasing into the petabyte and exabyte ranges, modeling, simulation, and information technology and processing requirements demand advanced supercomputing capabilities.

T11.01 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, Tele-Robotics, and Autonomous Systems" roadmap (TA04) indicates that extensive and pervasive use of robots can significantly enhance 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 proximity ops. 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 appropriate for quad-copters, Astrobee/SPHERES free-flying robots, and Spirit/Opportunity scale rovers are particularly encouraged.
- Robot software systems that support adaptive autonomy, automated instrument/sensor targeting, payload data triage, and 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.

Deliverables to NASA:

- Identify scenarios and use cases.
- Define specifications based on design trades.
- Develop concepts to address use cases.
- Build, test, and demonstrate prototype sub-systems or systems.
- Deliver prototypes to NASA.

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

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.

Topic: T12 Materials, Structures, Mechanical Systems and Manufacturing

Materials, Structures, Mechanical Systems, and Manufacturing This topic is extremely broad, covering five technology areas: materials, structures, mechanical systems, manufacturing, and cross-cutting technologies. The topic consists of enabling core disciplines and encompasses fundamental new capabilities that directly impact the increasingly stringent demands of NASA science and exploration missions.

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.

T12.02 Technologies to Enable Novel Composite Repair Methods
Lead Center: KSC
Participating Center(s): JSC

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 Increasing Predictability of Softgoods Material Behavior for Inflatable Space Structures
Lead Center: LaRC
Participating Center(s): JSC

This subtopic is seeking innovative design and fabrication methodologies that increase the predictability and repeatability of the mechanical behavior of softgoods material architectures, including broadcloth, webbing and cordage that are used in expandable space habitats. To date, high-strength softgoods materials used in deployable habitats have been manufactured to industrial or Mil-Spec standards that only require meeting a minimum strength requirement for acceptance. NASA is seeking high-strength softgoods material architectures and processes that significantly improve pristine repeatability on strength and stiffness, and provide improved predictability of mechanical properties when loaded over time. In addition, these materials may be packaged in an unloaded state for long periods of time prior to deployment, thus methods for maintaining predictability after a period of relaxation are being sought.

Integration of indicator fibers or yarns into these materials during manufacture is also of interest, to identify damaged or stressed areas of the softgoods during and after fabrication, and to provide a measure of the softgoods structural integrity over time. Post-fabrication integration of advanced health monitoring sensors, such as for strain and load, are covered under a separate subtopic.

NASA is also interested in modeling and simulation approaches that can model the effects and impact of the space environment (thermal, radiation, vacuum) on these materials over time to maintain structural margins. These modeling techniques in combination with materials built for higher predictability and integrated health monitoring should allow prediction of residual strength and remaining safe life for missions of several years.

In summary NASA seeks innovations in:

- Designing and fabricating high-strength softgoods material architectures with highly predictable strength and stiffness in the pristine state, with improved predictability of long-term behavior after extended packaged or inflated conditions in a space environment.
- Integrating specialized indicator fibers or yarns into these materials during fabrication, to enable evaluation of structural integrity.
- Advanced modeling and simulation methodologies to predict mechanical behavior of these materials after long-term exposure to the space environment.

Contractors should prove the feasibility of proposed innovations using suitable analyses and small scale tests in Phase I. In Phase II, significant testing / fabrication or software capabilities should be developed and demonstrated. A Technology Readiness Level (TRL) at the end of Phase II of 4 is desired.

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.

Topic: T13 Ground and Launch Systems Processing

Ground and Launch Systems Processing. The goal of this topic is to provide a flexible and sustainable US capability for ground processing as well as launch, mission, and recovery operations to significantly increase safe access to space. The Ground and Launch Systems Processing topic consists of four technology subareas, including: technologies to optimize the operational life-cycle, environmental and green technologies, technologies to increase reliability and mission availability, and technologies to improve mission safety/mission risk. The primary benefit derived from advances in this technology area is reduced cost, freeing funds for other investments.

T13.01 Embedded Intelligent Sensor Systems
Lead Center: SSC
Participating Center(s): KSC, MSFC

This subtopic area seeks to develop advanced instrumentation technologies which can be embedded in systems and subsystems. Embedded sensor systems have the potential for substantial reduction in time and cost of propulsion systems development, with substantially reduced operational costs and evolutionary improvements in ground, launch and flight system operational robustness. The technologies developed would be capable of addressing multiple mission requirements for remote monitoring such as vehicle health monitoring. The goal is to provide a highly flexible instrumentation solution capable of monitoring remote or inaccessible measurement locations. All this while eliminating cabling and auxiliary power.

Rocket propulsion test facilities within NASA provide excellent test beds for testing and using the innovative technologies discussed above. Rocket propulsion development is enabled by rigorous ground testing 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 primary emphasis is to develop near-term products that augment and enhance proven, state-of-the-art propulsion test facilities. But the ultimate goal is develop sensor technologies capable of being embedded in structures and systems that are smaller, more energy efficient allowing for more complete and accurate vehicle health assessments. Development of a range of self-powered devices that maximize the safety and reliability of extended missions will enhance human space flight capabilities in support of human and robotic exploration missions. It is anticipated these sensor system will achieve orders of magnitude reduction in mass and size in the future.

Specific technology needs include the following:

- 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 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. 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 costs by allowing real-time analysis of data, information, and knowledge through efficient interfaces to enable integrated awareness of the system condition by users.

Topic: T14 Thermal Management Systems

Reserved for future Solicitations.

Topic: T15 Aeronautics

A strong national program of research and development (R&D) for aeronautics technology forms the foundation of the U.S. aeronautics and aviation enterprise. Aeronautics R&D is critical for national security and homeland defense, an efficient national air transportation system, and the economic well-being and quality of life of our citizens. The National Aeronautics Research and Development Plan (Plan) lays out high-priority national aeronautics R&D challenges, goals, and supporting objectives to guide the conduct of U.S. The Plan includes an important new goal regarding the integration of unmanned aircraft systems into the National Airspace System. In addition, this R&D Plan:

- Supports the coordinated efforts of the Federal departments and agencies in the pursuit of stable and long-term foundational research.
- Ensures U.S. technological leadership in aeronautics for national security and homeland defense capabilities.
- Advances aeronautics research to improve aviation safety, air transportation, and reduce the environmental impacts of aviation.
- Promotes the advancement of fuel efficiency and energy independence in the aviation sector; and Spurs the development of innovative technologies that enable new products and services.

Most of the R&D goals and objectives will require stable and long-term foundational research across a breadth of aeronautics disciplines to provide the underlying basis for new technological advances and breakthroughs. Such foundational research is often cross-cutting, resulting in technology advances that have applications across several Principles. Moreover, new ideas and technologies that are generated by foundational research will help inform future updates to the National Aeronautics Research and Development Plan.

T15.01 Power Systems for Hybrid Electric Propulsion
Lead Center: GRC

Proposals are sought which support the technology development of power systems for aircraft hybrid electric propulsion. Hybrid electric propulsion systems, involving distributed propulsion provided by an electric power system, requires the integration of propulsion, electric power, and aerodynamics.

Distributed propulsion systems using electric motor driven fans, with power electronics used for voltage and frequency control, and having peak load equal to the total power generation provides unique challenges associated with the power system control and protection methods. The nonlinear, constant power propulsor loads also complicate the stable operation of the power control, and the limited capacity of the generators complicates the protection system and recovery control following faulted operation. Proposals addressing the power management and stability issues inherent in these kinds of power systems, and the power control methods that can be exploited to enable the power system for distributed hybrid electric propulsion are needed.

The inclusion of electric power for distributed propulsion, with much faster dynamics, also requires innovative methods for simulation of the integrated system. Advanced hybrid (algebraic and dynamic) power system simulations using load flows methods in conjunction with dynamics as needed to allow for an integrated simulation capability are also of interest.

New approaches for advanced power electronic switching devices that go beyond wide band gap semiconductors and utilize graphene or carbon nanotubes, and added manufacturing methods that can be utilized to manufacture an integrated electro-magnetic and electrical structure for electric machines are also of interest.

T15.02 Aeronautical Communications, Navigation, Surveillance and Information (CNSI) Systems for UAS
Lead Center: GRC

Under the Aeronautics Research Mission Directorate, work will be performed to conduct fundamental, cutting-edge research into new aircraft technologies as well as the integration of new operations concepts and technologies into the Next Generation Air Transportation System (NextGen). Communications, Navigation, Surveillance and Information (CNSI) technology development supports the goals of these research programs in such areas as increasing airspace system capacity and efficiency, improving aviation system safety, and advancing the integration of unmanned aircraft into the national airspace system (NAS). Aviation nationally and globally is being developed upon a new paradigm of digital information transaction, supporting coordination and collaboration between airspace users and service providers based on collection and sharing of information on a much greater scale than ever before. NASA has contributed to this technological advance through the testing of control communications for unmanned aircraft, development of aircraft antennas for high frequency satellite communications, testing and demonstration of secure, high-rate wireless communications for airports, ground and flight testing of air-ground communications channels, and simulation, modeling and analysis of digital air traffic communications. Future research and technology development supports such initiatives as autonomous NAS operations and vehicles, mobile components of system-wide information management, beyond-line-of-sight control communications for unmanned aircraft, and national airspace system-wide performance assessments.

This solicitation seeks innovative approaches to Unmanned Aircraft Systems (UAS) communications for civil aviation in the current and future NAS, including for small UAS (< 55 lbs).

Desired focus areas include:

- CNSI operations technologies supporting unmanned vehicle integration into the national and global airspace systems, including advanced civil aviation air traffic control systems (including UAV traffic management), air traffic management, and airspace operations.
- CNSI system concepts, architectures and networks.
- Aeronautical CNSI components and subsystems for operation in civil aviation bands. These designs must account for all applicable aircraft certification and airworthiness requirements.
- Beyond line of sight communications technologies for UAS.

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/experimental 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
		1.3.0 Air Breathing Propulsion Systems	Propulsion Efficiency - Turbomachinery Technology for Reduced Fuel Burn	A1.07
		1.5.0 Unconventional/Other Propulsion Systems	Terrestrial and Planetary Balloons	S3.06
			Affordable Nano/Micro Launch Propulsion Stages	T1.01
TA	**STR Technology Area (TA) Level 1 Description**	**STR Technology Area (TA) Level 2 Description**	**Subtopic Description**	**Subtopic**
TA02	2.0.0 In-Space Propulsion Technologies	2.1.0 Chemical Propulsion	Low Emissions/Clean Power - Combustion Technology/Emissions Measurement Techniques	A1.03
			LOX/Methane In-Space Propulsion	H2.01
			Cryogenic Fluid Management for In-Space Transportation	H2.04
		2.2.0 Non-Chemical Propulsion	Nuclear Thermal Propulsion (NTP)	H2.02
			High Power Electric Propulsion	H2.03
			Propulsion Systems for Robotic Science Missions	S3.02
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	Thermal Energy Conversion	H8.01
			Advanced Photovoltaic Systems	H8.03
			Power Generation and Conversion	S3.01
			Self-Powered, Ultra-Miniature Devices	T3.02
			Power Systems for Hybrid Electric Propulsion	T15.01

		3.2.0 Energy Storage	Advanced Next Generation Batteries	H8.04
		3.3.0 Power Management and Distribution	High Power/Voltage Electronics	Z1.01
		3.4.0 Cross Cutting Technology	Solid Oxide Fuel Cells and Electrolyzers	H8.02
			Power Electronics and Management, and Energy Storage	S3.03
			Energy Transformation and Multifunctional Power Dissemination	T3.01
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	Wireless Technology	Z6.01
		4.2.0 Mobility	Robotic Systems - Mobility, Manipulation, and Human-System Interaction	H6.01
			Extreme Environments Technology	S4.04
		4.3.0 Manipulation	Robotic Mobility, Manipulation and Sampling	S4.02
			Regolith Resources Robotics - R^3	T4.02
		4.4.0 Human-Systems Integration	Augmented Reality	Z5.01
		4.5.0 Autonomy	Unmanned Aircraft Systems Technology	A2.02
			Requirements Management for Spacecraft Autonomy and Space Mission Automation	H6.02
			Command, Data Handling, and Electronics	S3.09
			Spacecraft Autonomy and Space Mission Automation for Consumables	H6.03
			Integrating ISHM with Flight Avionics Architectures for Cyber-Physical Space Systems	H6.04
			Contamination Control and Planetary Protection	S4.05
			Fault Management Technologies	S5.05
			Dynamic Servoelastic (DSE) Network Control, Modeling and Optimization	T4.01
			Coordination and Control of Swarms of Space Vehicles	T4.03
			Information Technologies for Intelligent and Adaptive Space Robotics	T11.01
		4.6.0 Autonomous Rendezvous and Docking	Spacecraft Technology for Sample Return Missions	S4.03

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
			Slow and Fast Light	S3.08
		5.2.0 Radio Frequency Communications	Autonomous Ka-band Spacecraft Terminals	T5.01
		5.4.0 Position, Navigation, and Timing	Flight Dynamics and Navigation Systems	H9.03
			Aeronautical Communications, Navigation, Surveillance and Information (CNSI) Systems for UAS	T15.02
		5.5.0 Integrated Technologies	Advanced Space Communication Systems	H9.02
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	Environmental Control and Life Support for Spacecraft and Habitats	H3.02
			International Space Station (ISS) Utilization	H14.01
			Sustainability in Space	T6.03
			Closed-Loop Living System for Deep-Space ECLSS with Immediate Applications for a Sustainable Planet	T6.04
		6.2.0 Extravehicular Activity Systems	Dust Tolerant, High Pressure Oxygen Quick Disconnect for Advanced Spacesuit and Airlock Applications	H4.01
			Trace Contaminant Control for Advanced Spacesuit Applications	H4.02
			EVA Space Suit Power, Avionics, and Software Systems	H4.03
			Space Suit Environmental Protection Garment Materials and Technologies	T6.01
		6.3.0 Human Health and Performance	Task Analysis Visualization and Data Management Tool	H12.01
			Passive Vital Sign Monitoring	H12.02
			Novel Imaging Technologies for Space Medicine	H12.03
		6.5.0 Radiation	Radiation Shielding Technologies - Transport Codes	H11.01
			Space Radiation Storms: Monitoring, Forecasting and Impact Analysis	T6.02

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	In situ Resource Utilization - Production of Feedstock for Manufacturing and Construction	H1.01
		7.6.0 Cross-Cutting Systems	Synthetic/Engineering Biology for NASA Applications	T7.01
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	In Situ Sensors and Sensor Systems for Lunar and Planetary Science	S1.06
			Airborne Measurement Systems	S1.07
			Surface & Sub-surface Measurement Systems	S1.08
			Cryogenic Systems for Sensors and Detectors	S1.09
			Proximity Glare Suppression for Astronomical Coronagraphy	S2.01
			Precision Deployable Optical Structures and Metrology	S2.02
			Technologies for Planetary Compositional Analysis and Mapping	T8.01
		8.2.0 Observations	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
			Guidance, Navigation and Control	S3.05
		8.3.0 Sensor Systems	Environmental Monitoring	H3.01
			Lidar Remote Sensing Technologies	S1.01
			Microwave Technologies for Remote Sensing	S1.02
			Sensor and Detector Technology for Visible, IR, Far IR and Submillimeter	S1.03
			Detector Technologies for UV, X-Ray, Gamma-Ray and Cosmic-Ray Instruments	S1.04
			Particles and Field Sensors and Instrument Enabling Technologies	S1.05
			Unmanned Aircraft and Sounding Rocket Technologies	S3.04
			Photonic Integrated Circuits	T8.02

			Detection technologies for extant or extinct life for use on robotic missions	T8.03
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	Ablative Thermal Protection Systems Technologies	H7.01
			Diagnostic Tools for High Velocity Testing and Analysis	H7.02
		9.3.0 Landing	Navigation and Hazard Avoidance Sensor Technologies	T9.01
		9.4.0 Vehicle Systems Technology	Planetary Entry, Descent and Landing and Small Body Proximity Operation Technology	S4.01
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
		11.2.0 Modeling	Structural Efficiency - Aeroelasticity and Aeroservoelastic Control	A1.01
			Quiet Performance - Propulsion Noise Reduction Technology	A1.02
			Physics-Based Computational Tools - Stability and Control/High Lift Design Tools	A1.05
			Enabling NASA Science through Large-Scale Data Processing and Analysis	S5.03
			Integrated Science Mission Modeling	S5.04
		11.4.0 Information Processing	Earth Science Applied Research and Decision Support	S5.02
			Distributed Spacecraft Missions (DSM) Technology Framework	T11.02
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	Multifunctional Materials and Structures: Integrated Structural Health Monitoring for Long Duration Habitats	H5.03
			NDE Sensors	H13.02
			Advanced Metallic Materials and Processes Innovation	Z3.01
			Technologies to Enable Novel Composite Repair Methods	T12.02
			Increasing Predictability of Softgoods Material Behavior for Inflatable Space Structures	T12.03
		12.2.0 Structures	Large Deployable Structures for Smallsats	H5.01

			Extreme Temperature Structures	H5.02
			In-Space Structural Assembly	H5.04
			Advanced Structural Health Monitoring	T12.01
		12.4.0 Manufacturing	Joining for Large-Scale Polymer Matrix Composite (PMC) Structures	Z4.01
			Experimental and Analytical Technologies for Additive Manufacturing	T12.04
		12.5.0 Cross-Cutting	Flight Test and Measurements Technologies	A2.01
			NDE Simulation and Analysis	H13.01
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	13.3.0 Technologies to Increase Reliability and Mission Availability	Improved Test and Launch Operations via Interface Design	H10.01
			Advanced Propulsion Systems Ground Test Technology	H10.02
			Embedded Intelligent Sensor Systems	T13.01
TA	**STR Technology Area (TA) Level 1 Description**	**STR Technology Area (TA) Level 2 Description**	**Subtopic Description**	**Subtopic**
TA14	14.0.0 Thermal Management Systems	14.2.0 Thermal Control Systems	Thermal Control Systems	S3.07
			Active Thermal Control Systems for Space Exploration	Z2.01

Research Topics Index

AERONAUTICS RESEARCH

HUMAN EXPLORATION AND OPERATIONS

SCIENCE

SPACE TECHNOLOGY

STTR