

National Aeronautics and Space Administration

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

Fiscal Year 2015 General Solicitation

Opening Date: November 14, 2014

Closing Date: January 28, 2015

Fiscal Year 2015 SBIR/STTR Solicitation Noteworthy Changes

Changes to both Phase I and Phase II SBIR/STTR Solicitations:

1.3 Program Management

Dryden Flight Research Center (DFRC) has been changed to Armstrong Flight Research Center (AFRC).

1.4 Three-Phase Program

The guidelines for Phase II-E and Phase II-X proposals have been streamlined and consolidated. Please refer to (<http://sbir.nasa.gov/content/post-phase-ii-initiatives>) for matching levels and other related information.

1.7 Commercialization Technical Assistance

When seeking commercialization technical assistance, firms will be asked to provide the DUNS number of the vendor.

3.2.4 Technical Proposal

The use of Federal / Non-Federal laboratories and equipment (Part 8) has been streamlined and consolidated.

5.11.3 1852.225-70 Export Licenses

Now includes language regarding Export Administration Regulations (EAR). For further information on EAR visit (<https://www.bis.doc.gov/index.php/regulations/export-administration-regulations-ear>).

5.12.5 1852.203-71 Requirement to Inform Employees of Whistleblower Rights

5.12.6 1852.209-73 Representation by Offerors that they are not the Association of Community Organizations for Reform Now (ACORN) or a subsidiary of ACORN. (DEVIATION FEB 2012)

5.12.7 1852-209.74 CERTIFICATION BY OFFERORS REGARDING FEDERAL INCOME TAX FILING and FEDERAL INCOME TAX VIOLATIONS. (DEVIATION FEB 2012)

Specific Phase I Changes:

1.4 Three-Phase Program

The Maximum period of performance for an STTR Phase I has returned to 12 months.

Specific Phase II Changes:

2.2.3.4 Milestone Plan

NASA has a new program requirement which mandates that the SBIR/STTR 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 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.

4.3 Payment Schedule for Phase II

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

5.3 Deadline for Phase II Proposal Receipt

All Phase II proposal submissions shall be received no later than 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>).

**Part 1: Phase I Proposal Instructions and
Evaluation Criteria for the
NASA Fiscal Year 2015 SBIR/STTR Solicitation**

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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 2015 Solicitation period for Phase I proposals begins November 14, 2014 and ends January 28, 2015.

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 2015. 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 Authority and Executive Order

SBIR and STTR opportunities are solicited annually pursuant to the Small Business Innovation Development Act of 1982, P.L. 97-219 (codified at 15 U.S.C. 638) as amended by the Small Business Innovation Research (SBIR) Program, Extension, P.L. 99-443 which extended the program through September 30, 1993. On October 28, 1992, through the Small Business Innovation Research and Development Act of 1992 (P.L. 102-564), Congress reauthorized and extended the SBIR Program for another seven years (2000). Subsequently, on December 21, 2000, through the Small Business Reauthorization Act of 2000 (P.L. 106-554) Congress again reauthorized the SBIR Program. With the approval of H.R. 2608, Continuing Appropriations Act 2012, the SBIR Program was authorized through December 31, 2011. On December 31, 2011, the President signed into law the National Defense Reauthorization Act of 2012 (Defense Reauthorization Act), P. L. 112-81, Section 5001, Division E of the Defense Reauthorization Act contains the SBIR/STTR Reauthorization Act of 2011 (SBIR/STTR Reauthorization Act), which extends both the SBIR and Small Business Technology Transfer (STTR) programs through September 30, 2017.

1.3 Program Management

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. All of the NASA Centers actively participate in the SBIR/STTR programs; and to reinforce NASA's objective of infusion of SBIR/STTR developed technologies into its programs and projects, each Center has personnel focused on that activity.

Fiscal Year 2015 SBIR/STTR Program Description

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 needs are explicitly described in the topics and subtopics descriptions developed by technical experts at NASA's Centers. The range of technologies is broad, and the list of topics and subtopics may vary in content from year to year. See section 9.1 for details on the Mission Directorate research topic descriptions for 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 as described in section 9.2.

As technological innovation is at the core of the SBIR/STTR program it is critical to NASA's Technology Transfer efforts that any new innovation derived from an SBIR/STTR award is reported to NASA in accordance with its New Technology Reporting Requirements.

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

1.4 Three-Phase Program

Both the SBIR and STTR programs are divided into three funding and development stages.

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

Phase I

The purpose of Phase I is to determine the scientific, technical, commercial merit and feasibility of the proposed innovation, and the quality of the SBC's performance. Phase I work and results should provide a sound basis for the continued development, demonstration and delivery of the proposed innovation in Phase II and follow-on efforts. Successful completion of Phase I objectives is a prerequisite to consideration for a Phase II award.

Phase II

The purpose of Phase II is the development, demonstration and delivery of the innovation. Only SBCs awarded a Phase I contract are eligible to submit a proposal for a Phase II funding agreement. Phase II projects are chosen as a result of competitive evaluations and based on selection criteria provided in the Phase II Proposal Instructions and Evaluation Criteria.

Opportunities for Continued Technology Development Post-Phase II

Phase II Enhancement (Phase II-E) Option

The objective of the Phase II-E is to further encourage the advancement of innovations developed under Phase II via an option of R/R&D efforts underway on current Phase II contracts. Eligible firms shall secure an external investor to partner with and invest in enhancing their technology for further research, infusion, and/or commercialization.

Under this option, NASA will match external investor funds with SBIR/STTR funds to extend an existing Phase II project for a minimum of 4 months to perform additional R/R&D.

New work proposed under a Phase II-E effort must build upon and demonstrably advance the R/R&D conducted during Phase II, and should therefore lead to new outcomes not achievable with Phase II funding alone.

Eligible external investors include a NASA project, NASA contractor, a non-SBIR/non-STTR government program or a commercial investor.

The non-SBIR/non-STTR contribution is not limited since it is regulated under the guidelines for Phase III awards. The matching levels SBIR/STTR will provide will depend on matching levels offered at time of the Phase II-E proposal.

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

Phase II eXpanded (Phase II-X) Option

The objective of the Phase II-X Option is to establish a strong and direct partnership between the NASA SBIR/STTR Program and other NASA projects undertaking the development of new technologies and innovations for future use. Under a Phase II-X option, innovations developed in Phase II are to be advanced via an extension of R/R&D efforts to the current Phase II contract. There are two specific requirements to be met for firms to be eligible for a Phase II-X option.

- First, eligible firms must secure a NASA program or project (other than the NASA SBIR/STTR Program) as a partner to invest in enhancing their technology for further research or infusion.
- Second, there is a minimum funding requirement for Phase II-X, as eligible firms must secure at least \$75,000 in NASA program or project funding.

Contributions from other NASA programs or projects are not limited since it is regulated under the guidelines for Phase III awards. Under a Phase II-X option, the NASA SBIR/STTR Program will match, on a 2-for-1 basis at the SBIR/STTR matching levels offered at time of the Phase II-X proposal.

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

Phase III

NASA may award Phase III contracts for products or services with non-SBIR/STTR funds, however, under the NASA CRP program NASA is permitted to use a limited amount of SBIR/STTR funds. The competition for SBIR/STTR Phase I and Phase II awards satisfies any competition requirement of the Armed Services Procurement Act, the Federal Property and Administrative Services Act, and the Competition in Contracting Act. Therefore, an agency that wishes to fund a Phase III project is not required to conduct another competition in order to satisfy those statutory provisions. Phase III work may be for products, production, services, R/R&D, or any combination thereof that is derived from, extends, or concludes efforts performed under prior SBIR/STTR funding agreements. A Federal agency may enter into a Phase III agreement at any time with a Phase I or Phase II awardee.

There is no limit on the number, duration, type, or dollar value of Phase III awards made to a business concern. There is no limit on the time that may elapse between a Phase I or Phase II and a Phase III award. The small business size limits for Phase I and Phase II awards do not apply to Phase III awards.

1.5 Eligibility Requirements

1.5.1 Small Business Concern

Only firms qualifying as SBCs, as defined in section 2.26, are eligible to participate in these programs. Socially and economically disadvantaged and women-owned SBCs are particularly encouraged to propose.

1.5.2 Place of Performance

R/R&D must be performed in the United States (section 2.31). However, based on a rare and unique circumstance (for example, if a supply or material or other item or project requirement is not available in the United States), NASA may allow a particular portion of the research or R&D work to be performed or obtained in a country outside of the United States. Proposals must clearly indicate if any work will be performed outside the United States, including subcontractor performance. Prior to award, approval by the Contracting Officer for such specific condition(s) must be in writing.

1.5.3 Principal Investigator (PI) Employment Requirement

The primary employment of the Principal Investigator (PI) shall be with the SBC under the SBIR Program, while under the STTR Program, either the SBC or 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

1.5.4 Restrictions on Venture Capital-owned Businesses

As set forth in the SBIR Reauthorization Act of 2011, small businesses owned in majority part by multiple venture capital operating companies, hedge funds, or private equity firms may be eligible for SBIR awards. SBA's regulations 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, and SBIR Select solicitations.**

1.5.5 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. 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. The required benchmark Transition Rate is 0.25. Additional information can be found at: <http://www.sbir.gov/faq/performance>.

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.

1.6 NASA SBIR/STTR Technology Available (TAV)

All subtopics have the option of using Technology Available (TAV) with NASA IP (defined below), which may also include NASA non-patented software technology requiring a Software Usage Agreement (SUA) or similar permission for use by others. All subtopics address the objective of increasing the commercial application of innovations derived from Federal R&D. 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 for either infusion or commercial viability and likely requires innovation on behalf of the private sector. NASA provides these technologies "as is" and makes no representation or guarantee that additional effort will result in infusion or commercial viability.

The NASA technologies identified in a subtopic or via the NASA Technology Transfer Portal <http://technology.nasa.gov>: (1) are protected by NASA-owned patents <http://technology.nasa.gov/patents>, (2) are non-patented NASA-owned or controlled software http://technology.nasa.gov/NASA_Software_Catalog_2014.pdf, or (3) are otherwise available for use by the public. In the event an offeror requests to use NASA owned or controlled technologies, which are not NASA patents or NASA software, NASA shall consider such request and permit such uses as NASA, in its sole discretion, deems appropriate and permissible. If a proposer elects to use a NASA patent, a non-exclusive, royalty-free research license will be required to use the NASA IP during the SBIR/STTR contract performance period.

Similarly, if a proposer wishes to use NASA software, the parties will be required to enter into a Software Usage Agreement on a non-exclusive, royalty-free basis in order to use such NASA software for government purposes and "Government-Furnished Computer Software and Related Technical Data" will apply to the contract. As used herein, "NASA IP" refers collectively to NASA patents and NASA software. Disclaimer: All subtopics include an opportunity to license or otherwise use NASA IP on a non-exclusive, royalty-free basis, for research use under the contract. Use of the NASA IP is strictly voluntary. Whether or not a firm uses NASA IP within their proposed effort will not in any way be a factor in the selection for award. NASA software release is governed by NPR 2210.1C.

Use of NASA Software

Software identified and requested under a SBIR/STTR contract shall be treated as Government Purpose Rights. Government purpose releases includes releases to other NASA Centers, Federal government agencies, and recipients who have a government contract. The software may be used for "government purposes" only. Non U.S. citizens will not be allowed access to NASA software under the SBIR/STTR contract.

A Software Usage Agreement (SUA) shall be requested after contract award from the appropriate NASA Center Software Release Authority (SRA). The SUA request shall include the NASA software title, version number, requesting firm contract info including recipient name, and SBIR/STTR contract award info. The SUA will expire when the contract ends.

Use of NASA Patent

All offerors submitting proposals citing a NASA patent must submit a non-exclusive, royalty-free license application if the use of a NASA patent is desired. The NASA license application is available on the NASA SBIR/STTR website: http://sbir.gsfc.nasa.gov/sites/default/files/research_license_app.doc. NASA only will grant research licenses to those SBIR/STTR offerors who submitted a license application and whose proposal resulted in an SBIR/STTR award under this solicitation. 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.

SBIR/STTR offerors are notified that no exclusive or non-exclusive commercialization license to make, use or sell products or services incorporating the NASA patent will be granted unless an SBIR/STTR offeror applies for and receives such a license in accordance with the Federal patent licensing regulations at 37 CFR Part 404. Awardees with contracts that identify a specific NASA patent will be given the opportunity to negotiate a non-exclusive commercialization license or, if available, an exclusive commercialization license to the NASA patent.

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

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

1.7 Commercialization Technical Assistance

In accordance with the Small Business Act (15 U.S.C. 632), NASA will authorize the recipient of a Phase I SBIR award to purchase technical assistance services, such as access to a network of 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 in either Phase I or Phase II.

1.8 General Information

1.8.1 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)

Facsimile: 301-937-0204

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

1.8.2 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.

2. Definitions

2.1 Allocation of Rights Agreement

A written agreement negotiated between the Small Business Concern and the single, partnering Research Institution, allocating intellectual property rights and rights, if any, to carry out follow-on research, development, or commercialization.

2.2 Awardee

The organizational entity receiving an SBIR/STTR Phase I, Phase II, or Phase III award.

2.3 Commercialization

The process of developing products, processes, technologies, or services and the production and delivery (whether by the originating party or others) of the products, processes, technologies, or services for sale to or use by the Federal government or commercial markets.

2.4 Cooperative Research or Cooperative Research and Development (R/R&D)

For purposes of the NASA STTR Program, cooperative R/R&D is that which is to be conducted jointly by the SBC and the RI in which a minimum of 40 percent of the work (before any cost sharing or fee/profit proposed by the firm) is performed by the SBC and a minimum of 30 percent of the work is performed by the RI.

2.5 Economically Disadvantaged Women-Owned Small Businesses (EDWOSBs)

To be an eligible EDWOSB, a firm must:

(1) Be a Women Owned Small Business (WOSB) that is at least 51% owned by one or more women who are “economically disadvantaged”. (2) Have one or more economically disadvantaged women manage the day-to-day operations, make long-term decisions for the business, hold the highest officer position in the business and work at the business full-time during normal working hours. A woman is presumed economically disadvantaged if she has a personal net worth of less than \$750,000 (with some exclusions), her adjusted gross yearly income averaged over the three years preceding the certification less than \$350,000, and the fair market value of all her assets is less than \$6 million.

Please note that for both WOSB and EDWOSB, the 51% ownership must be unconditional and direct. For a general definition please see FAR 2.101 (https://www.acquisition.gov/far/current/html/Subpart_2_1.html).

2.6 Essentially Equivalent Work

Work that is substantially the same research, which is proposed for funding in more than one contract proposal or grant application submitted to the same Federal agency or submitted to two or more different Federal agencies for review and funding consideration; or work where a specific research objective and the research design for accomplishing the objective are the same or closely related to another proposal or award, regardless of the funding source.

2.7 Feasibility

The practical extent to which a project can be performed successfully.

2.8 Federal Laboratory

As defined in 15 U.S.C. §3703, means any laboratory, any federally funded research and development center, or any center established under 15 U.S.C. §§ 3705 & 3707 that is owned, leased, or otherwise used by a Federal agency and funded by the Federal Government, whether operated by the Government or by a contractor.

2.9 Funding Agreement

Any contract, grant, cooperative agreement, or other funding transaction entered into between any Federal agency and any entity for the performance of experimental, developmental, research and development, services, or research work funded in whole or in part by the Federal Government.

2.10 Funding Agreement Officer

A contracting officer, a grants officer, or a cooperative agreement officer.

2.11 Historically Underutilized Business Zone (HUBZone) Small Business Concern

A HUBZone small business concern means a small business concern that appears on the List of Qualified HUBZone Small Business Concerns maintained by the Small Business Administration. To see the full definition of a HUBzone see the FAR 2.101 (https://www.acquisition.gov/far/current/html/Subpart_2_1.html) or go to the SBA HUBzone site (www.sba.gov/hubzone) for more details.

2.12 Infusion

The integration of SBIR/STTR developed knowledge or technologies within NASA programs and projects, other Government agencies and/or commercial entities. This includes integration with NASA program and project funding, development and flight and ground demonstrations.

2.13 Innovation

An innovation is something new or improved, having marketable potential, including: (1) development of new technologies, (2) refinement of existing technologies, or (3) development of new applications for existing technologies.

2.14 Intellectual Property (IP)

The separate and distinct types of intangible property that are referred to collectively as “intellectual property,” including but not limited to: patents, trademarks, copyrights, trade secrets, SBIR/STTR technical data (as defined in section 2.23), ideas, designs, know-how, business, technical and research methods, other types of intangible business assets, and including all types of intangible assets either proposed or generated by the SBC as a result of its participation in the SBIR/STTR Program.

2.15 NASA Intellectual Property (NASA IP)

NASA IP is NASA-owned, patented technologies that NASA is offering under a non-exclusive, royalty-free research license for use under the SBIR award.

2.16 New Technology Reporting Requirements

Anyone performing experimental, developmental, or research work under a NASA funding agreement, including SBIR/STTR Awardees, is required to disclose any new technology, invention or innovation as a result of the work performed under the contract. Any improvement, regardless of how big or small, should be reported via the New Technology Report (NTR) process defined below. Reportable items include a discovery, an invention, an innovation, or simply an advance in the state of the art. More detail on NASA’s New Technology Reporting requirements can be found at: <https://invention.nasa.gov>.

2.17 New Technology Report (NTR)

NASA's New Technology Report (NTR), also known as a NASA Form 1679, is the method by which new technologies (inventions and/or innovations) are disclosed. The NTR captures essential information about the technology /innovation, including its purpose, features, benefits and uses. NTR's should be submitted within two months after the inventor discloses it in writing to the Awardee's personnel responsible for patent matters. NTRs may be submitted via NASA's e-NTR system, by way of a link in the EHB.

2.18 New Technology Summary Reports (NTSR): Interim and Final

The New Technology Summary Report is a required deliverable in all research contracts. It is used to summarize any and all technologies (inventions and/or innovations) developed during the performance of the contract. If no new technologies were developed under the contract, the Awardee shall submit an NTSR which contains a certification stating no new technology was developed. NTSRs may be submitted via NASA's e-NTR system, by way of a link in the EHB.

2.19 NASA's Electronic New Technology Reporting System (e-NTR)

NASA's e-NTR system is an on-line system used to submit NTRs, Interim NTSRs and Final NTSRs. The system may be found at URL: <https://invention.nasa.gov>. In addition, for SBIR/STTR awardees, the e-NTR system link may be found within the SBIR/STTR EHB.

2.20 Principal Investigator (PI)

The one individual designated by the SBC to provide the scientific and technical direction to a project supported by the funding agreement.

2.21 Research Institution (RI)

A U.S. research institution is one that is: (1) a contractor-operated Federally funded research and development center, as identified by the National Science Foundation in accordance with the Government-wide Federal Acquisition Regulation issued in Section 35(c)(1) of the Office of Federal Procurement Policy Act (or any successor legislation thereto), or (2) a nonprofit research institution as defined in Section 4(3) of the Stevenson-Wydler Technology Innovation Act of 1980, or (3) a nonprofit college or university.

2.22 Research or Research and Development (R/R&D)

Creative work that is undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture, and society, and the use of this stock of knowledge to devise new applications. It includes administrative expenses for R&D. It excludes physical assets for R&D, such as R&D equipment and facilities. It also excludes routine product testing, quality control, mapping, collection of general-purpose statistics, experimental production, routine monitoring and evaluation of an operational program, and training of scientific and technical personnel.

Basic Research: systematic study directed toward fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications toward processes or products in mind. Basic research, however, may include activities with broad applications in mind.

Applied Research: systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met.

Development: systematic application of knowledge or understanding, directed toward the production of useful materials, devices, and systems or methods, including design, development, and improvement of prototypes and new processes to meet specific requirements.

Note: NASA SBIR/STTR programs do not accept proposals solely directed towards system studies, market research, routine engineering development of existing products or proven concepts and modifications of existing products without substantive innovation (see section 1.1).

2.23 SBIR/STTR Technical Data

Technical data includes all data generated in the performance of any SBIR/STTR funding agreement.

2.24 SBIR/STTR Technical Data Rights

The rights an SBC obtains for data generated in the performance of any SBIR/STTR funding agreement that an awardee delivers to the Government during or upon completion of a federally funded project, and to which the Government receives a license.

2.25 Service Disabled Veteran-Owned Small Business

A Service-Disabled Veteran-Owned Small Business is one that is: (1) Not less than 51% of which is owned by one or more service-disabled veterans or, in the case of any publicly owned business, not less than 51% of the stock of which is owned by one or more service-disabled veterans; (2) management and daily business operations, which are controlled by one or more service-disabled veterans or, in the case of a service-disabled veteran with permanent and severe disability, the spouse or permanent caregiver of such veteran; and (3) is small as defined by e-CFR §125.11.

Service-disabled veteran means a veteran, as defined in 38 U.S.C. 101(2), with a disability that is service connected, as defined in 38 U.S.C. 101(16). For a general definition, see FAR 2.101 (https://www.acquisition.gov/far/current/html/Subpart_2_1.html).

2.26 Small Business Concern (SBC)

An SBC is one that, at the time of award of Phase I and Phase II funding agreements, meets the following criteria: (1) Is organized for profit, with a place of business located in the United States, which operates primarily within the United States or which makes a significant contribution to the United States economy through payment of taxes or use of American products, materials or labor; (2) is in the legal form of an individual proprietorship, partnership, limited liability company, corporation, joint venture, association, trust or cooperative; except that where the form is a joint venture, there can be no more than 49 percent participation by business entities in the joint venture; (3) is at least 51 percent owned and controlled by one or more individuals who are citizens of, or permanent resident aliens in, the United States; except in the case of a joint venture, where each entity to the venture must be 51 percent owned and controlled by one or more individuals who are citizens of, or permanent resident aliens in, the United States; and (4) has, including its affiliates, not more than 500 employees.

The terms “affiliates” and “number of employees” are defined in greater detail in 13 CFR Part 121. For a general definition please see FAR 2.101 (https://www.acquisition.gov/far/current/html/Subpart%202_1.html).

2.27 Socially and Economically Disadvantaged Individual

See 13 C.F.R. § 124.103 & 124.104 (<http://www.sbir.gov/about/sbir-policy-directive>).

2.28 Socially and Economically Disadvantaged Small Business Concern

See 13 C.F.R. § 124, Subpart B (<http://www.sbir.gov/about/sbir-policy-directive>).

2.29 Subcontract

Any agreement, other than one involving an employer-employee relationship, entered into by an awardee of a funding agreement calling for supplies or services for the performance of the original funding agreement.

2.30 Technology Readiness Level (TRLs)

Technology Readiness Level (TRLs) is a uni-dimensional scale used to provide a measure of technology maturity.

Level 1: Basic principles observed and reported.

Level 2: Technology concept and/or application formulated.

Level 3: Analytical and experimental critical function and/or characteristic proof of concept.

Level 4: Component and/or breadboard validation in laboratory environment.

Level 5: Component and/or breadboard validation in relevant environment.

Level 6: System/subsystem model or prototype demonstration in a relevant environment (Ground or Space).

Level 7: System prototype demonstration in an operational (space) environment.

Level 8: Actual system completed and (flight) qualified through test and demonstration (Ground and Space).

Level 9: Actual system (flight) proven through successful mission operations.

Additional information on TRLs is available in Appendix A.

2.31 United States

Includes the 50 States, the territories and possessions of the Federal Government, the Commonwealth of Puerto Rico, the District of Columbia, the Republic of the Marshall Islands, the Federated States of Micronesia, and the Republic of Palau.

2.32 Veteran-Owned Small Business

A veteran-owned SBC is a small business that: (1) is at least 51% unconditionally owned by one or more veterans, as defined at 38 U.S.C. 101(2); or in the case of any publicly owned business, at least 51% of the stock of which is unconditionally owned by one or more veterans; and (2) whose management and daily business operations are controlled by one or more veterans. For a general definition please see FAR 2.101 (https://www.acquisition.gov/far/current/html/Subpart_2_1.html).

2.33 Women-Owned Small Business (WOSB)

To be an eligible WOSB, a company must: (1) be a small business that is at least 51% percent unconditionally and directly owned and controlled by one or more women who are United States citizens. (2) have one or more women who manage the day-to-day operations, make long-term decisions for the business, hold the highest officer position in the business and work at the business full-time during normal working hours.

Please note that for a WOSB the 51% ownership must be unconditional and direct. For a general definition please see FAR 2.101 (https://www.acquisition.gov/far/current/html/Subpart_2_1.html).

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 should 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.

3.2.2 Format Requirements

Proposals that do not follow the formatting requirement are subject to rejection 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 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 must 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 proposals 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 will 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 will 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 1.6).

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.

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 2015 and existing projects commit the time of the PI concurrently with this proposed activity. Any attempt to circumvent the restriction on PIs working more than half time for an academic or a nonprofit organization by substituting an ineligible PI will result in rejection of the proposal. However, for an STTR the PI can be primarily employed by either the SBC or the RI. Please see section 1.5.3 for further explanation.

Part 7: 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:

Describe available equipment and physical facilities (this should include physical location [address of where the work is to be performed], square footage, and major equipment) necessary to carry out the proposed Phase I, projected Phase II, and projected Phase III efforts. Items of equipment or facilities to be purchased (as detailed in the cost proposal) shall be justified under this section.

Use of Non Federal Laboratory/facilities or equipment:

In accordance with the Federal Acquisition Regulations (FAR) Part 45, it is NASA's policy not to provide facilities (capital equipment, tooling, test and computer facilities, etc.) for the performance of work under SBIR/STTR contracts. Generally an SBC will furnish its own facilities to perform the proposed work on the contract. When a proposed project or product demonstration requires the use of a unique Federal facility that is not designated as a Federal laboratory to be funded by the SBIR/STTR Program, then the offeror shall provide a) a signed letter on company letterhead from the SBC Official explaining why the SBIR/STTR research project requires the use of the Federal facility or personnel, including data that verifies the absence of non-Federal facilities or personnel capable of supporting the research effort, and a statement confirming that the facility proposed is not a Federal laboratory b) a statement, signed by the appropriate Government official at the facility, verifying that it will be available for the proposed period of performance. If the proposed facility is not a Federal laboratory than a SBA waiver will be required. Proposals requiring waivers must explain why the waiver is appropriate. NASA will provide this request, along with an explanation to SBA during the negotiation process. NASA cannot guarantee that a waiver can be obtained from SBA. These letters should be uploaded in Form C of your proposal. **Failure to provide this explanation and a written letter of availability from the Government official authorized to approve such use may invalidate any proposal selection.**

Use of Federal Laboratory/facilities or equipment:

When a proposed project or product demonstration requires the use of a Federal laboratory then the offeror must provide a letter justifying the use of a Federal laboratory from the SBC official, as well as, a letter from the Government agency that verifies the availability. These letters should be uploaded in Form C of your proposal. **Failure to provide a written letter of availability from the Government official authorized to approve such use of the Federal laboratory and the letter of justification from the SBC shall invalidate any proposal selection.**

Additionally, any proposer requiring the use of Federal laboratory, property, or facilities shall, within twenty (20) business days of notification of selection for negotiations, provide to the NASA Shared Services Center Contracting Officer all required documentation, to include, 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, property and facility responsibilities and liabilities. If a selected proposal indicates that NASA facilities are to be used in conjunction with SBIR/STTR funds as part of the work effort it is required that the offeror and the proposed NASA facility enter into a Space Act Agreement (SAA). The final awarding of the SBIR/STTR contract is dependent on the receipt of the documentation of the finalized agreement to use any Federal laboratory, property or facility.

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 1.5.2.

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 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 section 2.6), 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, section 2.1) 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

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. 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 "Audit Information" will be used to assist the contracting officer with negotiations if the proposal is selected for award. If the audit provided is not acceptable, they will be advised by the contracting officer on what is required to determine reasonable cost and/or rates. There is a separate "Audit Information" section in Forms C that shall also be completed. 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.

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 and responsibility. 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 Debriefing of Unsuccessful Offerors

After Phase I selections for negotiation have been announced, all unsuccessful offerors will be notified. 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.

5. Considerations

5.1 Awards

5.1.1 Availability of Funds

All Phase I 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 Contracting

To simplify making contract awards and to reduce processing time, all contractors selected for Phase I 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.

Phase I Model Contract

An example of the Phase I 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 Phase I Reporting

All Phase I 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 Phase I 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 Phase I results into products and services for NASA mission programs and other potential customers. Phase I 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. For SBIR Phase I and STTR Phase I contracts, 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 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 for Phase I

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

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

Please note: NASA will be transitioning to the DOD system, Wide Area WorkFlow (WAWF). During the duration of the contract your firm may be required to register with the WAWF system. It is a secure web based system for electronic invoicing, receipt, and acceptance. The WAWF website is located at: (<https://wawf.eb.mil/>).

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 qualified individuals from outside 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.

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 Limited Rights Information and Data

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 or Phase II contract. The following is a brief description of FAR 52.227-20, it is not intended to supplement or replace the FAR.

5.7.1 Non-Proprietary Data

Some data of a general nature are to be furnished to NASA without restriction (i.e., with unlimited rights) and may be published by NASA. This data will normally be limited to the project summaries accompanying any periodic progress reports and the final reports required to be submitted. The requirement will be specifically set forth in any contract resulting from this solicitation.

5.7.2 Proprietary Data

If the contractor desires to continue protection of proprietary data, it shall deliver form, fit, and function data and shall not deliver the proprietary data. Data is considered to be "proprietary" when the data is developed at a private expense and (1) embodies trade secrets or contains commercial, financial and confidential, privileged information, or (2) is computer software.

5.7.3 Non-Disclosure Period

As part of SBIR contracts, for a period of 4 years after acceptance of all items to be delivered under an SBIR /STTR contract, the Government agrees to use these data for Government purposes only and they shall not be disclosed outside the Government (including disclosure for procurement purposes) during such period without permission of the Contractor, except that subject to the foregoing use and disclosure prohibitions, such data may be disclosed for use by support Contractors. After the aforesaid 4-year period, the Government has a royalty-free license to use, and to authorize others to use on its behalf, these data for Government purposes, but is relieved of all disclosure prohibitions and assumes no liability for unauthorized use of these data by third parties.

5.7.4 Copyrights

Subject to certain licenses granted by the contractor to the Government, the contractor receives copyright to any data first produced by the contractor in the performance of an SBIR/STTR contract.

5.7.5 Invention Reporting, Election of Title and Patent Application Filing

NASA SBIR and STTR contracts will include FAR 52.227-11 Patent Rights – Ownership by the Contractor, which requires the SBIR/STTR contractors to do the following. Contractors must disclose all subject inventions to NASA within two (2) months of the inventor's report to the awardees. 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. To the extent authorized by 35 USC 205, the Government will not make public any information disclosing such inventions, allowing the contractor the permissible time to file a patent.

Per the NASA FAR Supplement 1852.227-11 Patent Rights--Retention by the Contractor (Short Form) 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>.

5.8 Profit or Fee

Phase I 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.

5.9 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 in section 2.26. 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.

5.10 Essentially Equivalent Awards and Prior Work

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

5.11 Additional Information

5.11.1 Precedence of Contract Over Solicitation

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

5.11.2 Evidence of Contractor Responsibility

In addition to the information required to be submitted in section 2.2.11 (Phase II section), 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.

5.11.3 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.

5.11.4 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.

5.12 Required Registrations and Submissions

5.12.1 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.

5.12.2 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.

5.12.3 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.

5.12.4 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.

5.12.5 1852.203-71 Requirement to Inform Employees of Whistleblower Rights

- (a) (a) The Contractor shall inform its employees in writing, in the predominant native language of the workforce, of contractor employee whistleblower rights and protections under 10 U.S.C. 2409, as described in subpart 1803.09 of the NASA FAR Supplement.
- (b) (b) The Contractor shall include the substance of this clause, including this paragraph (b), in all subcontracts.

5.12.6 1852.209-73 Representation by Offerors that they are not the Association of Community Organizations for Reform Now (ACORN) or a subsidiary of ACORN. (DEVIATION FEB 2012)

- (a) In accordance with section 534 of The Consolidated and Further Continuing Appropriation Act of 2012 (Pub. L.112-55) none of the funds made available by the Act may be distributed to the Association of Community Organizations for Reform Now (ACORN) or its subsidiaries.
- (b) The offeror represents, by submission of its offer, that it is not the Association of Community Organizations for Reform Now (ACORN) or a subsidiary thereof.

5.12.7 1852-209.74 CERTIFICATION BY OFFERORS REGARDING FEDERAL INCOME TAX FILING and FEDERAL INCOME TAX VIOLATIONS. (DEVIATION FEB 2012)

- (a) In accordance with section 527 of The Consolidated and Further Continuing Appropriation Act of 2012 (Pub. L.112-55) none of the funds made available by the Act may be used to enter into a contract in an amount greater than \$5 Million unless the prospective contractor certifies in writing to NASA that, to the best of its knowledge and belief, the contractor has filed all Federal tax returns required during the three years preceding the certification, has not been convicted of a criminal offense under the Internal revenue Code of 1986, and has not, more than 90 days prior to certification, been notified of any unpaid Federal tax assessment for which the liability remains unsatisfied, unless the assessment is the subject of an installment agreement or offer in compromise that has been approved by the Internal Revenue Service and is not in default, or the assessment is the subject of a non-frivolous administrative or judicial proceeding.

5.12.8 1852.209-75 Representation by Corporations Regarding an Unpaid Delinquent Tax Liability or a Felony Conviction under any Federal Law. (DEVIATION FEB 2012)

- (a) In accordance with sections 544 and 543 of The Consolidated and Further Continuing Appropriation Act of 2012 (Pub. L.112-55), 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 the agency has considered suspension or debarment of the

- corporation and made a determination that this action is not necessary to protect the interests of the Government; or
- (2) Was convicted (or had an officer or agent of such corporation acting on behalf of the corporation 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 the agency has considered suspension or debarment of the corporation and made a determination that this action is not necessary to protect the interests of the Government.

5.12.9 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.

5.12.10 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>.

5.12.11 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.

5.12.12 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/>.

5.13 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. EDT on Wednesday, January 28, 2015 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.

6.4 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.

6.5 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.

6.6 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 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 1.4).
8. Proposed project duration does not exceed 6 months (sections 1.4).
9. Entire proposal including Forms A, B, and C submitted via the Internet.
 - a) All firm-level forms must 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. EDT on January 28, 2015 (section 6.3).**

STTR 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 1.4).
8. Proposed project duration does not exceed 12 months (sections 1.4).
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 must 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. EDT on January 28, 2015 (section 6.3).**
13. Signed Allocation of Rights Agreement available for Contracting Officer within 10 days of selection.

National Aeronautics and Space Administration

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

**Part 2: General Phase II Proposal
Instructions and Evaluation Criteria**

*The electronic version of this document
is at: <http://sbir.nasa.gov>*

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1. Phase II Program Description

1.1 Introduction

This document provides a general description of the NASA SBIR/STTR Phase II Program and proposal submission requirements. All small business concerns (SBCs) that are awarded and have successfully completed their Phase I contracts are invited to submit Phase II proposals. Receipt of Phase II proposals are due on the last day of performance under SBIR/STTR Phase I contracts, the submission period will be available approximately 6 weeks prior to the contract completion date.

Proposals must be submitted online via the Proposal Submissions Electronic Handbook at <http://sbir.nasa.gov> and include all relevant documentation.

1.2 Phase II Description

Phase II

The purpose of Phase II is the development, demonstration and delivery of the innovation. Only SBCs awarded a Phase I contract are eligible to submit a proposal for a Phase II funding agreement. Phase II projects are chosen as a result of competitive evaluations and based on selection criteria provided in the Phase II Proposal Instructions and Evaluation Criteria.

Maximum value and period of performance for Phase II contracts:

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

1.3 Eligibility Requirements

1.3.1 Small Business Concern

Only firms qualifying as SBCs are eligible to participate in these programs. Socially and economically disadvantaged and women-owned SBCs are particularly encouraged to propose.

1.3.2 Place of Performance

R/R&D must be performed in the United States. 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.

1.3.3 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 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 NASA SBIR/STTR Technology Available (TAV)

All subtopics have the option of using Technology Available (TAV) with NASA IP (defined below), which may also include NASA non-patented software technology requiring a Software Usage Agreement (SUA) or similar permission for use by others. All subtopics address the objective of increasing the commercial application of innovations derived from Federal R&D. 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 for either infusion or commercial viability and likely requires innovation on behalf of the private sector. NASA provides these technologies "as is" and makes no representation or guarantee that additional effort will result in infusion or commercial viability.

The NASA technologies identified in a subtopic or via the NASA Technology Transfer Portal <http://technology.nasa.gov>: (1) are protected by NASA-owned patents <http://technology.nasa.gov/patents>, (2) are non-patented NASA-owned or controlled software http://technology.nasa.gov/NASA_Software_Catalog_2014.pdf, or (3) are otherwise available for use by the public. In the event an offeror requests to use NASA owned or controlled technologies, which are not NASA patents or NASA software, NASA shall consider such request and permit such uses as NASA, in its sole discretion, deems appropriate and permissible. If a proposer elects to use a NASA patent, a non-exclusive, royalty-free research license will be required to use the NASA IP during the SBIR/STTR performance period.

Similarly, if a proposer wishes to use NASA software, the parties will be required to enter into a Software Usage Agreement on a non-exclusive, royalty-free basis in order to use such NASA software for government purposes and "Government-Furnished Computer Software and Related Technical Data" will apply to the contract. As used herein, "NASA IP" refers collectively to NASA patents and NASA software. Disclaimer: All subtopics include an opportunity to license or otherwise use NASA IP on a non-exclusive, royalty-free basis, for research use under the contract. Use of the NASA IP is strictly voluntary. Whether or not a firm uses NASA IP within their proposed effort will not in any way be a factor in the selection for award. NASA software release is governed by NPR 2210.1C.

Use of NASA Software

Software identified and requested under a SBIR/STTR contract shall be treated as Government Purpose Rights. Government purpose releases includes releases to other NASA Centers, Federal government agencies, and recipients who have a government contract. The software may be used for "government purposes" only. Non U.S. citizens will not be allowed access to NASA software under the SBIR/STTR contract.

A Software Usage Agreement (SUA) shall be requested after contract award from the appropriate NASA Center Software Release Authority (SRA). The SUA request shall include the NASA software title, version number, requesting firm contract info including recipient name, and SBIR/STTR contract award info. The SUA will expire when the contract ends.

Use of NASA Patent

All offerors submitting proposals citing a NASA patent must submit a non-exclusive, royalty-free license application if the use of a NASA patent is desired. The NASA license application is available on the NASA SBIR/STTR website: http://sbir.gsfc.nasa.gov/sites/default/files/research_license_app.doc. NASA only will grant research licenses to those SBIR/STTR offerors who submitted a license application and whose proposal resulted in an SBIR/STTR award under this solicitation. 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.

SBIR/STTR offerors are notified that no exclusive or non-exclusive commercialization license to make, use or sell products or services incorporating the NASA patent will be granted unless an SBIR/STTR offeror applies for and receives such a license in accordance with the Federal patent licensing regulations at 37 CFR Part 404. Awardees with contracts that identify a specific NASA patent will be given the opportunity to negotiate a non-exclusive commercialization license or, if available, an exclusive commercialization license to the NASA patent.

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.

1.5 Commercialization Technical Assistance

In accordance with the Small Business Act (15 U.S.C. 632), NASA will authorize the recipient of a Phase I SBIR award to purchase technical assistance services, such as access to a network of 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 in either Phase I or Phase II.

2. Proposal Preparation Instructions and Requirements

2.1 Fundamental Considerations

The object of Phase II is to continue the R/R&D effort from the completed Phase I.

2.2 Phase II Proposal Requirements

2.2.1 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.

2.2.2 Format Requirements

Proposals that do not follow the formatting requirement are subject to rejection during administrative screening.

Page Limitations and Margins

Any page(s) going over the required page limited 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 must 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 2.2.4, **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 proposals 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 will 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.

2.2.3 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.

2.2.3.1 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 5. 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.

2.2.3.2 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 5. 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.

2.2.3.3 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 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.

2.2.3.4 Milestone Plan

NASA has a new program requirement which mandates that the SBIR/STTR 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.

2.2.4 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 will be rejected during administrative screening. The required table of contents is provided below:

Phase II Table of Contents

Part 1: Table of Contents.....	Page 4
Part 2: Identification and Significance of the Innovation and Results of the Phase I Proposal	
Part 3: Technical Objectives	
Part 4: Work Plan	
Part 5: Related R/R&D	
Part 6: Key Personnel	
Part 7: Phase III Efforts, Commercialization and Business Planning	
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 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 1.4).

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.

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 Phase I section 1.5.3 for further explanation.

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

Part 7: Phase III Efforts, Commercialization and Business Planning

Present a plan for commercialization (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:

Describe available equipment and physical facilities (this should include physical location [address of where the work is to be performed], square footage, and major equipment) necessary to carry out the proposed Phase I, projected Phase II, and projected Phase III efforts. Items of equipment or facilities to be purchased (as detailed in the cost proposal) shall be justified under this section.

Use of Non Federal Laboratory/facilities or equipment:

In accordance with the Federal Acquisition Regulations (FAR) Part 45, it is NASA's policy not to provide facilities (capital equipment, tooling, test and computer facilities, etc.) for the performance of work under SBIR/STTR contracts. Generally an SBC will furnish its own facilities to perform the proposed work on the contract. When a proposed project or product demonstration requires the use of a unique Federal facility that is not designated as a Federal laboratory to be funded by the SBIR/STTR Program, then the offeror shall provide a) a signed letter on company letterhead from the SBC Official explaining why the SBIR/STTR research project requires the use of the Federal facility or personnel, including data that verifies the absence of non-Federal facilities or personnel capable of supporting the research effort, and a statement confirming that the facility proposed is not a Federal laboratory b) a statement, signed by the appropriate Government official at the facility, verifying that it will be available for the proposed period of performance. If the proposed facility is not a Federal laboratory than a SBA waiver will be required. Proposals requiring waivers must explain why the waiver is appropriate. NASA will provide this request, along with an explanation to SBA during the negotiation process. NASA cannot guarantee that a waiver can be obtained from

SBA. These letters should be uploaded in Form C of your proposal. **Failure to provide this explanation and a written letter of availability from the Government official authorized to approve such use may invalidate any proposal selection.**

Use of Federal Laboratory/facilities or equipment:

When a proposed project or product demonstration requires the use of a Federal laboratory then the offeror must provide a letter justifying the use of a Federal laboratory from the SBC official, as well as, a letter from the Government agency that verifies the availability. These letters should be uploaded in Form C of your proposal. **Failure to provide a written letter of availability from the Government official authorized to approve such use of the Federal laboratory and the letter of justification from the SBC shall invalidate any proposal selection.**

Additionally, any proposer requiring the use of Federal laboratory, property, or facilities shall, within twenty (20) business days of notification of selection for negotiations, provide to the NASA Shared Services Center Contracting Officer all required documentation, to include, 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, property and facility responsibilities and liabilities. If a selected proposal indicates that NASA facilities are to be used in conjunction with SBIR/STTR funds as part of the work effort it is required that the offeror and the proposed NASA facility enter into a Space Act Agreement (SAA). The final awarding of the SBIR/STTR contract is dependent on the receipt of the documentation of the finalized agreement to use any Federal laboratory, property or facility.

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 Phase I section 1.5.2.

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 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%
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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 section 2.2.4, 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.

2.2.5 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 5. This agreement counts as one page toward the 50-page limit.

2.2.6 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.

2.2.7 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.

2.2.8 Firm Level Certifications

Firm level certifications that are applicable across all proposal submissions submitted to this solicitation must be completed via the “Certifications” section of the Proposal Submission Electronic Handbook. The offeror shall answer Yes or No as applicable. An example of the certification can be found in the NASA SBIR/STTR Firm Library (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.

2.2.9 Audit Information

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. 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 “Audit Information” will be used to assist the contracting officer with negotiations if the proposal is selected for award. If the audit provided is not acceptable, they will be advised by the Contracting Officer on what is required to determine reasonable cost and/or rates. There is a separate “Audit Information” section in Forms C that shall also be completed. 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.

2.2.10 Prior Awards Addendum

If the SBC has received more than 15 Phase II awards in the prior 5 fiscal years, submit name of awarding agency, date of award, funding agreement number, amount, topic or subtopic title, follow-on agreement amount, source, and date of commitment and current commercialization status for each Phase II. If your firm has received any SBIR or STTR Phase II awards, even if it has received fewer than 15 in the last 5 years, it is still recommended that you complete this form for those Phase II awards your firm did receive. This information will be useful when completing the Commercialization Metrics Survey, and in tracking the overall success of the SBIR and STTR programs. Any NASA Phase II awards your firm has received will be automatically populated in the electronic form, as are any Phase

II awards previously entered by the SBC during prior submissions (you may update the information for these awards). The addendum is not included in the 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.

2.2.11 Commercial Metrics Survey

NASA has instituted a comprehensive commercialization survey/data gathering process for firms with prior NASA SBIR/STTR awards. If the SBC has received any Phase III awards resulting from work on any NASA SBIR or STTR awards, provide the related Phase I or Phase II contract number, name of Phase III awarding agency, date of award, funding agreement number, amount, project title, and period of performance. The survey will also ask for firm sales and ownership information, as well as any commercialization success the firm has had as a result of Phase II SBIR or STTR awards. This information will allow firms to demonstrate their ability to carry SBIR/STTR research through to achieve commercial success, and allow agencies to track the overall commercialization success of their SBIR and STTR programs. The survey is not included in the 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

2.2.12 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.

2.2.13 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.

3. Method of Selection and Evaluation Criteria

3.1 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.

3.1.1 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.

3.1.2 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 2.2.4, 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 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.

3.1.3 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. 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.

3.2 Debriefing of Unsuccessful Offerors

After selection for negotiations have been announced, debriefings for proposals will be available to the offeror's corporate official or designee via e-mail. Telephone requests for debriefings will not be accepted. Debriefings are not opportunities to reopen selection decisions. To request debriefings on proposals, offerors must request via e-mail to the SBIR/STTR Program Support Office at ARC-SBIR-PMO@mail.nasa.gov within 60 days after the announcement of selection for negotiation. Late requests will not be honored.

4. Considerations

4.1 Awards

4.1.1 Availability of Funds

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

SBIR Contracts	STTR Contracts
NASA anticipates that approximately 35-40 percent of the successfully completed Phase I projects from the SBIR fiscal year 2015Solicitation will be selected for Phase II. Phase II agreements will be firm-fixed-price contracts with performance periods not exceeding 24 months and funding not exceeding \$750,000.	NASA anticipates that approximately 35-40 percent of the successfully completed Phase I projects from the STTR fiscal year 2015Solicitation will be selected for Phase II. Phase II agreements will be firm-fixed-price contracts with performance periods not exceeding 24 months and funding not exceeding \$750,000.

4.1.2 Contracting

To simplify making contract awards and to reduce processing time, all contractors selected for Phase II contracts should 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.

Phase II Model Contract

An example of the Phase 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.**

4.2 Phase II Reporting

All Phase II 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 Phase II 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 Phase II results into products and services for NASA mission programs and other potential customers. Phase II 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. For SBIR Phase II and STTR Phase II contracts, 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 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.

4.3 Payment Schedule for Phase II

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

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

Please note: NASA will be transitioning to the DOD system, Wide Area WorkFlow (WAWF). During the duration of the contract your firm may be required to register with the WAWF system. It is a secure web based system for electronic invoicing, receipt, and acceptance. The WAWF website is located at: (<https://wawf.eb.mil/>).

4.4 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).

4.5 Access to Proprietary Data by Non-NASA Personnel

4.5.1 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 qualified individuals from outside 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.

4.5.2 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.

4.6 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.

4.7 Cost Sharing

Cost sharing occurs when a contractor proposes to bear some of the burden of reasonable, allocable and allowable contract costs. Cost sharing is permitted, but not required for proposals under this Solicitation. Cost sharing is not an evaluation factor in consideration of your proposal. Cost sharing, if included, should be shown in the budget summary. No profit will be paid on the cost-sharing portion of the contract.

4.8 Profit or Fee

Phase II 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.

4.9 Joint Ventures and Limited Partnerships

Both joint ventures and limited partnerships are permitted, provided the entity created qualifies as an SBC. 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 page limit for the Phase II proposal.

4.10 Addition Information

4.10.1 Evidence of Contractor Responsibility

In addition to the information required to be submitted in section 2.2.13, 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 providing information on all resources required for contractor performance, i.e., financial capability, work force, and facilities.

4.11 Required Registrations and Submissions

4.11.1 Firm SBA Firm Registry

SBA maintains and manages a Company Registry at 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.

4.11.2 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.

4.11.3 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.

4.11.4 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.

4.11.5 1852.203-71 Requirement to inform employees of whistleblower rights

- (a) The Contractor shall inform its employees in writing, in the predominant native language of the workforce, of contractor employee whistleblower rights and protections under 10 U.S.C. 2409, as described in subpart 1803.09 of the NASA FAR Supplement.
- (b) The Contractor shall include the substance of this clause, including this paragraph (b), in all subcontracts.

4.11.6 1852.209-73 Representation by Offerors that they are not the Association of Community Organizations for Reform Now (ACORN) or a subsidiary of ACORN. (DEVIATION FEB 2012)

- (a) In accordance with section 534 of The Consolidated and Further Continuing Appropriation Act of 2012 (Pub. L.112-55) none of the funds made available by the Act may be distributed to the Association of Community Organizations for Reform Now (ACORN) or its subsidiaries.
- (b) The offeror represents, by submission of its offer, that it is not the Association of Community Organizations for Reform Now (ACORN) or a subsidiary thereof.

4.11.7 1852-209.74 CERTIFICATION BY OFFERORS REGARDING FEDERAL INCOME TAX FILING and FEDERAL INCOME TAX VIOLATIONS. (DEVIATION FEB 2012)

- (a) In accordance with section 527 of The Consolidated and Further Continuing Appropriation Act of 2012 (Pub. L.112-55) none of the funds made available by the Act may be used to enter into a contract in an amount greater than \$5 Million unless the prospective contractor certifies in writing to NASA that, to the best of its knowledge and belief, the contractor has filed all Federal tax returns required during the three years preceding the certification, has not been convicted of a criminal offense under the Internal revenue Code of 1986, and has not, more than 90 days prior to certification, been notified of any unpaid Federal tax assessment for which the liability remains unsatisfied, unless the assessment is the subject of an installment agreement or offer in compromise that has been approved by the Internal Revenue Service and is not in default, or the assessment is the subject of a non-frivolous administrative or judicial proceeding.

4.11.8 1852.209-75 Representation by Corporations Regarding an Unpaid Delinquent Tax Liability or a Felony Conviction under any Federal Law. (DEVIATION FEB 2012)

- (a) In accordance with sections 544 and 543 of The Consolidated and Further Continuing Appropriation Act of 2012 (Pub. L.112-55), 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 the agency has considered suspension or debarment of the corporation and made a determination that this action is not necessary to protect the interests of the Government; or
 - (2) Was convicted (or had an officer or agent of such corporation acting on behalf of the corporation 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 the agency has considered suspension or debarment of the corporation and made a determination that this action is not necessary to protect the interests of the Government.

4.11.9 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" are available online at <http://nодis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7150&s=2>.

4.11.10 Human and/or Animal Subject

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

4.11.11 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/>.

4.12 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.

5. Submission of Proposals

5.1 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.

5.2 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 (see Phase I section 6.2.1).

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 2.2.4.

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

5.2.1 What Needs to Be Submitted

The entire proposal including Forms A, B, C, the briefing chart, and other firm level forms must be submitted out 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 sections 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.

5.2.2 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.

5.2.3 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.

5.3 Deadline for Phase II Proposal Receipt

All Phase II proposal submissions shall be received no later than 5:00 p.m. EDT 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.

5.4 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.

5.5 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.

5.6 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.

6. 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) and 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 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 2.2.2).**
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 2.2.
4. The technical proposal contains all eleven parts in order (section 2.2.4).
5. A letter of commitment from the facility manager, if the research or R&D effort requires use of federal facilities (section 2.2.4).
6. Certifications in Form A are completed, and agree with the content of the technical proposal.
7. Proposed funding does not exceed \$750,000 (sections 1.2, 4.1.1).
8. Proposed project duration does not exceed 24 months (sections 1.2, 4.1.1).
9. Entire proposal including Forms A, B, and C submitted via the Internet.
 - a) All firm-level forms must 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 5.3).**

STTR 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 2.2.2, 2.2.5).**
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 2.2.
4. The technical proposal contains all eleven parts in order (section 2.2.4).
5. A letter of commitment from the facility manager, if the research or R&D effort requires use of federal facilities (section 2.2.4).
6. Certifications in Form A are completed, and agree with the content of the technical proposal.
7. Proposed funding does not exceed \$750,000 (section 1.2, 4.1.1).
8. Proposed project duration does not exceed 24 months (section 1.2, 4.1.1).
9. Research Agreement has been electronically endorsed by both the SBC Official and the RI (sections 2.2.5, 5.2).
10. Entire proposal including Forms A, B, C, and Research Agreement submitted via the Internet,
 - a) All firm-level forms must 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 5.3).**
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 that 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 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 solicitations for some of the broader subtopics began emphasizing specific areas of interest that vary from year-to-year. This does not reflect a reduction in scope for the subtopic or a change in ARMD interest in its technology objectives. It is intended to focus attention on an element of the subtopic that has the greatest potential for infusion into ARMD programs at the time of the solicitation. Each year ARMD plans to continue varying the focus of some of the subtopics to ensure opportunities for technology advancements across all elements of a subtopic, and maintain alignment with ARMD needs.

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

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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 of future air vehicles.

It also solicits research in revolutionary aircraft concepts; lightweight high strength structures and materials; more efficient propulsion systems; low emissions propulsion concepts; measurement techniques, and advanced concepts for high lift and low drag aircraft that meet the performance, efficiency and environmental requirements of future aircraft, and the goals of the NextGen.

This topic covers aircraft technologies covered by the former Fundamental Aeronautics Program as well as ground test technologies formerly covered by the Ground and Flight Test Techniques and Measurement topic under the Aeronautics Test Program, which are now under the Advanced Air Vehicles Program (AAVP). The re-structuring will emphasize development of tools, technologies, test techniques, and knowledge to meet 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 (2013). AAVP 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-Hybrid Nanocomposites

Lead Center: LaRC

Two of the primary goals of the Advanced Air Vehicles program are safety and efficiency, which can be achieved simultaneously through designer materials tailored for future aircraft structures. The SOA for lightweight structures are carbon fiber reinforced polymeric composites which make up approximately 50% of the weight of Boeing's 787. Adoption of all-carbon nanotube (CNT) composites to exploit their potential for enhancing structural efficiency is viewed as too far term, given the current state of CNT technology maturation. A more attainable approach is to take advantage of the multifunctionality offered by CNTs through the use of hybrid composites where CNTs are integrated into conventional carbon fiber reinforced composite structures. Hybrid composites enable improved mechanical properties such as interlaminar strength, while simultaneously increasing electrical and thermal conductivity to enable

features such as lightning strike protection, embedded sensing, etc. The targeted outcome is reduced weight and enhanced safety performance for future hybrid composite aircraft structures. For this subtopic, the plan is to start phase 1 with a systems analysis approach to identify the benefits and target areas for hybrid composite utility and to provide some direction and benefit analysis for applying hybrid composites in aircraft structures. Then the intention of the Phase II would be to tailor, build and test the materials to demonstrate the property enhancements identified in Phase I.

A1.02 Aerodynamic Efficiency Drag Reduction Technology

Lead Center: LaRC

The challenge of energy-efficient flight has at its foundation aerodynamic efficiency, and at the foundation of aerodynamic efficiency is low drag. Drag can be broadly decomposed into four components: viscous or skin friction drag, lift-induced drag, wave or compressibility drag, and excrescence drag due to various protruding items such as antennae, wipers, lights, etc. The relative impact of these four forces depends upon the targeted flight regime and vehicle-specific design requirements. The first force, however, viscous skin friction, stands out as particularly significant across most classes of flight vehicles and effective measures for its control would have a major impact of flight efficiency. In particular, supersonic, low-boom flight and new generations of energy-efficient subsonic transport airplanes including high L/D strut-braced designs, the blended wing body (BWB), so called “double-bubble” designs and other concepts with large expanses of surface area would benefit from effective viscous drag control.

Viscous skin friction can be classified as either laminar or turbulent. While the laminar case and its attendant laminar flow control (LFC) techniques remain important scientific and technological disciplines, the goal of high Reynolds number flight efficiency requires that the turbulent case receive renewed attention. In place of the first-principles-derived theoretical framework of the laminar flow stability problem, in the turbulence case we have a wide collection of experimental observations, data correlations, various CFD approaches requiring turbulence closure models and, at low Reynolds numbers, full direct numerical simulation of the Navier-Stokes equations (DNS). While such experimental and CFD-derived knowledge, has greatly increased our understanding of turbulent boundary layer physics over the past decades, key relationships between wall layer and outer layer dynamics essential to a full understanding remain to be identified and verified.

Inadequacies in our understanding of boundary layer turbulence increase reliance upon a more qualitative, physics-guided approach to discovery. For example, the experimental observation of reduced skin friction in the corners of triangular cross-section pipes lead to the discovery of drag-reducing V-groove riblets (subsequently also associated with the skin of certain shark species). The quasi-periodic, low-speed streak structures observed in the near-wall layer of turbulent boundary layers lead to the implementation of mechanically controlled spanwise waves or lateral oscillations of the wall to disrupt the processes associated with low speed streak bursting. Similar observations have either been made or suggested with respect to the stabilizing influence of convex and in-plane curvature; long length-to-diameter ratio particulates; passive, active and reactive wall motion; manipulation of the wall layer by various geometrical devices (e.g., vortex generators (VG) and large eddy breakup devices (LEBU)), and various weakly ionized gas (WIG) and magnetohydrodynamic/electrohydrodynamic (MHD/EHD) concepts. This solicitation is offered in this spirit of innovation based on experimental or computational observations guided by a basic, though not necessarily complete, physical understanding of the turbulent processes.

In order to stimulate innovation in the area of turbulent viscous drag reduction, proposals are sought subject to the following guidelines:

- Proposals shall address passive, active or reactive concepts for external, attached, fully developed, turbulent boundary layer viscous drag reduction in air.
- Experimental, hardware-based proposals and theoretical/computational proposals based on realizable hardware are preferred.
- All practical physical concepts are acceptable including but not limited to: mechanical/electro-mechanical actuators, weakly-ionized-gas (WIG) concepts, laser/microwave energy deposition, MHD/EHD devices, surface microstructure/geometry, embedded mechanical devices (VG's, LEBU's), wall mass transpiration, heat transfer, wall motion, wall curvature effects and pressure gradient (vehicle shaping).
- Significant enhancements or refinements of existing concepts and technologies are acceptable.

- First order assessment or technically plausible discussion of any net system energy saving claims shall be provided.
- Proof-of-concept experimental demonstrations are encouraged for Phase I where applicable but are not required.
- Target conditions are flight-relevant Reynolds numbers at either high subsonic ($0.7 < M < 0.9$) or low supersonic ($M < \sim 3$) speeds. Proposals at lower Mach and Reynolds numbers shall provide discussion of a developmental path towards flight-relevant conditions but not necessarily inclusive of actual flight.

A1.03 Low Emissions Propulsion and Power

Lead Center: GRC

Participating Center(s): AFRC, ARC, LaRC

Proposals are sought which support electric propulsion of transport aircraft, including turboelectric propulsion (turbine prime mover with electric distribution of power to propulsors) and various hybrid electric concepts, such as gas turbine engine and battery combinations.

Turboelectric propulsion for transport aircraft applications will require components with high specific power (hp/lb or kW/kg) and high efficiency, and cryogenic and superconducting components will likely be required. The cryogenic components of interest include fully superconducting generators and motors (i.e., superconducting stators as well as rotors), cryogenic inverters and active rectifiers, and cryocoolers. Proposals related to the superconducting machines may include aspects of the machines themselves and their subcomponents, as well as low AC loss superconducting materials for the stator windings. Generators with at least 10 MW capacity and motors of 2 to 4 MW capacity are of interest. Technology is sought that can contribute to superconducting machines with specific power more than 10 hp/lb.

Hybrid propulsion with non-cryogenic components will likely require new materials and configurations to reach required high specific power and efficiency. Hence ideas are sought for achieving 2-3X increase in specific power at high efficiency for non-cryogenic motors through a multidisciplinary approach utilizing advanced motor designs, better materials, and new structural concepts.

New approaches to achieving conductors with lower electrical resistivity than copper are particularly sought, e.g., conductors based on carbon nanotubes. However, such approaches must be backed by plausible reasons why a resistivity lower than that of copper can be expected to be achieved, in contrast to the best reported resistivity values for carbon nanotube fibers, which are nearly an order of magnitude higher.

Ideas are also sought to address challenges related to high voltage power transmission in future hybrid electric aircraft.

New modeling and simulation tools for hybrid electric aircraft propulsion systems are also of interest.

Some studies of turboelectric distributed propulsion components and systems can be found in the following and referenced therein:

- “Stability, Transient Response, Control, and Safety of a High-Power Electric Grid for Turboelectric Propulsion of Aircraft”, Michael Armstrong, Christine Ross, Danny Phillips, and Mark Blackwelder, NASA/CR—2013-217865, 2013
- “Turboelectric Distributed Propulsion in a Hybrid Wing Body Aircraft”, J. Felder, G. Brown, H. Kim, J. Chu, 20th ISABE Conference, Göteborg, Sweden, 12-16 Sept., 2011
- “Weights and Efficiencies of Electric Components of a Turboelectric Aircraft Propulsion System”, G. V. Brown, 49th AIAA Aerospace Sciences Meeting, Orlando FL, January 4-7, 2011
- “Turboelectric Distributed Propulsion Engine Cycle Analysis for Hybrid-Wing-Body Aircraft”, J. L. Felder, H. D. Kim, G. V. Brown, 47th AIAA Aerospace Sciences Meeting, Orlando FL, January 5-8, 2009

A1.04 Quiet Performance**Lead Center: LaRC****Participating Center(s): GRC**

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

- Fundamental and applied computational fluid dynamics techniques for aeroacoustic analysis, which can be adapted for design purposes.
- Prediction of aerodynamic noise sources including those from the airframe and those that arise from significant interactions between airframe and propulsion systems including those relating to sonic boom.
- Prediction of sound propagation from the aircraft through a complex atmosphere to the ground. This should include interaction between noise sources and the airframe and its flow field.
- Propagation of sonic boom through realistic atmospheres, especially turbulence effects.
- Innovative source identification techniques for airframe (e.g., landing gear, high lift systems) noise sources, including turbulence details related to flow-induced noise typical of separated flow regions, vortices, shear layers, etc.
- Concepts for active and passive control of aeroacoustic noise sources for conventional and advanced aircraft configurations, including adaptive flow control technologies, and noise control technology and methods that are enabled by advanced aircraft configurations, including integrated airframe-propulsion control methodologies. Innovative acoustic liner and porous surface concepts for the reduction of airframe noise sources and/or propulsion/airframe interaction are solicited but engine nacelle liner applications are specifically excluded.
- Development of synthesis and auditory display technologies for subjective assessments of aircraft community noise, including sonic boom.

A1.05 Physics-Based Conceptual Aeronautics Design Tools**Lead Center: GRC****Participating Center(s): LaRC**

NASA continues to investigate the potential of advanced, innovative propulsion and aircraft concepts to improve fuel efficiency and reduce the environmental footprint of future generations of commercial transports across the breadth of the flight speed regimes. Propulsion systems, such as open rotors and hybrid-electric propulsion, are viewed as potential options for helping meet aggressive, long range (i.e., 'N+3' timeframe) emission reduction targets. Accurate representation of the propulsion system is critical in confidently assessing the potential of a concept. Conceptual design and analysis of unconventional propulsion concepts and technologies is used for technology portfolio investment planning, development of advanced concepts to provide technology pull and independent technical assessment of new concepts. The agency's systems analysts need to have the best conceptual design/analysis tools possible to support these efforts. 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. However, modeling gaps still remain in many disciplines.

Historically, empirical and semi-empirical weight estimation methods have been utilized during the conceptual design phase. These techniques work well for the conceptual design of conventional propulsion systems with parameters that reside within the historical databases used to develop the methodologies. However, these methods are not well suited for unconventional propulsion concepts, or even conventional concepts which reside outside of the database. Developing higher order, more accurate tools suitable for conceptual design is a difficult challenge. The first issue is analysis turnaround time. To perform the configuration trades and optimization typical of conceptual design, runtimes measured in seconds or minutes, instead of hours or days, are required. However, rapid analysis turnaround time alone is insufficient. To be suitable for conceptual design, tools and methods are needed which accurately predict the 'as-

'built' characteristics. 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. What is usually required is a combination of these methods with some semi-empirical corrections. A final challenge in conceptual design is a lack of detailed design information. Lower order, empirical-based methods often require only gross design parameters as inputs. 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 are consistent with the amount of design knowledge that is available at the conceptual design stage.

NASA has a well-established propulsion systems analysis tool suite that is based on the Numerical Propulsion System Simulation (NPSS) and the Weight Analysis of Turbine Engines (WATE) codes. Ideally, new capabilities that arise from this solicitation should be compatible with NPSS and/or WATE or offer significantly increased capability beyond/outside of these state-of-the-art tools.

For FY 2015, the focus is on addressing remaining capability gaps. Examples of desired capability improvements include the following:

- Physics-based methodologies and sizing of hybrid-electric propulsion components.
 - Weight/volumetric estimates for major components (e.g., batteries, fuel cells, motors, generators, cryocoolers, transformers, inverters, rectifiers).
- Heat exchanger performance and weight/volume estimation modeling tools.
- Computational counter-rotating open rotor performance tools.
 - Low/Medium-fidelity modeling approaches for predicting open rotor performance based on key blade characteristics.
- Multi-fidelity environmental analysis tools.
 - Combustion emission indices generation consistent with advanced combustor architectures.
 - Advanced acoustic-modeling addressing propulsion/airframe shielding, Fan/turbomachinery noise and/or jet noise.
- Multi-fidelity Propulsion-Airframe Integration (PAI) performance analysis tools.
 - Propulsion installation analysis methods (inlet/nacelle/nozzle analysis in the presence of an airframe).
 - Advanced mission-analysis methods incorporating multiple degrees of freedom and including expansive/adaptable propulsion operability capability.
- Macro Systems Analysis tools addressing propulsion-related impacts.
 - Reduced-order atmospheric chemistry/global mixing tools.
 - Safety/reliability analysis tools consistent with conceptual-level design/analysis.
 - Global airport throughput network and commerce models.

A1.06 Vertical Lift

Lead Center: ARC

Participating Center(s): GRC, LaRC

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

- The use of small vertical lift UAVs has increased in recent times with many civilian missions being proposed, including autonomous surveillance, mapping, etc. Much of the current research associated with these vehicles has been in the areas of electric propulsion, batteries, small sensors and autonomous control laws, while very little attention has been paid to their acoustic signature. The generation and propagation of noise associated with this small class of vertical lift UAVs are not well understood and validated prediction tools do not currently exist. The objective of a proposed effort would be to develop tools for the modeling and prediction of the high frequency acoustics for small vertical lift UAVs, such as quad-copters, coaxials, ducted fan rotors, etc.
- A transition to low-carbon propulsion has the promise of dramatically reducing the emissions from full-scale rotorcraft, as well as reducing overall fuel consumption and operating cost. All electric and hybrid propulsion systems could be beneficial to rotorcraft due to high power requirements of hover and integrated motor-drive

systems designs that could be realized. The objective of a proposed effort would be to develop and demonstrate hybrid/electric technologies for full-scale rotorcraft drive and propulsions systems that show benefits in-terms of weight, efficiency, emissions and fuel consumption. Validated modeling and analysis tools for all-electric and hybrid propulsions systems are also sought in this solicitation.

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

A1.07 Efficient Propulsion and Power

Lead Center: GRC

For 2014, this sub-topic will focus on propulsion controls and dynamics. Propulsion controls and dynamics research is being done under various projects in the Fundamental Aeronautics Program (FAP) and Aviation Safety Program (ASP). For turbine engines, work on Distributed Engine Control (DEC) and Active Combustion Control (ACC) is currently being done under the Aeronautics Sciences (AS) project, and is expected to transition to the new Transformative Tools and Technologies (TTT) project in FY15. Aero-Propulso-Servo-Elasticity (APSE) research will continue under the High Speed project. Model-Based Engine Control research is currently being conducted under the Vehicle System Safety Technologies project, and is expected to transition to the TTT project in FY15. Propulsion controls and dynamics technologies that help achieve the goals of the following NASA ARMD strategic thrusts: Innovation in Commercial Supersonic Aircraft; Ultra-Efficient Commercial Vehicles; and Assured Autonomy for Aviation Transformation, will be given preference. Following technologies are of specific interest:

- *High Efficiency Robust Engine Control* - Typical current operating engine control logic is designed using SISO (Single Input Single Output) PI (Proportional+Integral) control. The control logic is designed to provide minimum guaranteed performance while maintaining adequate safety margins throughout the engine operating life. Additionally, the control logic indirectly provides control of variables of interest such as Thrust, Stall Margin, etc. since these variables cannot be measured or are not measured in flight because of restrictions on sensor cost/placement/reliability, etc. All this results in highly conservative control design with resulting loss in efficiency. NASA is currently conducting research in Model-Based Engine Control (MBEC) where-in an on-board real-time engine model, tuned to reflect current engine condition, is used to generate estimate of quantities of interest that are to be regulated or limited and these estimates are used to provide direct control of Thrust, etc. Alternate methods such as Model Predictive Control, Adaptive Control, direct non-linear control, etc. are of interest. However, the alternative methods must achieve the same objectives as the current MBEC approach by providing practical application of the control logic in terms of operation with sensor noise, operation across varying atmospheric conditions, operation across varying engine health condition over the operating life, and real-time operation within engine control hardware limits. The emphasis is on practical application of existing control methods rather than theoretical derivation of totally new concepts. Control design approaches that can accommodate small to medium engine component faults and can still provide desired performance with safe operation are of special interest. The pre-requisite for proposals for engine control design methods is that the NASA C-MAPSS40k (Commercial Modular Aero-Propulsion System Simulation for 40,000 lb class thrust engine) be used for control design and evaluation. This simulation can only be used by U.S. citizens since it is subject to export control laws. Methods for real-time engine parameter identification using flight data are also of interest by themselves.
- *Distributed Engine Control* - Current engine control architectures impose limitations on the insertion of new control capabilities primarily due to weight penalties and reliability issues related to complex wiring harnesses. Obsolescence management is also a primary concern in these systems because of the unscheduled cost impact and recertification issues over the engine life cycle. NASA in collaboration with AFRL (Air Force Research Lab) has been conducting research in developing technologies to enable Distributed Engine Control (DEC) architectures. Modularity is an inherent feature of distributed engine control architecture. Modularity enables the rapid integration of the individual functions of control into a cohesive system by virtue of common digital interfaces and the well-defined flow of data. This interface structure can persist regardless if the control function exists in hardware or simulation. At the engine system level, distributed architecture enables scalability and reuse of control functional elements across engine platforms, but it also simplifies the insertion of new control technologies within the smart devices. NASA is interested in the development and simulation of these distributed control functions for high temperature embedded application

on the engine core. NASA is particularly interested in the design and development of these applications for assessing the benefit they bring to the engine system.

- *Active Combustion Control* - The overall objective is to develop all aspects of control systems to enable safe operation of low emissions combustors throughout the engine operating envelope. Low emission combustors are prone to thermo-acoustic instabilities. So far NASA research in this area has focused on modulating the main or pilot fuel flow to suppress such instability. Advanced, ultra-low emissions combustors utilize multi-point (multi-location) injection to achieve a homogeneous, lean fuel/air mixture. There is new interest in using precise control of fuel flow in such a manner as to suppress or avoid thermo-acoustic instabilities. Miniature fuel metering devices (and possibly also fuel flow measurement devices) are needed that can be physically distributed to be close to the multi-point fuel injector in order to enable the control system to accurately place a given proportion of the overall fuel flow to each of the fuel injection locations.
- *Aero-Propulso-Servo-Elasticity (APSE)* - The objective of NASA research effort in APSE is to develop a comprehensive variable cycle engine (VCE) type dynamic propulsion system model that can be utilized for thrust dynamics and integrated APSE vehicle controls and performance studies, like vehicle ride quality and vehicle stability under typical flight operations, vehicle maneuvering and atmospheric disturbances, for supersonic vehicles. Innovative approaches to dynamic modeling that are of interest include supersonic external compression inlets; multi flow paths convergent-divergent type nozzles with a spike; parallel flow path modeling of propulsion components upstream of the combustor to accurately model the distortion effects, maneuvering and atmospheric disturbances; and integration of dynamic propulsion models with aircraft simulations incorporating flexible vehicle structural modes.

A1.08 Ground Testing and Measurement Technologies

Lead Center: LaRC

Participating Center(s): GRC

This subtopic supports the experimental modeling and simulation requirements of NASA's Aeronautics Research Mission Directorate, as well as the testing requirements of other government and commercial entities. The subject facilities are managed by the Aeronautics Evaluation and Test Capability (AETC) Project within the NASA Advanced Air Vehicles Program. The primary objective of this subtopic is to develop innovative tools and technologies that enhance testing and measurement capabilities, improve ground test resource utilization and efficiency, and provide capability sustainment. Where possible, the tools and technologies should be applicable for the broad national scope of government, commercial, and university capabilities.

Wind tunnel vehicle design databases have traditionally included the foundational measurements of forces and discrete surface pressures and temperatures. However, designing and testing future vehicles with non-traditional aerodynamic geometries, possibly including highly integrated and distributed propulsion and flow control systems, will require enhanced, remotely sensed global surface measurements that cover a wide range of operational conditions. Enhanced optical systems are required to visualize the flow interactions both on and off the surface. Non-intrusive measurement systems offering multi-component velocities, density, and pressure in the tunnel stream are required to routinely quantify and baseline the test environment and to establish boundary conditions for advanced computational simulations. Non-intrusive measurements of off-body and near-body flow parameters both at a point and globally (i.e., planar or volumetric) are necessary to examine fluid-fluid and fluid-structure interactions for computational solution validation. The development of diagnostics for simultaneous volumetric measurements are particularly desired and will require a concentrated research effort in the development of enhanced laser and imaging techniques (including light field imaging), the development of new optical configurations, and the development of near real-time to real-time acquisition and processing architectures. In particular, development of techniques that significantly increase data capture per test point are needed, including the ability to simultaneously measure multiple flow parameters at high acquisition rates to capture rapidly evolving or oscillatory flow phenomena. Maturation of current particle-based, molecular, and/or surface diagnostics and unification of compatible instruments are desired. In all cases, significant measurement accuracy enhancements are required. Measurement systems must be robust and user-friendly for practical and routine application.

Proposals for clean seeding methods that do not contaminate wind tunnel walls or anti-turbulence screens are solicited. Seedless methods for velocity measurements near a model surface are particularly desired for adverse test environments where seeding contaminants are prohibited, may alter the model surface flow, or possibly damage gas

reclamation systems. Two such environments occur at NASA Langley for -250°F cryogenic testing at the National Transonic Facility and heavy-gas testing using R134a at the Transonic Dynamics Tunnel.

Proposals are also solicited for shear stress sensors that are applicable to high-temperature/high-flow-rate environments such as those encountered in engine and high-speed testing where surface heating is important.

Small models and/or packaging constraints for large models can make model attitude measurements difficult. Testing in the non-gravity direction precludes use of traditional angle sensors. Many test configurations require multiple angle of attack systems, including redundant systems to guard against in-test failure. Maintaining calibration currency and accuracy of multiple systems significantly increases test costs and complexity. Proposals are solicited for accurate, real-time, optical, non-intrusive techniques for determining model attitude.

The impact of icing on vehicle performance for flight certification is increasingly important. Currently, the NASA Glenn Icing Research Tunnel cannot reproduce the full range of test conditions defined in the FAA Appendix O Supercooled Droplet Icing Conditions. Simulation of Appendix O conditions for freezing rain and drizzle scenarios requires a bimodal droplet distribution with much larger size droplets. These large droplets have an extended cooling period before entering the test section; and, they don't follow the flow, falling toward the test section floor. Innovative ideas and technology advancements are solicited to create and control Appendix O conditions in current facilities.

Many NASA wind tunnel facilities conduct tests at elevated temperatures (400°F to 700°F) or at extremely low temperatures (-250). Displacement measurement components in actuator systems for the setting of hydraulic cylinder positions and other hardware that is 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.

Additional information about the mission and facility capabilities may be obtained at (<http://www.aeronautics.nasa.gov/atp/index.html>).

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 real-time, in-flight data used to determine aerodynamic, structural, flight control, and propulsion system performance characteristics. These data will also be used to provide 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:

- Dryden Aeronautical Test Range.
- Aero-Structures Flight Loads Laboratory.
- Flight Research Simulation Laboratory.
- Research Test Bed Aircraft.

Proposals should address innovative methods and technologies to extend the health, maintainability and test capabilities 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.
- 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.
- Remote optical-based measurement technologies enabling simultaneous spatial/spectral/temporal measurement capability in the infrared wavebands are desired to assess technology leaps in propulsion system efficiency and to evaluate impacts to the environment. Temporal acquisition rates greater than or equal to 1 kHz (full hyperspectral image cubes/sec) are desired to resolve performance information commensurate with the expected phenomenology. 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 (e.g., non-destructive examination of composites through ultrasonic techniques).

A2.02 Unmanned Aircraft Systems Technology**Lead Center: AFRC****Participating Center(s): 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 2015 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:

- Develop 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.
- The development of 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.
- Development of prognostic safety risk management solutions and concepts for emergent risks.
- Development of 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 System (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) will be concluding the successful Aviation Safety Program (AvSP). The newly expanded Airspace Operations and Safety Program (AOSP) will be 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. Rather than be focused on the current National Airspace System (NAS), ARMD's RSSA will be focused towards a future NAS where a gate-to-gate trajectory-based system capability exists 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, these areas:

- Research and development products to address technologies, simulation capabilities and procedures for reducing flight risk in areas of attitude and energy aircraft state awareness
- Develop 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 prognostic decision support tools and methods capable of supporting real-time safety assurance.

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.

(<http://www.nasa.gov/directorates/heo/home/index.html>)

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TOPIC: H1 In-Situ Resource Utilization

The purpose of In-Situ Resource Utilization (ISRU) is to harness and utilize resources (both natural and discarded material) at the site of exploration to create products and services which can enable new approaches for exploration and significantly reduce the mass, cost, and risk of near-term and long-term space exploration. The ability to make propellants, life support consumables, fuel cell reagents, and radiation shielding can provide significant benefits for sustained human activities beyond Earth very early in exploration architectures. 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. While the discipline of ISRU can encompass a large variety of different concept areas, resources, and products, the ISRU Topic will focus on technologies and capabilities associated with acquiring and processing regolith/soil resources for mission consumable production and construction.

H1.01 Regolith ISRU for Mission Consumable Production

Lead Center: JSC

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

In-Situ Resource Utilization (ISRU) involves collecting and converting local resources into products that can reduce mission mass, cost, and/or risk of human exploration. The primary destinations of interest for human exploration, the Moon, Mars and its moons, and Near Earth Asteroids, all contain regolith/soil that contain resources that can be harvested into products. The resources of primary interest are water and other components that can be released from the regolith/soil by heating, and oxygen found in the minerals to make consumables for life support, power, and propulsion system applications. State of the art (SOA) technologies for many ISRU processes either do not exist, are too complex, are too inefficient (mass, power, and/or volume), or are not designed to operate in the extraterrestrial environment in which the resource is found, especially the micro-gravity environment for asteroids. The subtopic seeks proposals for critical technologies associated with the design, fabrication, and testing of hardware associated with extracting and transferring regolith/soil materials from extraterrestrial bodies and processing the material to extract water/volatiles and oxygen. Technologies developed under this subtopic are applicable to feasibility testing on parabolic flights and the ISS, assessment and processing of material on the redirected asteroid to trans-lunar space, and robotic precursor missions to the lunar poles and surface of Phobos and Mars. Proposals should address one or more of the categories below.

Simulants for Ground Testing

1. Simulants for ordinary chondrites (LL, L, H) and carbonaceous chondrites (CI, CM) asteroids that replicate asteroid material characteristics such as physical (particle size/shape, particle size distribution, hardness), thermal, mineral/chemical , and volatile content for ground testing. Proposers must justify proposed simulant components and preparation based on documented research/publications.

Regolith/soil Acquisition and Preparation

The first step in production of mission consumables from in situ resources is acquisition and preparation of the resource for processing. Proposals in this category should address one or more of the following:

2. Excavation, transfer, and preparation of hydrated and icy-soil/regolith on Mars.
3. Excavation, transfer, and preparation of asteroidal material from ordinary and carbonaceous chondrite asteroids.
4. Excavation, transfer, and preparation of lunar polar icy regolith.

Notes: Proposals must address both the physical/mineral properties of the regolith/soil and the environmental conditions of the resources location. For item 3 proposals must address options for anchoring or maintaining position at the site of excavation to overcome forces applied during excavation and transfer of asteroidal material. Concepts need to minimize the generation of material that can float off and create a hazard. The proposal must identify the potential mass, power, and operation life impact of the selected option. All acquisition and preparation proposals must identify and address any issues with measuring and maintaining constant/known material transfer rates, and the impact of continuous versus batch-mode processing of the material. Proposals can combine regolith/soil acquisition and preparation with processing if it allows for reduced mass, power, and/or complexity.

Soil/Regolith Processing for Mission Consumables

Once the soil/regolith has been acquired and prepared, it is ready for processing. Proposals in this category should address one or more of the following:

5. Water/volatile extraction and separation from carbonaceous chondrites asteroidal material. Identify potential contaminants for subsequent cleaning based on the method utilized for volatile extraction. Besides water, carbon-based gases are of significant interest for fuel and plastic production. Proposals should consider additional steps (higher temperatures, reactants, etc.) that may increase the extraction and collection of carbon-based gases. Proposers are also encouraged to examine the applicability of micro-gravity asteroidal processing techniques for crew/trash waste processing.
6. Water/volatile extraction and separation from lunar polar icy material. Identify potential contaminants for subsequent cleaning based on the method utilized for volatile extraction.
7. Water vapor and other volatile separation and collection from other gases/liquids. Separation techniques must address potential contaminants.
8. Regenerative dust separation from product and reactant gases.
9. Oxygen extraction from ordinary and carbonaceous chondrites asteroidal material. Regeneration of reactants used in oxygen extraction is required.
10. Metal extraction from ordinary and carbonaceous chondrites asteroidal material. Regeneration of reactants used in metal extraction is required.

Notes: Proposals must specify whether the process is performed in batches or by continuous processing with appropriate sealing techniques to minimize reactant/product losses identified. Proposers are encouraged to address more than one of the Soil/Regolith Processing needs above. Proposals can combine regolith/soil processing with acquisition and preparation if it allows for reduced mass, power, and/or complexity. Proposals addressing only item 7 or 8 need to identify the potential soil/regolith processing technique it is applicable for as well as minimum and maximum flow rates and/or product/reactant concentrations.

Further Requirements for Proposals

All proposals need to identify the SOA of applicable technologies and processes:

- *For Lunar polar-based ISRU* - Assume ice content in regolith is between 5 and 10% at temperatures below 100 K. Regolith excavation down to at least 1 meter below the surface is required for Phase II. Proposals must address material transfer, handling, and processing of polar material under temporary sunlight and continuous shadowed solar/thermal conditions.
- *For Mars-based ISRU* - Assume hydrated soils between 3 and 15% (nominal 8%); icy soils containing 40% or more of ice. Soil excavation down to a minimum of 0.5 meters below the surface is required for Phase II. Proposals must recognize and address issues with perchlorate minerals in the Mars soil during processing and product separation. For hydrated soils, proposals must consider meeting time averaged excavation and processing rates of 3.5 to 7 kg/hr (8%) to 9 to 19 kg/hr (3%) soil to achieve time averaged water extraction and processing rates of 0.55 to 1.125 kg/hr. Proposals must consider and address operating life issues for surface applications that can last for up to 480 days of continuous operation.

- *For Asteroid-based ISRU* - Technologies requested are subscale to allow for future testing on the reduced gravity assets and the ISS, but must be extensible to larger scale applications. For testing on the ISS, proposed hardware will need to process resource materials on the order of hundreds of grams to 5 kilograms within 1 to 5 hours to investigate gravity-dependent/independent phenomena. Proposed technologies must show extensibility to future ISRU missions to an asteroid which will require an increase in acquisition and processing by 1 to 2 orders of magnitude with material excavation/acquisition down to at least 3 meters. Proposals must address design and operation issues associated with performing material transfer, handling, and/or processing of solid material with gas, liquid, or molten reactants under micro-gravity and vacuum conditions. Regolith processing reactors must further address material transfer into the reactor before processing and removal from the reactor after processing while minimizing loss of reactants/products and minimizing contamination of external surfaces.

TOPIC: H2 Space Transportation

Achieving space flight remains a challenging enterprise. It is an undertaking of great complexity, requiring numerous technological and engineering disciplines and a high level of organizational skill. Human Exploration requires advances in operations, testing, and propulsion 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, 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 (including passenger transportation) supporting future orbital 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, for support 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 technologies that dramatically alter acquisition, reusability, reliability, and operability of space transportation systems.

H2.01 In-Space Chemical Propulsion

Lead Center: GRC

Participating Center(s): JSC, MSFC

The goal of this subtopic is to examine a range of key technology options associated with space engines that use methane as the propellant. Successful proposals are sought for focused investments on key technologies and design concepts that may transform the path for future exploration of Mars. In-space propulsion is defined as the development and demonstration of technologies for ascent, orbit transfer, pulsing attitude/reaction control, and descent engines. Key operational and performance parameters include:

- Reaction control thruster development in the 5 to 100 lbf thrust class with a target vacuum specific impulse of 325-sec. 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.
- Ascent/descent pressure-fed engines with 1,500 to 25,000 lbf thrust with a target vacuum specific impulse of 350 to 360-sec. The engine should be capable of throttling to 5:1 (20% power), and the chamber pressure should range from 200 to 650 psig.
- Ascent/descent pump-fed engine development is projected to range from 10,000 to 25,000 lbf thrust with a minimum vacuum specific impulse of 360-sec. The propulsion system should be capable of stable throttling to 10:1 (10% power). The engine shall achieve 90% rated thrust within 0.5 second of the issuance of the ‘Engine ON’ command.

Specific technologies of interest for operation with liquid and gaseous methane are sought. Relevance of the technology to compatibility and applicability to challenges with methane must be identified. In addition, these engines should be compatible with the future use of in situ produced propellants such as oxygen and methane. For all proposed technologies, the proposer shall show in the proposal how the component would fit in a system cycle based on thermal capabilities and pressure budgets. Propulsion technologies of interest that support the performance parameters defined above include:

- New additive manufacturing techniques that can be demonstrated to allow for rapid manufacturing, surface finishes, structural integrity, and significant cost savings for complex combustion devices and turbomachinery components compared to the conventional manufacturing. Manufacturing methods must scale to a final flight component.
- Low-mass propellant injectors that provide stable and uniform combustion over a wide range of propellant inlet conditions.
- Combustion chamber designs using high temperature materials, coatings, and/or ablatives for combustion chambers, nozzles, and nozzle extensions.
- Regenerative cooled combustion chamber technologies which offer improved performance and adequate chamber life.
- 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 fatigue life impellers, zero net positive suction head (NPSH) inducers, low leakage seals, and long life in situ propellant fed bearings.

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.

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 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 released to stay within the current environmental regulations. The NTP primary test requirements can have multiple start-ups (>8) with the longest single burn time ~50 minutes.

Specific engine technologies of interest to meet the proposed requirements include:

- High temperature (> 2600K), low burn-up composite, carbide, and/or ceramic-metallic (cermet) based nuclear fuels with improved coatings and/or claddings to maximize hydrogen propellant heating and to reduce fission product gas release and particulates into the engine's exhaust stream.
- Long life, lightweight, reliable turbopump modeling, designs and technologies including seals, bearing and fluid system components. Throttle ability is also considered. Zero net positive suction head (NPSH) hydrogen inducers have been demonstrated that can ingest 20-30% vapor by volume. The goal would be to develop inducers that can ingest 55% vapor by volume for up to 8 hours with less than 10 percent head fall off at the design point. Develop the capability to model (predict) turbopump cavitation dynamics. This includes first order rotating and alternating cavitation (1.1X –2X) and higher (6X-10X) order cavitation dynamics.
- High temperature and cryogenic radiation tolerant instrumentation and avionics for engine health monitoring. Non-invasive designs for measuring neutron flux (outside of reactor), chamber temperature, operating pressure, and liquid hydrogen propellant flow rates over wide range of temperatures are desired. Sensors need to operate for months/years instead of hours. Robonaut type inspections for prototype flight test considered.
- Concepts to cooldown the reactor decay heat after shutdown to minimize the amount of open cycle propellant used in each engine shutdown. Depending on the engine run time for a single burn, cool down time can take many hours.
- Low risk reactor design features which allow more criticality control flexibility during burns beyond the reactor circumferential rotating control drums, and/or provide nuclear safety for ground processing, launch, and possible launch aborts.

Specific ground test technologies of interest to meet the proposed requirements include:

- Effluent scrubber technologies for efficient filtering and management of high temperature, high flow hydrogen exhausts. Specific interests include:
 - Filtering of radioactive particles and debris from exhaust stream having an efficiency rating greater than 99.9%.
 - Removal of radioactive halogens, noble gases and vapor phase contaminants from a high flow exhaust stream with an efficiency rating greater than 99.5%.
- Technologies providing a low power nuclear furnace to 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 technologies that can lead to high-power (100-kW to MW-class) 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, and at very high power levels enable piloted 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 system efficiencies exceeding 60% and 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.

Specific technologies of interest in addressing high power electric propulsion challenges include but are not limited to:

- Advanced concepts for high power plasma thruster systems that provide quantifiable benefits over state of the art high power electric propulsion systems. Proposals addressing advanced technology concepts should include a realistic and well-defined roadmap defining critical technology development milestones leading to an eventual flight system.
- Electric propulsion systems and components that enable the use of alternative space storable propellants, such as condensable or metal propellants and potential in-situ resource derived propellants.
- Advanced manufacturing methods for the fabrication of high power thruster components and associated systems; of particular interest is additive manufacturing for complex parts and components. 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.
- 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 (equal to or $>10^9$ pulses) operation.

In addressing technology requirements, proposers should identify candidate thruster systems and potential mission applications that would benefit from the proposed technology.

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.

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, transfer, and instrumentation to support NASA's exploration goals. This includes a wide range of applications, scales, and environments consistent with future NASA missions. Specifically, listed in order of NASA's current priority:

- Simple mass efficient techniques for vapor cooling of structural skirts (aluminum, stainless, or composites) on large upper stages containing liquid hydrogen and liquid methane (can include para-to-ortho hydrogen catalyst for hydrogen applications).
- Lightweight, multifunctional cryogenic insulation systems (including attachment methods) that can survive exposure to the free stream during the launch/ascent environment in addition to high performance (less than 0.5 W/m² with a warm boundary of 220 K) on orbit or <5 W/m² on Mars surface.

- Advanced cryogenic spacecraft components including:
 - Valves (minimum $\frac{1}{2}$ " tube size) for low (< 50 psi, $C_v > 5$, goal of 100+) pressure liquid hydrogen with low internal (~ 1 sccm, goal of < 0.1 sccm) and external (~ 3 sccm, goal of < 0.1 sccm) leakage (> 500 cycles with a goal of 5,000 cycles).
 - Isolation valve/regulation (minimum $\frac{1}{2}$ ") for high pressure (> 4500 psi) gaseous helium systems (< 70 K fluid, $C_v > 2.1$) with low internal (~ 1 sccm) and external (~ 3 sccm) leakage (> 500 cycles with a goal of 5,000 cycles).
 - Spherical all-composite 1-2 m diameter propellant tank for Mars application using LO₂/LCH₄; Pressure from 350-1000 psig; Temperature range from ambient to 77 K (LN₂); and Ghe permeability less than 1×10^{-4} sccs/m² (at 500 psi, 77 K).
- Micro-gravity cryogenic pressure control components for thermodynamic vent systems including:
 - Improved alternatives to state of the art spray bars for using fluid dynamics to collapse the ullage and thoroughly mix a propellant tank in micro-gravity.
 - Low voltage (28 VDC) two-phase flow tolerant mixing pumps of flow rates between 10 and 40 gpm.
 - Novel methods of packaging and manufacture to minimize feedthroughs to the tank and ease of installation into a tank.
- Innovative concepts for cryogenic fluid instrumentation including:
 - Fiberoptic and wireless concepts to enable accurate measurement (with minimal sensitivity to electromagnetic interference) of propellant pressures and temperatures in low-gravity storage tanks
 - Cryogenic pressure transducers (0 – 50 psia typical range, 1% full scale accuracy, 0.5 Hz response) at 20 K.
 - Low power (< 15 W goal) video camera systems for viewing fluid dynamics within a propellant tank (3 – 5 m diameter).
- Wicking materials or other novel methods/materials of liquid acquisition for use with liquid oxygen, liquid methane, and liquid hydrogen for low temperature heat pipes or tank expulsion.

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

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 atmosphere revitalization, environmental monitoring and fire protection systems, crew accommodations, water recovery systems and thermal control. Technologies must be directed at long duration missions in microgravity, including Earth orbit and planetary transit. 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.

H3.01 Environmental Monitoring for Spacecraft Cabins

Lead Center: JPL

Participating Center(s): GRC, JSC, KSC

Measurement of Inorganic Species in Water

There is limited capability for water quality analysis onboard current spacecraft. Several hardware failures have occurred onboard ISS which demonstrate the need for measurement of inorganic contaminants. Monitoring capability is of interest for identification and quantification of inorganic species in potable water, thermal control system cooling water, and human wastewater. Examples of inorganic species of interest and their levels in potable water are specified in Spacecraft Water Exposure Guidelines (SWEGs), released as JSC 63414 (Last revised - November 2008). Target compounds identified in the SWEGs that will be needed for exploration missions include ammonium, antimony, barium, cadmium, manganese, nickel, silver, and zinc. But there is also interest in measurement of other cations and anions including iron, copper, aluminum, chromium, calcium, magnesium, sodium, potassium, arsenic, lead, molybdenum, fluoride, bromide, boron, silicon, lithium, phosphates, sulfates, chloride, iodine, nitrate and nitrite. Detection limits should be below 0.5 mg/L where possible. The proposed analytical instrument should be compact, microgravity compatible, and have limited power and consumable requirements. Sample volumes should be minimized.

Particulate Monitor for Air

Instruments that measure indoor aerosols in spacecraft cabins to monitor air quality and for characterizing the background particle environment and major particle sources are desired. Real-time measurement instruments must be compact and low power, without volatile working fluids, intuitive for crew to operate, requiring minimal maintenance, and able to maintain calibration for years. A large measurement range is necessary in low gravity due to the absence of gravitational settling, and it is expected that more than one instrument, or a multi-sensor unit, will be required to cover the desired range from nanometer (ultrafine) to 50 microns in diameter. A major portion of aerosols on the International Space Station (ISS) are from lint and fibers, so instruments must not rely on spherical morphology for accurate measurements. High accuracy should be quantitatively demonstrated for the range of interest. Development of an instrument that covers a sub-range, as broad as possible, that optimizes the performance within that range and that can subsequently be easily expanded, or integrated with other instrumentation, to cover the full range and requirements will also be of interest. Ideally, the instrument would be portable, with a graphical user interface for crew to read directly and also with the ability to log data and offer standard data transfer interfaces for longer-term indoor air quality surveys.

Microbial Monitor

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, every attempt to monitor microbial communities on-board the ISS has relied on traditional, culture-based approaches. Such techniques are laborious (7 days), require a considerable amount of crew time (up to 5 hrs), sample return, and ground based analysis (1 month after sample return), and are fraught with difficulty, as different microbial species require various media or cultural conditions to grow. In current microbial quality verification protocols, which use a single medium and a single culture condition, many types of cells will go undetected.

Molecular detection of biological agents offers increased sensitivity and specificity, such that lower levels of contaminating material can be detected and unambiguous identification can be achieved. NASA is interested in an integrated molecular system that could combine all required steps such as:

- Sample collection/concentration/extraction.
- Amplification/enrichment.
- Detection.

The scope this solicitation is the first item, i.e., sample collection, concentration, and extraction. However, integration of any two of the above mentioned steps as a single module with a capability to develop the interface of the third step can also be proposed. Technologies that determine microbial content of the air and water environment of the crew habitat falls within acceptable limits and life support system is functioning properly and efficiently are solicited. Required technology characteristics include:

- 2 year shelf-life.
- Functionality in microgravity and low pressure environment (~8 psi).

Technologies that show improvements in miniaturization, reliability, life-time, self-calibration, and reduction of expendables are also of interest. The proposed integrated molecular microbial monitoring/detection system should be capable of measuring total microbial burden as well as identifying “problematic” microbial species on-board ISS (ISS MORD: SSP 50260; <http://emits.sso.esa.int/emits-doc/ESTEC/AO6216-SoW-RD9.pdf>).

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 for NASA testing.

H3.02 Bioregenerative Technologies for Life Support

Lead Center: KSC

Participating Center(s): ARC, JSC

Food Production Technologies for Space Exploration

NASA is interested in food production and related food safety technologies for ISS, transit missions, and eventual surface missions (fractional gravity). Of special interest is the use of photosynthetic organisms such as plants to produce food, and contribute to cabin O₂ production and CO₂ removal. Food production technologies should address how light use efficiency will be improved to reduce energy costs, including advanced electric and solar lighting concepts. Electric light sources should achieve at least 1.5 µmol photosynthetically active radiation per Joule of electrical energy, and solar collection systems should achieve at least a 40% delivery efficiency of solar light. Innovative concepts for gravity independent watering and nutrient delivery techniques are also needed. Technical approaches could include selecting or adapting the plants for optimal performance in smaller growing volumes common to space. All systems should consider minimizing power, mass, consumables, and biologically produced waste, while maximizing reliability and efficiency. Consumables and waste products that allow their residual water to be recovered or are easily refurbished are desirable. System TRLs should be 2-4 for Phase I. Phase II projects that evolve from the call are expected to deliver a working prototype to NASA.

Biological Systems for Wastewater Treatment

NASA is interested in efficient biological or biochemical approaches to assist in purifying and recycling wastewater in confined spaces such as crewed spacecraft or space habitats. Of special interest are biological approaches and bioreactors for removing carbon, nitrogen and phosphorus, and reduction of biosolids. Specific technologies or approaches are sought for:

- Development of long term stable inocula.
- Inoculation and start-up of bioreactors in flight, including remote operations.

Systems should consider operating with low power, low consumables, small volumes, high reliability and rapid deployment, as well as addressing multi-phase flow issues for reduced gravity. Consumables that allow their residual water to be recovered or be easily refurbished are desirable. Proposed systems shall be capable of treating combined waste waters from hygiene activities (containing surfactants/dander/body oil), human urine (with minimal flush water and a bio compatible preservative), and humidity condensate (containing VOCs). Proposed systems should also be capable of maintaining viability during long periods of quiescent operations (90-365 days) when no human generate waste water is available. Proposed systems should use fewer consumables than the current ISS physico-chemical system. System TRLs should be 2-4 for Phase I. Phase II projects that evolve from the call are expected to deliver a working prototype to NASA.

H3.03 Spacecraft Cabin Atmosphere Quality and Thermal Management

Lead Center: MSFC

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

Advances in spacecraft atmospheric quality management are sought to address cabin ventilation and flow delivery to air scrubbing equipment, suspended particulate matter removal and disposal, and volatile trace chemical contaminant removal. Methods to separate particulate matter from both the cabin atmosphere and from Environmental Control and Life Support (ECLS) system process gas streams are sought. Interest in humidity control and separation processes within life support system processes are of interest. Specifics regarding areas of interest in spacecraft atmospheric quality management are the following.

Multifunctional Filtration Techniques

Techniques and methods are sought leading to compact, low power, autonomous, regenerable bulk particulate matter separation and collection techniques suitable for general cabin air purification. The particulate matter removal techniques and methods must accommodate high volumetric flow rates up to 11.3 m³/minute, yet possess pressure drop <125 Pa. Filtration performance equivalent to HEPA rating is desired. Configurations incorporating multi-stage filtration that separate and optimize regeneration and capturing efficiency functionalities may be considered. The particulate matter separation and collection technique must be suitable for seamless integration into a spacecraft cabin ventilation system from a volumetric perspective. The techniques and methods must safely store and enable easy disposal of collected particulate matter by the crew while minimizing exposure during the disposal operation.

Combination of the particulate matter separation and collection technique with techniques possessing high removal capacity for volatile chemical contaminants, with a focus on light polar organic compounds (e.g., ethanol and acetone) and linear and cyclic siloxanes, is of interest. The volatile chemical contaminant removal techniques must accommodate high volumetric flow rates up to 11.3 m³/minute and possess pressure drop <125 Pa. The technique must provide for a minimum 1 year service life and a goal of 3 years.

ECLS System Process Gas Filtration Techniques

Techniques and methods leading to compact, regenerable methods for removing particulate matter generated in ECLS system process equipment such as carbon formation reactors and methane plasma pyrolysis reactors. Filtration performance approaching HEPA rating is desired for ultrafine particulate matter with minimal pressure drop. The gas filter should be capable of operating for hours at high particle loading rates and then employ techniques and methods to restore its capacity back to nearly 100% of its original clean state through in-place and autonomous regeneration or self-cleaning operation. Compact storage of the particulate matter after it is collected is as important as the effective collection. The device must minimize crew exposure to accumulated particulate matter and enable easy particulate matter disposal.

Process Gas Phase Moisture Removal and Collection

Innovative technologies are sought to dehumidify a hot, humid airstream and remove and collect the product as condensate for further processing. The airstream pressure is between 0.2 and 1.0 atmospheres, its temperature is 150°C and it is saturated with water vapor. The dewpoint of the airstream must be reduced to 10°C and the condensed liquid that results must be completely removed. Cooling at ambient temperature and electrical power are available. Both the electric power and liquid carryover must be minimized.

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. The systems must perform their function while using fewer of the limited spacecraft mass, volume and power resources. Advances are sought for microgravity thermal control in the following areas:

- 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 setpoint control and operate stably at 25% of their design heat load in a deep space (0 K) environment. Innovative components, working fluids, and systems may be needed to achieve this goal.
- Lightweight non-venting phase change heat exchangers are sought to ameliorate the environmental transients that would be seen in planetary (or lunar) orbit. Heat exchangers that have minimal structural mass and good thermal performance are sought. The goal is a ratio exceeding 2/3 phase change material mass and 1/3 structural mass.
- Two-phase heat transfer components and system architectures that will allow the acquisition, transport, and rejection of waste heat loads in the range of 100 kW to 10 megawatts are sought.
- Non-toxic working fluids are needed that are compatible with aluminum components and combine low operating temperature limits (<250K) and favorable thermophysical properties - e. g., viscosity and specific heat.

Technologies are expected to be raised from TRL2 to TRL 3/4 during Phase I. Minimum deliverables at the end of Phase I are analysis/test reports, but delivery of development hardware for further testing is desirable. In addition, the necessity and usefulness of moving on to a Phase II should be demonstrated. Technologies would be expected to be matured from TRL 3/4 to TRL 5 during a potential Phase II effort. Expected deliverables for a Phase II effort are analysis/test reports and prototypic hardware.

TOPIC: H4 Extra-Vehicular Activity and Crew Survival Systems Technology

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 space suit pressure garment systems (PGS); the portable life support system (PLSS); the power, avionics and software (PAS) systems including 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, with improved comfort, productivity, less fatigue, and lower injury risks. Reductions in commodity and life-limited part consumption rates and the size/weight/power of worn systems are needed. Primary goals for crew survival systems include development of technologies enhancing crew survival in the post-landing environment, significant mass reduction of hardware, and development of space-qualified survival hardware technologies designed to operate after exposure to space vacuum and thermal effects. Launch, Entry, and Abort (LEA) crew survival equipment development is a critical need tied to any future manned Design Reference Mission (DRM), as well as providing benefit to both Orion/MPCV and Commercial Crew Program engineering efforts. All proposed Phase I research must lead to specific Phase II experimental development that could be integrated into a functional EVA system.

H4.01 Crew Survival Systems for Launch, Entry, Abort

Lead Center: JSC

This subtopic seeks technology innovation supporting the launch, entry, and abort (LEA) crew survival equipment needs for future human exploration beyond low-earth orbit. Primary goals include development of technologies enhancing crew survival in the launch, entry, and abort phases of flight as well as the post-landing environment, significant mass reduction of hardware, and development of space-qualified survival hardware technologies designed to operate after exposure to space vacuum and thermal effects. LEA crew survival equipment development is a critical need tied to any future manned Design Reference Mission (DRM) laid out by the agency, as well as providing benefit to both Orion/MPCV and Commercial Crew Program engineering efforts. Many candidate technologies will have direct application to Orion's EM-2 mission and follow on manned spaceflight activities.

Systems and technologies relating to enhancement of post-landing survival and rescue following manned exploration spacecraft launch, entry, and abort (LEA) events are sought in the following areas:

- *Lightweight Survival Life Raft Materials, Construction Methods, and Related Technologies* - Programmatic need exists for a low mass, self-inflating life raft under 30 lbm. Technologies should be directed to enable crew survivability in the post landing off-shore ocean environment meeting SOLAS and/or FAA standards and Orion/MPCV Design Specification for Natural Environments (DSNE) sea state definitions while meeting a 30 lbm mass constraint. Of particular interest is significant mass reduction in raft inflation systems, innovative construction techniques and techniques / methods for enhanced operability by long-duration spaceflight de-conditioned crew members. The current space equivalent baseline is an FAA six person raft. Currently this type of raft does not exist without ‘breaking’ the 30 lbm mass requirement or sacrificing survivability attributes. Efforts should focus upon novel lighter weight materials and constructions methods, as well as inflation systems. Another area of concern from the medical community is raft ops and ingress by deconditioned crew members experiencing neurovestibular effects of long-duration spaceflight.
- *Suit-Integrated Global Coverage Personal Locating Technologies* - Current commercially-available Personal Locating Beacons (PLBs) are not optimized for use in the manned spaceflight thermal and vacuum environment or integration into a survival suit cover layer. Innovative technologies/efforts should be directed towards novel flexible patch antenna development, robust beacon packaging technologies, analytical methodology for integrated beacon operational analysis, and beacon triggering (RF, saltwater, etc.) technologies. Additionally, there is interest in prototype electronics board development for use with future satellite-based GPS/Doppler locating systems such as the NASA-led Distress Alerting Satellite System (DASS). This technology development subheading also includes development of high-reflectivity materials in the visible, IR, and radar wavelengths.
- *Occupant Protection Materials, Analytical Tools, and Technologies* - Products and materials leading to enhanced occupant protection in the capsule landing loads environment. Innovative technologies and efforts should be directed towards acceleration, vibration, and impact attenuation systems designed to mitigate dynamic flight event impacts on the crew member. Of potential interest are materials and products to protect crew members from head and neck injuries during landing load shocks. Additionally, technologies such as innovative restraint mechanisms preventing crew member flail and flail-related injuries during dynamic flight events are of potential interest. When considering impact attenuation material properties, attention should be paid to preventing crew member exposure to rate changes of acceleration greater than 500 g/s. Material space-rating requirements should be taken into account in relation to the manned spaceflight thermal / vacuum environment. Within this subtopic, analytical methods should be directed to prevention of extremity flail, head, and neck injuries during linear, vibrational, and angular acceleration events.
- *In-Suit Waste Management Technologies* - Development of technologies allowing for long-duration waste management for use by a pressurized suited crew member. In the event of cabin depressurization or other contingency, crew members may need to take refuge in LEA pressure garments for a long-duration (144-hour) return trajectory back to Earth. Technology development should be tailored to a 144-hour suited contingency, meeting the NASA Human Systems Integration Requirement (HSIR) inside an LEA suit pressurized to 4.3 PSID referenced to the ambient environment. Waste management technologies should address fecal and urine waste containment and human physiological responses / countermeasures to long duration waste management in a pressurized survival suit environment from one to six days. Advanced technologies and materials should ideally provide for urine collection of up to 1L per day per crew member, for a total of 6 days. Additionally, mitigation and/or elimination of urine-generated ammonia inside the pressure garment volume is a candidate area of interest. Fecal collection rates should be targeted for 75 grams of fecal mass and 75 mL fecal volume per crew member per day for a total of 6 days duration.

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.

H4.02 EVA Space Suit Pressure Garment Systems**Lead Center: JSC**

Space suit pressure garments technology developments are focused on providing enabling technologies for long-duration missions inclusive of extensive extra-vehicular activity (EVA). To that end, priority technologies address mass reductions, durability and reliability. Mass reduction for exploration pressure garments is driven, in addition to launch mass considerations, by the human factor of on-back weight for a planetary walking suit configuration following a long-duration micro-gravity transit, which may reduce astronaut load bearing capability. Driving reference missions such as a 1.5-year Mars surface stay include on the order of 700 hours of EVA. Therefore, long-duration exploration missions require, in some cases orders of magnitude, increases in suit durability or new approaches to providing long duration mission EVA capability or logistics. The following technology areas address mass reduction, increased durability, or both.

Multi-function Materials

The pressure garment must perform functions such as: gas retention and structural integrity including fall cases; mobility to perform science and surface asset set-up and maintenance; and environmental protection from thermal extremes, micrometeoroids and secondary impacts, dust, and tears. The combination of performance of two or more of these functions in single pressure garment material layer contributes to mass reduction. For example, a composite structure that provides gas retention, structural integrity, and thermal protection/regulation would be beneficial. Another example would be a fabric that mitigates the effects of dust and is thermal protection in a single layer is sought.

Self-diagnosing and Self-healing Materials

Fabric wear due to repetitive joint cycling, dust and UV radiation exposure, and handling is anticipated. To improve safety and decrease crew time investment in the EVA system, materials that can indicate wear or self-heal are valuable. Current materials with these capabilities are heavy, stiff, or require prohibitive power quantities. Ideally, self-diagnosing and self-healing capabilities would be combined in with a material that also performs one of the functions described in the ‘Multi-function materials’ section

Titanium Bearings

This topic addresses both mass reduction and increasing durability. The emphasis on mass reduction is countered by the need for increased mobility, which tends to increase mass due to the addition of low torques bearings in joint mobility systems. Titanium bearings are being incorporated to decrease the mass of joint mobility systems. However, refinement of titanium bearings to meet durability requirements is required based on 2014 bearing in-configuration oxygen compatibility testing, which passed for flammability, but indicated cycle wear issues. To address titanium bearing wear, coatings, treatments, lubricants, ball material, and space ball materials are all considerations to be investigated. Titanium bearings that can withstand 8 psi suit pressure plug loads in addition to suit manloads over tens of thousands of cycles are required for exploration pressure garments.

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.

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, a significant risk for the development of spacesuit avionics is the non-availability certain ancillary electronic devices that are rated for spaceflight. 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-cm²/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 no particular order of priority, key innovations sought include:

- Wireless Communication:
 - 802.11n baseband processor that supports channel bonding and possibly multiple RF channels.
 - Low-power (<5W), low-rate (500-1000kbps) baseband software-defined radio that is, at the very least, capable of supporting the existing Space-to-Space Communications System (SSCS) wireless suit interface.
 - Dual-band WLAN-class RF front-end module capable of supporting the SSCS (410 to 420 MHz) and a channel-bonded 802.11n system (40MHz of bandwidth) operating at the 2.4GHz ISM band. Consideration will also be given to devices capable of supporting the 802.11n system operating in the 900MHz region. Consideration for supporting multiple antennas for the 802.11n system will be given, but this is not required.
- Human-Machine Interface (HMI) for Informatics:
 - Input device technologies that provide mouse-like functionality or a minimum of directional control to navigate display menu system. In general devices need to minimize hand use. Technologies that require hand use must be limited to operation with a single gloved EVA hand. Devices must minimize SWAP and computing power needed for final implementation. Solutions must be reliable and robust enough for vacuum space environments.

- 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.
- Audio:
 - Simultaneously sampled, deep bit-width, low rate Analog to Digital Converter (ADC) circuits and/or Pulse Density Modulator (PDM) circuits. Requirements are for devices with dynamic range greater than 90 dB (threshold) and as much as 110 dB (goal) with sampling rates > 24 kS/s (threshold) and as high as 48 kS/s (goal). Requirements exist for 8 channel devices (threshold) simultaneously sampled (< 1 ps jitter) with a goal of 16 channels. Devices should support a Least Significant Bit (in Pulse Code Modulation) of 1 micro-Volt or less with a noise floor of 10 micro-Volts or less.
 - Highly linear, high Signal to Noise Ratio (SNR) Micro Electro Mechanical System (MEMS) microphones with PDM output. Microphones should exhibit < 1% THD at 105 dB SPL (threshold) and 115 dBSP (goal). Microphones should have frequency response of +/-10 dB from 80 Hz to 12 kHz and SNR > 50 dB (threshold) and > 60 dB (goal).
 - High dynamic range, audio frequency Digital to Analog Converters (DACS). Converters should provide >100 dB spur free dynamic range (TBR).
 - High efficiency, low power (< 1 W output), audio frequency power amplifiers.
 - High efficiency, audio frequency pre amplifiers with adjustable gain (0 to 30 dB).
 - High speed (> 100 Mb/s) serial communications transceivers suitable for protocols such as Ethernet, Low Voltage Differential Signal (LVDS) and Rocket-IO.

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 Spacecraft Materials and Structures

The SBIR topic area of Lightweight Spacecraft Materials and Structures 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 multifunctional materials and structures, deployable structures, and extreme environment structures. 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 Deployable Structures

Lead Center: LaRC

Participating Center(s): GRC, JSC

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

- Large deployable solar arrays for 50+ kW solar electric propulsion (SEP) missions.
- Lightweight deployable hatches for manned inflatable structures.

Design solutions must minimize mass and launch volume while meeting other mission requirements including deployed strength, stiffness, and durability.

Innovations are sought in the following areas for both capabilities (deployable solar arrays and deployable hatches):

- Novel design, packaging, deployment, and in-space manufacturing or assembly concepts.
- Lightweight, compact components including booms, ribs, 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 Arrays

NASA is currently developing solar array systems for solar electric propulsion in the 30-50 kW power range for near-term missions such as the Asteroid Redirect Mission (ARM). This subtopic seeks structures and materials innovations for the next generation of lightweight solar arrays beyond 50 kW. NASA has a vital interest in developing much larger arrays over the next 20 years with up to 1 MW of power (4000 m² total deployed area) for SEP-powered exploration missions. Scaling up solar array size by over an order-of-magnitude will require game changing innovations. In particular, novel flexible-substrate designs are needed that minimize structural mass and packaging volume while maximizing deployment reliability, deployed stiffness, deployed strength, and longevity.

Nominal solar array requirements for large-scale SEP applications are:

- Specific power > 120 W/kg at beginning of life (BOL).
- Packaging efficiency > 40 kW/m³ BOL.
- Deployment reliability > 0.999.
- Deployed stiffness > 0.1 Hz.
- Deployed strength > 0.1 g (all directions).
- Lifetime > 5 yrs.

Variations of NASA's in-house large solar array concept referred to as the Compact Telescoping Array (CTA) could be used for design, analysis, and hardware studies. Improved packaging, joints, deployment methods, etc. to enable CTA-type solar arrays up to 4000 m² in size (1 MW) with up to 250 W/kg and 60 kW/m³ BOL are of special interest. The CTA is described in Reference 1.

Capability #2: Deployable Hatches

NASA is also seeking concepts for lightweight, deployable hatch systems for manned inflatable structures that require ingress/egress across a pressure differential. Designs should be efficient and tight-sealing and use softgoods materials in whole or in part. "Softgoods" refers to advanced high-strength fabrics or woven materials. Applications of this technology include barometric chambers, airlocks and habitats, and large-scale space hangars for on-orbit assembly. The pressure vessel geometry could require hatches that conform to flat, singly-curved, or doubly-curved surfaces. Concepts will be evaluated on mass efficiency, minimal packaging volume for launch, operational reliability and simplicity, and strategy for integration into a soft-goods structure. Proposals should detail a concept of operations including packaged and deployed geometry, deployment approach, and operation of sealing/unsealing the hatch. Reference 2 provides additional information on deployable soft space structures.

Nominal hatch requirements are:

- 40-inch diameter clear opening for ingress/egress.
- Designed for a differential pressure of 15.2 psi.
- Hatch can be sealed and verified even when parent vessel is at vacuum.
- The hatch can be easily operated by a suited astronaut.

For both capabilities, contractors should prove the feasibility of proposed innovations using suitable analyses and tests in Phase I. In Phase II, significant hardware 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.

References:

- Mikulas, M. M. et al., "Telescoping Solar Array Concept for Achieving High Packaging Efficiency," To be presented at the AIAA Spacecraft Structures Conference, January 2015.
- Bell L., "Deployable Soft Space Structures: Concepts and Application Requirements," 50th AIAA Structures, Dynamics and Materials Conference, Paper 2009-2168, May 2009.

H5.02 Extreme Temperature Structures

Lead Center: MSFC

Participating Center(s): LaRC

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 systems and manufacturing processes which enable the capability to store and transfer cryogenic propellants (liquid oxygen & liquid hydrogen) to orbit. Operating temperature ranges for these fluids are -183°C to -253°C. Specific areas include:
 - Composite systems to be used in the construction of storage vessels or ductwork for cryogenic propellants. 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 composite structures. Concepts must address seal systems for both composite to composite and composite to metal applications. Techniques must consider scale up and manufacturability factors.
- *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 1500°C to 3000°C, while maintaining structural integrity. Significant reductions in vehicle weight can be achieved with the application of hot structures, which do not require parasitic thermal protection systems. This area seeks innovative technologies in one or more of the following:
 - Light-weight, low-cost, composite material systems that include continuous fibers.
 - Significant improvements of in-plane and thru the thickness mechanical properties, compared to current high temperature laminated composites.
 - Decreased processing time and increased consistency for high temperature materials.
 - Improvement in potential reusability for multiple missions.
 - Low conductivity, low thermal expansion, high impact resistance.

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

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/501625main_TA12-ID_rev6_NRC-wTASR.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), inflatable, protective (radiation and micrometeoroids and orbital debris), sensing, healing, in-situ inspectable (e.g., IVHM), actuating, integral cooling/heating, and power generating (thermal-electric, photovoltaic ...), 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 FY15, this SBIR subtopic seeks innovative structures and materials technologies and capabilities for three principle areas:
 - Integration of acoustic metamaterial concepts into the primary structure to reduce interior acoustic and vibration environments. Specifically, innovations are solicited which maintain the load bearing capability of the primary structure while simultaneously reducing interior noise and vibration levels below 400 Hz. Successful innovations are anticipated to enable the design of lighter and cheaper spacecraft and launch vehicle structures, as well as lower costs associated with ruggedizing and qualifying spacecraft and launch vehicle secondary structures.
 - Sensory materials incorporated into a primary structure to provide health monitoring data, and low-mass/wireless methods of transmitting localized structural responses to diagnostic models for material and structural state. Manufacturing technologies capable of producing structural components with embedded capability for sensing strain, damage initiation and propagation, and temperature are of particular interest. Ideally, the sensing technology should also augment the load carrying capability or some other structural design requirement. Technologies should enable weight reduction with similar or better structural performance when compared to traditional approaches.
 - Thin film conformal layers on structures or integrated in structures with different functional capabilities. Examples include conformal solar cells, conformal antennas, conformal energy storage, and conformal energy harvesting. The conformal layer should provide additional functionality to the structure without adversely affecting the load bearing capability. The conformal functional layer offers the potential for significant weight reduction and reduced complexity for spacecraft, rovers, and habitats. For example, conformal photovoltaic layer on spacecraft, rover, or habitat can eliminate the need for separate solar array panels."

TOPIC: H6 Autonomous & 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.

H6.01 Mobility Subsystem, Manipulation Subsystem, and Human System Interaction

Lead Center: JSC

Participating Center(s): ARC, KSC

The objective of this subtopic is to create human-robotic technologies (hardware and software) to improve the exploration of space.

Robots can perform tasks to assist and off-load work from astronauts. Robots may perform this work before, in support of, or after humans.

Ground controllers and astronauts will remotely operate robots using a range of control modes (tele-operation to supervised autonomy), over multiple spatial ranges (shared-space, line-of-sight, in orbit, and interplanetary), and with a range of time-delay and communications bandwidth.

Proposals are sought that address the following three subtopics:

- *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, and infrastructure-free localization.
- *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, and novel manipulation methods.
- *Human-system interaction (HSI)* - 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, ground data system tools, command planning and sequencing, real-time visualization/notification, and software for situational awareness.

TOPIC: H7 Entry, Descent, and Landing Technologies

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 modeling, testing, monitoring, and inspection of ablative thermal protection materials 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. 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. Inspection of thermal protection material/aeroshell interfaces is critical to assure quality and is extremely difficult for porous, low density composites.

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, Sensors and NDE Methods

Lead Center: ARC

Participating Center(s): GRC, JPL, JSC, LaRC

The technologies described below support the goal of developing advancements in instrumentation systems, inspection techniques, 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.

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/cm² (primarily convective) and integrated heat loads of up to 55 kJ/cm², and the second at heat fluxes of 100-200 W/cm² and integrated heat loads of up to 25 kJ/cm². 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/cm² (primarily convective) and integrated heat loads of 10 kJ/cm², and the second pulse at heat fluxes of 30-50 W/cm² and heat loads of 5 kJ/cm². 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/cm², with radiation contributing up to 75% of that flux, and integrated heat loads from 75-150 kJ/cm². These materials are currently based upon 3-D woven architectures. Technologies sought are:

- 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.
- Non Destructive Evaluation (NDE) tools for evaluation of bondline and in-depth integrity for light-weight rigid and/or flexible ablative materials. Non Destructive Evaluation (NDE) tools are sought to verify design requirements are met during manufacturing and assembly of the heat shield, e.g., verifying that anisotropic materials have been installed in their proper orientation, and that the bondline as well as the TPS materials have the proper integrity and are free of voids or defects. Void and/or defect detection requirements will depend upon the materials being inspected. Typical internal void volume detection requirements are on the order of 6 mm on a side (6x6x6), and bondline defect detection requirements are on the order of 25.4 mm by 25.4 mm by the thickness of the adhesive.
- 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 ablatives (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:

- *Sensors* - Sensor system design, including electronics, with specified measurement performance, mass, power, and volume. Proposed test approach for Phase II, which 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.
- *NDE* - Detection technique/process and equipment design, to meet the specified requirements. Validation test plan, to be executed on relevant materials in Phase II.
- *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:

- *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.
- *NDE* - Working engineering model of the detection system with the proposed performance characteristics. Full report of development, architecture, and measurement performance, including data from completed test proposed in Phase I (TRL 4-5).
- *Ablator and Mechanical Modeling* - Prototype (Beta) software and results from the validation test cases.

H7.02 Diagnostic Tools for High Velocity Testing & 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 thermochemistry 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.

The range of diagnostics to be considered is not restricted. Examples of diagnostics of interest include those that characterize high enthalpy flows (e.g., temperature, velocity, electron number density, pyrolysis/ablation byproducts) or characterization of test articles (recession, thermal emission, etc.). Proposals for adapting existing techniques to unique aspects of the facility (e.g., free flight in ballistic range, or short duration in shock tubes) are of interest, as well as the development of new techniques. Proposers are encouraged to contact operators and users of individual facilities to understand their specific challenges and requirements, and for details of interfacing into the existing systems.

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 Systems

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.
- Nuclear fission systems to power electric spacecraft and/or surface space power systems.
- Photovoltaic technology to power electric spacecraft.

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 CO₂ (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.

Technologies to enable space-based nuclear fission systems are sought for three power classes:

- Kilowatt-class to support robotic missions as precursors to human exploration.
- 10 kWe-class power conversion devices and 400-500K radiators to support large surface power and 100 kWe-class electric propulsion vehicles.
- 100 kWe-class power conversion devices, >500K radiators, and high temperature fuels, materials, and heat transport to support MW-class electric vehicles.

Photovoltaic (PV) technologies are sought to provide lower-cost power systems with particular emphasis on high power arrays to support solar electric propulsion spacecraft on deep space missions.

H8.01 Space Nuclear Power Systems

Lead Center: GRC

Participating Center(s): JPL, JSC, MSFC

NASA is developing fission power system technology for future space exploration applications using a stepwise approach. Initial small fission systems are envisioned in the 1 to 10 kWe range that utilize cast uranium-metal fuel and heat pipe cooling coupled to static or dynamic power conversion. Follow-on systems could produce 10s or 100s of kilowatts utilizing a pin-type uranium fueled reactor with pumped liquid metal cooling, dynamic power conversion, and high temperature radiators. The anticipated design life for these systems is 8 to 15 years with no maintenance. Candidate mission applications include power sources for robotic precursors, human outposts on the moon or Mars, and nuclear electric propulsion (NEP) vehicles. NASA is planning a variety of nuclear and non-nuclear system ground tests to validate technologies required to transfer reactor heat, convert the heat into electricity, reject waste heat, process the electrical output, and demonstrate overall system performance.

The primary goals for the early systems are low cost, high reliability, and long life. Proposals are solicited that could help supplement or augment the planned NASA system testing. Specific areas for development include:

- 800-1000 K heat transport technology for reactor cooling (liquid metal heat pipes, liquid metal pumps).
- 1-10 kWe-class power conversion technology (thermoelectric, Stirling, Brayton).
- 400-500 K heat rejection technology for waste heat removal (water heat pipes, composite radiators, water pumps).

The early systems are expected to provide the foundation for later systems in the multi-hundred kilowatt or megawatt range that utilize higher operating temperatures, alternative materials, and advanced components to improve system performance. Specific areas for development include:

- 100 kWe-class power conversion technologies.
- Waste heat rejection technologies for 500 K and above.
- High temperature reactor fuels, structural materials and heat transport technologies.

H8.02 Solid Oxide Fuel Cells and Electrolyzers

Lead Center: GRC

Participating Center(s): GRC, 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 hydrocarbon fuels, 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 cell, stack, materials and system development for operation on 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 O₂; scalable to 2 to 3.5 kg/hr O₂ at maturity. CO₂ 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 as specified after at least 500 hours of steady state operation on propellant-grade methane and oxygen with 2500 hours expected of a mature system. System should startup dry but after reaching operating conditions an amount of water/H₂ consistent with what can be obtained from anode recycle can be used. Amounts must be justified in the proposal.
- Minimal cooling required for power applications. 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.
- Minimal power (heating plus electrolysis) required for CO₂ electrolysis applications.
- Demonstrate electrolysis of the following input gases: 100% CO₂, Mars atmosphere mixture (95.7% CO₂, 2.7% N₂, 1.6% Ar), 100% water vapor, and 0.7 to 1.6:1 CO₂:H₂O mass ratio. A final test using pure CO₂ 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 for improvements in capability and reliability of PV power generation for space exploration missions. Power levels for PV applications may reach 100s of kWe. System and component technologies are sought that can deliver efficiency, cost, reliability, mass and volume improvements under various operating conditions, in extreme environments, and over wide temperature ranges.

PV technologies must enable or enhance the ability to provide low-cost, low mass and higher efficiency for power systems with particular emphasis on high power arrays to support solar electric propulsion missions. Areas of particular emphasis include:

- Advanced PV blanket and component technology/ designs that support very high power and high voltage (> 200 V) applications.
- PV power generation (cell, interconnect, and small self-deployable arrays) for CubeSat/ small satellite applications.
- PV module/ component technologies that emphasize low mass and cost reduction (in materials, fabrication and testing).
- Improvements to solar cell efficiency that are consistent with low cost, high volume fabrication techniques
- Automated/ modular fabrication methods for PV panels/ modules on flexible blankets (includes cell laydown, interconnects, shielding and high voltage operation mitigation techniques).
- Integrated PV system including cells, blanket, array, inverters, interconnect technologies, storage, structures, etc. with a balance-of-components while matching specifications of various systems.
- Simulated PV capability that take optimizes system components, ensures compatibility of modules/inverters, and takes temperature extremes and unique aspects of the space environment into account including radiation tolerance.

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.

TOPIC: H9 Space Communications and Navigation (SCaN)

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.

Today our communication and navigation capabilities, using Radio Frequency technology, can support our spacecraft to the fringes of the solar system and beyond. As we move into the future, we are challenged to increase current data rates - 300 Mbps in LEO to about 6 Mbps at Mars - to support the anticipated numerous missions for space science, earth science and exploration of the universe. Technologies such as optical systems, RF systems including ground based Earth stations, surface networks, cognitive and adaptive systems and networks, access links, reprogrammable communications systems, advanced antenna technology, innovative, relevant research in the areas of positioning, navigation, and timing (PNT) and communications in support of launch services are very important to the future of exploration and science activities of NASA.

This year, three major technology areas are being solicited:

- Long Range Optical Telecommunications, seeks innovative technologies for significant improvement in long range (> 0.1 AU) optical telecommunications providing increased data throughput in both directions, and lower spacecraft mass and power, in support of human and robotic space missions.
- Intelligent Communications Systems, seeks advancements of cognitive system capabilities to sense, detect, adapt, and learn from the environment to improve communication and/or navigation capabilities for NASA missions. And
- Flight Dynamics and Navigation Technology for the development of software tools, ground facilities, system concepts and on-board devices to enhance capabilities for providing spacecraft position, attitude, and velocity and for advancements that enable independence from earth supervision. For spacecraft systems, emphasis is placed on size, weight and power improvements to reduce the user spacecraft burden or provide greater capability within NASA's networks. Innovative solutions centered on operational issues are needed in all of the aforementioned areas. All technologies developed under this topic area to be aligned with the Architecture Definition Document and technical direction as established by the NASA SCaN Office.

For more details: <https://www.spacecomm.nasa.gov/spacecomm/>

H9.01 Long Range Optical Telecommunications

Lead Center: JPL

Participating Center(s): GRC, GSFC

This subtopic seeks innovative technologies for long range (> 0.1 AU) optical telecommunications supporting the needs of space missions where human and robotic explorers will visit distant bodies within the solar system and beyond. Multi-use technologies that will also benefit high rate optical communications in cis-lunar and Earth-Sun Lagrange point domains are of particular interest. Goals are increased data-rate capability in both directions and significant reductions of telecommunications system mass, power-consumption, and volume at the spacecraft.

Proposals are sought in the following areas (TRL3 Phase I, and TRL4-5 Phase II):

- *Spacecraft Disturbance Isolation Platforms and Related Technologies* - Compact, low mass, space-qualifiable, vibration isolation and spacecraft disturbance rejection assemblies with included re-usable launch lock that require less than 5 W of average power and mass less than 3 kg that will attenuate an integrated spacecraft micro-vibration angular disturbance of 150 micro-radians (with a spectrum of 10E-6 rad²/Hz below 0.1 Hz, with a 20 dB/decade roll-off), plus an assumed translational disturbance resulting from an offset of 2 m between the payload and the center of rotation of the spacecraft, to less than 0.15 micro-radians (1-sigma), for payloads massing between 3 and 25 kg. Proposed solutions may use control inputs from ground-beacon-based pointing sensor with noise of 150 nrad/sqrt (Hz). Also desired are innovative low-noise, low mass, low power, DC-kHz bandwidth inertial, angular, position, or rate sensors to assist platform stabilization, including beaconless pointing.
- *PPM Space Laser Transmitters* - Space-qualifiable, 1520 to 1630 nm laser transmitter for pulse-position modulated (PPM) with >25% DC-to-optical (wall-plug) efficiency. Transmitter must support laser pulse widths from 0.2 ns (or lower) to 16 ns (or greater) for PPM orders from 16 slots per symbol (6.25% average duty cycle) to 256 slots per symbol plus 64 slots of inter-symbol guard time (0.31% average duty cycle). Other desired parameters include: <35 ps pulse rise and fall times and jitter; <25% pulse-to-pulse energy variation (at a given pulse width); single spatial mode output with near transform limited spectral width, single polarization with at least 20 dB polarization extinction ratio; amplitude extinction ratio greater than 48dB, average output power of 10 to 100W; massing less than 500 g/W. Laser transmitter to feature slot-serial PPM data input at CML, LVDS, or AC-coupled PCEL levels and an RS-422 or LVDS levels control port. All power consumed by control electronics will be considered as part of DC-to-optical efficiency. Also of interest for the laser transmitter is robust and compact packaging with >100krad radiation tolerant electronics inherent in the design. Detailed description of approaches to achieve the stated efficiency is a must. Also of interest is a space-qualifiable high power fiber switch for implementing redundant space laser transmitters.
- *PPM Ground Laser Transmitters* - >2000W average power PPM laser transmitters for nested modulation forward links to support simultaneous data rates of ~10 b/s (outer code) and at least 10 Mb/s (inner code) with an outer rate inter-symbol guard time of 50%. Operational wavelength in either 1030 - 1080 nm or 1480 - 1570 nm bands. Other desired parameters include: spectral line width of 0.5 nm or less; amplitude extinction ratio greater than 35 dB; output M-squared of 1.2 or less; projected MTTF of at least 20,000 hours; high wall-plug AC-to-optical power efficiency.
- *Photon Counting Near-infrared Detectors Arrays for Ground Receivers* - Close packed (not lens-coupled) kilo-pixel arrays sensitive to 1520 to 1630 nm wavelength range with single photon detection efficiencies greater than 90%, single photon detection jitters less than 40 ps FWHM, total active diameter greater than 500 microns, 1 dB saturation rates of at least 10 mega-photons (detected) per pixel, false count rates (intrinsic dark rate plus after-pulsing rate) of less than 1 MHz/square-mm. Also desired are cryogenic read-out integrated circuits with an operating temperature of 40K capable of time-tagging electronic pulses from 64 high-bandwidth readout channels to an accuracy of 100 ps or better and a maximum count rate of 10 MHz per channel. The approach should demonstrate scalability to >1000 readout channels. Also of interest are: sub-Kelvin cryogenic systems which can support >1000 channels of high-bandwidth (2 GHz or higher) readout signals with a low-temperature hold time of 24 hours, and preferably can be tilted from vertical to near-horizontal during operations; cryogenic interconnects and vacuum feedthroughs for high-density cabling solutions capable of supporting kilochannel readouts from a 1 K detector focal plane stage to room temperature.
- *Photon Counting PPM Digital Ground Receivers* - Digital receiver and decoder assemblies for processing photon counting detector array outputs of PPM encoded data. Receiver to support PPM orders from 2 to 256, data rates to at least 1 Gb/s, and PPM slot widths down to 200 ps. Receiver shall support SCPPM or other demonstrated low-gap-to-capacity (< 1 dB) forward error correction code for PPM. Receiver shall provide signal and background photon flux estimates at kHz rates to support 2-axis control of a fine pointing mirror in a ground receiver telescope.

- *Photon Counting Near-infrared Detectors Arrays for Flight Receivers* - 128x128 or larger array with integrated read-out integrated circuit and thermo-electric cooling for the 1030 to 1080 nm or 1520 to 1650 nm wavelength range with single photon detection efficiencies greater than 40% and 1dB saturation loss rates of at least 2 mega-photons/pixel and dark count rates of <10 kHz/pixel. ROIC to provide time-stamping of each photon arrival with a precision of 500 ps or better, and an interface bus bandwidth of 125 MHz or less. Radiation doses of at least 5 krad (unshielded) shall result in less than 10% drop in single photon detection efficiency and less than 2X increase in dark count rate.
- *Advanced Flight Opto-electronics* - Ultra-small, low-mass, low-cost, low-power, modular transceivers, transponders, amplifiers, and components for 1520 to 1630 nm optical links at GHz modulation bandwidths, incorporating integrated photonic circuits and other components such as commercially-available ASICs to provide forward-error-correction and other digital signal processing as required.
- *Ground-based Telescope Assembly* - All-weather ground station telescope/photon-bucket technologies for implementing effective receive areas of > 100 square meters at a projected production cost of < \$300K per square meter. Operations wavelength is monochromatic at a wavelength in the range of 1000-1600nm. Key requirements: a maximum image spot size of <20 microradian (static error); capable of operation while pointing to within 3° of the solar limb; and field-of-view of >50 micro-radian. Telescope shall be positioned with a two-axis gimbal capable of <50 micro-radian pointing accuracy, with dynamic error <10 micro-radian RMS while tracking after tip-tilt correction.

Research should be conducted to convincingly prove technical feasibility (proof-of-concept) during Phase I, ideally through hardware development, with clear pathways to demonstrating and delivering functional hardware meeting all objectives and specifications, in Phase II.

References:

- (<http://trs-new.jpl.nasa.gov/dspace/bitstream/2014/42091/1/11-1338.pdf>)
- (http://ipnpr.jpl.nasa.gov/progress_report/42-183/183A.pdf)
- (http://ipnpr.jpl.nasa.gov/progress_report/42-185/185D.pdf)
- (http://ipnpr.jpl.nasa.gov/progress_report/42-182/182C.pdf)

H9.02 Intelligent Communication Systems

Lead Center: GRC

Participating Center(s): JPL

NASA seeks novel approaches to improve mission communication and navigation capabilities for science and exploration through advancements in cognitive systems and automation. Over the past 10 years software defined radios and their applications have emerged and demonstrated the potential and applicability of reconfigurable platforms and applications to space missions. The SCaN Testbed launched in 2012 demonstrated software defined radio applications capable of sensing and reacting to environment conditions. Building on this foundation, cognition and automation have the potential to improve system performance, increase data volume return, improve data transmission efficiency, and reduce user spacecraft burden to improve science return from NASA missions. Understanding how and where to apply cognitive and automation technologies is critical and should be discussed in the proposal.

This solicitation seeks advancements in cognitive and automation systems and components as applied to communication and navigation capabilities. 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 or navigation capabilities for the mission. The goal is to improve the state of the user spacecraft system to maximize science data return, enable substantial efficiencies, or adapt to unplanned scenarios. While much interest in cognitive radio entails dynamic spectrum access, this subtopic is also interested in other ways to apply cognition and automation. Areas of interest to develop and/or demonstrate are as follows:

- *Cognitive engine (algorithm) and component development* - to demonstrate new capability in sensing and adapting to the radio/mission environment. Technologies may include changes in physical (PHY) layer data rate, modulation, and coding, medium access control (MAC) layers for new protocols, and cognitive engines to negotiate changes between nodes and throughout the network, learning opportunities and techniques, and networking and application layers (and across layers) to adjust to signal conditions, efficiently using links for different data types (e.g., telemetry v. video), adaptive and intelligent routing, etc.
- *System wide distributed intelligence of cognitive and intelligent applications* - 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) system wide effects (e.g., protocols) to decisions made by one or more communication/navigation elements, how to handle unexpected or undesired decisions, how changing data rate, modulation, or frequency between nodes effects data distribution through relay satellites, and throughout space and ground network and multiple access techniques that optimize connectivity and throughput while minimizing onboard data storage and interference.
- *Flexible and adaptive hardware systems* - (e.g., signal processing platforms, adaptive front ends for RF or optical communications, and other intelligent electronics) which directly implements or demonstrates cognitive or intelligent applications as an alternative to more general software-based intelligent systems. Systems should highlight advancements to provide needed capability while minimizing on-board resources and cost.
- *Autonomous Ka-band and/or optical communications antenna pointing on mission spacecraft within intelligent multiple access systems* - 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 with both the relays and ground terminals on a coordinated, non-interfering basis along with other spacecraft using these same space- and ground-based assets. Areas of interest include (but are not limited to): autonomous navigation and pointing techniques with sufficient precision to minimize pointing loss; techniques to coordinate multiple autonomous activities and adaptive or cognitive radio systems that can continuously maximize data return via both multiple beam GEO relays and direct to ground links.

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) and show a path towards Phase II hardware/software demonstration with delivery of a demonstration unit or software product for NASA testing at the completion of the Phase II contract.

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). Delivery of the simulation or demonstration software and/or platform(s) to NASA. Plan for verification of specific measurements or capabilities to be performed at the end of Phase II.

Phase II Deliverables - Working engineering model of proposed product/platform or software, along with full report of development, capabilities, and measurements (showing specific improvement metrics). User's guide and other documents as necessary for NASA to recreate and use the demonstration capability or hardware component(s). Opportunities and plans should also be identified and summarized for potential commercialization.

Depending on the status at the time, there may be opportunity to port software (cognitive engines and applications) to the SCaN Testbed software defined radio ground and/or flight system on International Space Station (ISS) for demonstration and/or test in the actual space environment. At a minimum, the SCaN Testbed ground system radio testbed will provide an ideal cognitive application test environment, as user spacecraft, relay satellites, and control centers are all emulated in hardware. Software applications and infrastructure should consider 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 Technology**Lead Center: GSFC****Participating Center(s): GRC**

NASA is investing in the development of software tools, systems and devices to enhance 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. Interest includes software tools, ground facilities as well as system concepts and on-board devices to support organic capabilities for its deep-space missions. Products developed under this sub-topic can be in support of any mission phase from design and development through operation and disposal. Proposals can be for either near-Earth or interplanetary missions. Specific application areas that will be considered under this subtopic are:

- Software that fuses and analyzes spacecraft sensor data and other spacecraft tracking data available at ground/mission operations centers (i.e., facility software). Proposals for algorithms and software for flight dynamics GNC technologies can support mission engineering activities at any stage of development from the concept-phase/pre-formulation through operations and disposal. 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:
 - Applications of optimal control theory to high and low thrust space flight guidance and control systems.
 - Numerical methods and solvers for robust targeting, and non-linear, constrained optimization.
 - 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.
 - 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 combine measurements from multiple sensor suites in a highly-coupled manner to improve upon the overall system accuracy.
 - 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 celestial navigation techniques including devices and systems, especially those that support of deep-space, planetary missions. System concepts should support significant advances of independence from Earth supervision including the ability to operate effectively in the absence of Earth-based transmissions or transmissions from planetary relay spacecraft with those that operate in the complete absence of human intervention or Earth-based transmissions are preferred. Proposed solutions should meet objectives while minimizing spacecraft burden by requiring low power and minimal mass and volume. User spacecraft impact is of significant importance and proposed solutions include assessments of mass, power, thermal impact on targeted mission spacecraft as well as identifying any requirements placed on the user spacecraft by the proposed design. Of particular interest are concepts that support pointing of high rate optical communications terminals to earth terminals that do not rely on the use of optical uplinks or beacons for achieving proper pointing of the communication beam. However, concepts which are capable of supporting planetary missions of any type are of interest. Proposals that include re-purposing/cross-purposing of advanced sensors contemplated for future deep-space missions such as x-ray telescopes are preferred. In addition to advances in positioning, attitude estimation, orbit determination, guidance, navigation and control particular interest in the area of deep-space celestial navigation lies in the following focus topics:
 - Time and frequency keeping and dissemination.
 - Advanced methods and sensors for optical/IR detection of star fields (i.e., star cameras).
 - Advanced methods and sensors detecting RF and x-ray pulsars.
 - Methods to process celestial observations to perform Orbit Determination (OD) and precision attitude estimation.

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 Cryogenic Purge Gas Recovery and Reclamation

Lead Center: SSC

Participating Center(s): GRC, KSC

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

Fuel cell technology has demonstrated the ability to output high quality helium from a hydrogen/helium gas mixture. The helium/hydrogen gas mixture was collected, helium extracted and recovered. The recovered helium meets the stringent purity requirements for reuse. Proposals are sought that improve upon the demonstrated technology or develop new alternative cryogenic gas separation technology.

This subtopic has the potential to substantially reduce the costs of NASA's test and launch operations. Additional development is needed to increase the efficiency of the recovery process, capture large amounts of mixed gases, and provide real-time solid state sensor technologies for characterizing constituent gases. Helium is the highest value cryogenic gas, but other cryogenic gases could be conserved also.

Specific areas of interest includes the following technologies:

- Enhanced membrane technologies including Proton Exchange Membrane (PEM) fuel cells that increase the efficiency, recovery production rate or life span of fuel cell based separation technologies.
- Development of alternative cryogenic gas separation technologies.
- Technologies for the rapid capture and storage of high volumes of mixed cryogenic gases.
- Development of zero trapped gas system technologies to improve purge effectiveness.
- Development of real-time, solid state sensor technologies for monitoring the current state of the system concentration levels and helium/nitrogen purge process effectively (e.g., hydrogen, oxygen, water vapor content, etc.).

Examples of this type of technology:

- (<http://www.sustainableinnov.com/products/h2renew/>)
- (<http://www.extrel.com/>)

TOPIC: H11 Radiation Protection

The SBIR Topic area of Radiation Protection focuses on the development and testing of mitigation concepts to protect astronaut crews from the harmful effects of space radiation, both in low Earth orbit (LEO) and while conducting long duration missions beyond LEO. 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. Advances in radiation shielding systems technologies are needed to protect humans from all threats of space radiation. All particulate radiations are considered, including electrons, protons, neutrons, alpha particles, light ions, and heavy ions. This topic is particularly interested in mid-TRL (technology readiness level) technologies. Lightweight radiation shielding materials are needed to shield humans in aerospace transportation vehicles, large space structures, space stations, orbiters, landers, rovers, habitats, and spacesuits. The materials emphasis should be on non-parasitic radiation shielding materials, or multifunctional materials, where two of the functions are structural and radiation shielding. Non-materials solutions, such as utilizing food, water, trash, and treated waste already on board as radiation shielding are also sought. 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. Laboratory and spaceflight data are needed to validate the accuracy of radiation transport codes, as well as to validate the effectiveness of multifunctional radiation shielding materials and subsystems. Also of interest are comprehensive radiation shielding databases and design tools to enable designers to incorporate and optimize radiation shielding into space systems during the initial design phases. Research under this topic should be conducted to demonstrate technical feasibility during Phase I and show a path forward to Phase II hardware demonstration. When possible, deliver a demonstration unit for functional and radiation testing at the completion of the Phase II contract.

H11.01 Radiation Shielding Technologies

Lead Center: LaRC

Participating Center(s): MSFC

Advances in radiation shielding technologies are needed to protect humans from the hazards of space radiation during NASA missions. All space radiation environments in which humans may travel in the foreseeable future are considered, including low Earth orbit (LEO), geosynchronous orbit (GEO), Moon, Mars, and the Asteroids. All particulate radiations are considered, including electrons, protons, neutrons, alpha particles, and light to heavy ions. Mid-TRL (3 to 5) technologies of specific interest include, but are not limited to, the following:

- Lightweight innovative radiation shielding materials are needed to shield humans in aerospace transportation vehicles, large space structures such as space stations, orbiters, landers, rovers, habitats, and spacesuits. The

materials emphasis should be on non-parasitic radiation shielding materials, or multifunctional materials, where two of the functions are structural and radiation shielding. Materials of interest include, but are not limited to, polymers, polymer matrix composites, nanomaterials, and regolith derived materials. The objective is to replace primary, secondary, and interior structures, including equipment and components, with radiation protective materials. There is particular interest in the development of high hydrogen content materials and materials systems to replace traditional materials (particularly metals). Note that the goal is not necessarily mass reduction. The goal is replacing mass with mass that not only meets structural requirements, but also is more effective for radiation protection. Decreased mass is a bonus. High hydrogen materials can include polymer matrix composites, where the polymer and/or fibers are high in hydrogen content. Phase I deliverables are materials coupons. Phase II deliverables are materials panels or standard materials test specimens, along with relevant materials test data.

- Processing of regolith derived materials for radiation shielding structures is also of interest. The regolith can be combined with polymer matrix materials to increase the hydrogen content. Phase I deliverables are materials coupons. Phase II deliverables are materials panels or standard materials test specimens, along with relevant materials test data.
- Non-materials solutions are also of interest. Examples are utilizing food, water, supplies, trash, and treated waste already onboard as radiation shielding. This involves developing and utilizing storage containers for food, supplies, and treated waste as multipurpose radiation shielding. This includes developing multipurpose containers for biomaterials to contain treated waste safely without adversely affecting crew (smell/leakage/handling/transfer). Other options include developing water walls for crew quarters and vehicle walls to be used for storing drinking water, potable water, and treated waste, as well as repurposing the trash and treated waste into protective shielding. Phase I deliverables are detailed conceptual designs. Phase II deliverables are initial prototypes.
- NASA is also interested in out-of-the-box credible solutions for radiation shielding. Phase I deliverables are detailed conceptual designs. Phase II deliverables are initial prototypes.
- Advanced computer codes for rapid computing that can handle complex geometries and large collections of data are needed to model and predict the transport of radiation through space vehicles and structures. These are needed to support optimization studies and analyses for vehicle design and mission planning. Phase I deliverables are alpha tested computer codes. Phase II deliverables are beta tested computer codes.
- Experimental laboratory and spaceflight data are needed to validate the accuracy of radiation transport codes and analysis tools. Phase I deliverables are draft data compilations or databases. Phase II deliverables are formal, publishable, and archival data compilations or databases.

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 early lunar missions of extended duration. The Human Research Roadmap (<http://humanresearchroadmap.nasa.gov>) is a web-based version of the IRP that allows users to search HRP risks, gaps, and tasks.

The HRP is organized into Program Elements:

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

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

H12.01 Measurements of Net Ocular Blood Flow

Lead Center: GRC

Participating Center(s): JSC

The goal of this SBIR call is the development of rapid and accurate hardware to characterize the net blood flow to and from the eye. Due to limits on instrumentation, most of the literature on ocular blood flow to date has emphasized measurements that only partially characterize the net flow, such as minimum and maximum velocity in a single retinal arterial vessel or choroidal thickness in the vicinity of the fovea. However, there is significant spatial and interindividual variation in these ocular structures, for example, in choroidal and retinal thickness and in arterial and venous branching structures. Consequently, there are likely to be new insights to be gained from examining the choroid and retina from a bulk perspective. Recent advances in high-quality imaging, such as those based on wide-field Optical Coherence Tomography or high-resolution angiography, have allowed increased depth of penetration at high resolution for unparalleled accuracy in choroidal and retinal measurements that extend well beyond the posterior pole of the eye. The ready availability of computational resources renders it straightforward to capture and analyze the entire time history of ocular hemodynamics.

This SBIR solicits novel hardware that can quantify net ocular blood flow in the retina. Measurements of interest include the temporal history of the following:

- Maps of choroidal and retinal thickness, which include near- and far-field contributions.
- Net volume of the choroid and retina.
- Net volumetric blood flow to and from the choroid and retina.
- Pressures and net luminal areas at the entrance and exit of the choroid and retina.

Measurements must be presented in physical units, such as blood flow in milliliters per minute. The measurement system must also process the raw data, either in a real-time or post-processing mode. Data analysis capabilities should include the calculation of the overall time-averaged mean values, as well as the mean waveform over a cardiac cycle. It would be of significant interest if comparable measurements were made simultaneously of intraocular pressure, reference arterial pressure (systemic, brachial and/or ophthalmic artery), fundus pulsation amplitude, and/or heart rate.

Phase I Deliverables - Concept of hardware capable of producing some or all of the above measurements.

Phase II Deliverables - Prototype hardware and data from a pilot study.

H12.02 Unobtrusive Workload Measurement

Lead Center: JSC

Participating Center(s): ARC

Task design and associated hardware and software impose cognitive and physical demands on an operator and thus, drive the workload associated with a task. This solicitation is looking for technologies and methods to measure, assess, and predict astronaut workload unobtrusively, and to extend these technologies to measuring and predicting astronaut workload during long duration operations. Unobtrusive measures would be ones that do not require operators to specifically interact with a technology or provide inputs, and would not interrupt an operator's work.

Astronauts on long-duration missions will potentially have long periods of low workload and short bursts of high workload combined with reduced workload capacity that needs to be taken into account for system and mission design. Both high task demand and reduced workload capacity at any phase of a flight may lead to performance errors, which could potentially compromise mission objectives, and consequently the mission.

Astronauts, mission planners, and system designers require the capability to assess and predict when astronauts will be at a reduced capacity resulting from either work underload or from work overload. An unobtrusive workload tool could be used during development to ensure a system produces acceptable workload, or in real-time, to drive schedule modifications or to adapt interfaces based on the current workload the astronaut is experiencing. Unobtrusive objective measures such as video, voice, thermal infrared imaging or eye tracking methods may be more appropriate when measuring long duration workload, so long as the technology's credibility is ensured.

Phase I of this SBIR is to complete a review of the current state of the art in automatically, unobtrusively measuring and tracking workload and informing astronaut of such workload levels in scenarios that are applicable to long duration missions. This Phase I effort will identify suitable unobtrusive measurement technologies and the parameters that need to be included in a candidate workload algorithm and subsequently generate the algorithm. NASA has already supported the development of wrist and arm-worn devices, therefore any unobtrusive wearables proposed should consider alternative concepts and/or new implementations of existing wearable technologies. Phase II of this SBIR is to take the current state of the art and recommendations from the Phase I effort to develop an unobtrusive workload measurement tool prototype, and test and validate the tool.

H12.03 Technology for Monitoring Muscle Protein Synthesis and Breakdown in Spaceflight

Lead Center: JSC

Post flight decrements in skeletal muscle size and function are well documented, however, the true time course of muscle adaptations during long duration spaceflight have thus far been unaddressed. This information is of importance because it can help to identify:

- When the most critical stages of adaption to space are occurring.
- Whether changes are occurring at a constant rate or if they begin to plateau, and if so when.
- Targeted muscle countermeasures to mitigate true muscle loss.

Muscle protein synthesis and breakdown are typically measured via invasive biopsy which will not be feasible during space flight missions. Current terrestrial assays for protein synthesis involve use of stable isotopes to measure incorporation of amino acids into muscle and are determined in muscle biopsy samples. Markers for protein degradation (e.g., MuRF1, Atrogen-1) in muscle biopsy samples are often determined by real time PCR (mRNA expression) or Western blot analysis (protein expression), though these results are primarily qualitative. This subtopic seeks novel, non- or minimally-invasive technologies to measure muscle protein turnover for use in subsequent research studies. The most important measurement would be a synthesis: breakdown ratio indicative of the state of muscle balance (formation, breakdown or stability) as opposed to exact protein synthetic rates. However, absolute protein synthesis and breakdown rates are highly desirable.

This Subtopic addresses the following Human Research Program requirements:

- Risk of Impaired Performance Due to Reduced Muscle Mass, Strength and Endurance
- Gap M24. Characterize the time course of changes in muscle protein turnover, muscle mass and function during long duration space flight.

The technology developed should accurately be able to quantify protein synthesis, breakdown and total turnover. A successful proposal will include the technologies being considered and detailed test plan for evaluating them during Phase I. A vision for miniaturizing the device and operating the device in microgravity is required.

Phase I Deliverables - Test results and plan for developing a low volume, low mass, easy-to-operate prototype. The expected TRL resulting from the Phase I effort should be 4.

Phase II Deliverables - Prototype in year 1 with minimal human testing in year 2 to demonstrate efficacy.

TOPIC: H13 Non-Destructive Evaluation

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 3-D 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 Advanced NDE Modeling 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 3-D 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. It is assumed that all systems will have high resolution high volume data. Modeling efforts should be physics based and account for variations between material aging characteristics and induced damage such as micrometeoroid impact. Examples of damage states of interest include delamination, microcracking, porosity, fiber breakage. Techniques sought for data

reduction/interpretation will yield automated and accurate results to improve quantitative data interpretation to reduce large amounts of NDE/SHM data into a meaningful characterization of the structure. Realistic computational methods for validating SHM systems are also desirable. It is advantageous to use co-processor configurations for simulation and data reduction. Co-Processor configurations can include graphics processing units (GPU), system on a chip (SOC), field-programmable gate array (FPGA) and Many Integrated Core (MIC) Architectures. 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, outlining the proposed approach to develop a given product (TRL 2-4), and describing any models and algorithms developed/utilized. Plan for Phase II including proposed verification methods.

Phase II Deliverables - Software of proposed product, report including detailed description of algorithms and models, 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): 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 senior capability. It is desirable but not necessary to target structural components of space flight hardware. Examples of space flight hardware will include light weight structural materials including composites and thin metals.

Technologies sought include modular, smart, advanced Nondestructive Evaluation (NDE) sensor systems and associated capture and analysis software. It is advantageous for techniques to include the development on quantum, meta- and nano sensor technologies for deployment. Technologies enabling the ability to perform inspections on large complex structures will be encouraged. Technologies should provide reliable assessments of the location and extent of damage. Methods are desired to perform inspections in areas with difficult access in pressurized habitable compartments and external environments for flight hardware. Many applications require the ability to see through assembled conductive and/or thermal insulating materials without contacting the surface. Techniques that can dynamically and accurately determine position and orientation of the NDE sensor are needed to automatically register NDE results to precise locations on the structure. Advanced processing and displays are needed to reduce the complexity of operations for astronaut crews who need to make important assessments quickly. NDE inspection sensors are needed for potential use on free-flying inspection platforms. Integration of wireless systems with NDE may be of significant utility. It is strongly encouraged to provide explanation of how proposed techniques and sensors will be applied to a complex structure. Examples of structural components include but are not limited to multi-wall pressure vessels, batteries, tile, thermal blankets, micrometeoroid shielding, International Space Station (ISS) Radiators or aerospace structural components.

Phase I Deliverables - Lab prototype, feasibility study or software package including applicable data or observation of a measurable phenomena 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) 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 was formed in 2011 by combining the Space Operations Mission Directorate (SOMD) and the Exploration Systems Mission Directorate (ESMD) to optimize the elements, systems, and technologies of the precursor Directorates to the maximum extent possible. 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.

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. 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 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.
- Development of instruments and software for reconstructing 3-D tomographic images that provides a non-intrusive measurement of the spatial phase distribution in gas-liquid flows. Instruments must be capable of a high temporal acquisition (200 Hz or greater) with resolution between phase boundaries within the measured region on the order of 2-3 millimeters or better. The fluids are typically air-water systems. Providing flight qualified hardware with these capabilities will allow for real-time measurements of phase distribution for a number of life support and biology technologies such as reactor beds, separators, and plant habitats.
- Devices that provide rapid or snap freezing of samples are sought due to their capability to provide for the preservation of samples that support a broad range of space research in the plant, microbiology, cell biology and animal biology subject areas.
- Increased use of the Light Microscopy Module (LMM). Several additions to the module continue to be solicited, such as: laser tweezers, dynamic light scattering, stage stabilization (or sample position encoding) for reconstructing better 3-D confocal images.
- 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 handheld portable use. Battery powered wireless operation is desirable. Specific issues to be addressed include: pitting from micrometeoroid impacts, stress fractures, leaking of cooling gases and liquids and detection of abnormal hot spots in power electronics and circuit boards.

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.

H14.02 International Space Station (ISS) Demonstration of Improved Exploration Technologies **Lead Center: JSC**

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. Successful submissions will describe requisite testing on ISS. Proposals that do not require testing at the ISS should respond to other subtopic solicitations in appropriate technical areas. If submitted to this subtopic they will be considered non-responsive.

NASA encourages submissions that increase the Technology Readiness Level of space exploration and pioneering technologies in areas that include but are not limited to the following:

- Ambient temperature catalyst replacement for the ISS Water Processing Assembly.

- High pressure oxygen generation applicable to both ISS and future human space flight vehicles, demonstrated on ISS.

For all proposed technologies, research should at a minimum 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 flight unit or software package for ISS testing.

Phase I Deliverables - Research to identify and evaluate candidate technologies applications to demonstrate the technical feasibility and show a path towards a hardware/software demonstration. 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 prototypes that can be demonstrated on orbit (TRL 8). The contract should deliver 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.

Proposals should be generated to assume costs that are limited to the deliverables and the ISS Program, if chosen for flight, would provide safety, upmass and other integration costs.

Potential NASA Customers include:

- International Space Station Program (http://www.nasa.gov/mission_pages/station/main/index.html).
- Orion Multipurpose Crew Vehicle (<http://www.nasa.gov/exploration/systems/mpcv/index.html>).

H14.03 Recycling/Reclamation of 3-D Printer Plastic Including Transformation of Launch Package Solutions into 3-D Printed Parts

Lead Center: MSFC

Participating Center(s): ARC, JSC, KSC

The National Aeronautics and Space Administration (NASA) has a long-term strategy to fabricate components and equipment on-demand for crew exploration missions. The greater the distance from Earth and the longer the mission duration, the more difficult resupply becomes; thus requiring a significant change from the current space travel supply chain model. The ISS is an ideal platform to begin testing and transitioning from the current model for resupply and repair to one that is more suitable for exploration missions. 3-D Printing, more formally known as Additive Manufacturing, is the method of building parts/objects/tools layer-by-layer. 3-D Printers on-board ISS will use extrusion-based additive manufacturing, which involves building an object out of plastic deposited by a wire-feed via an extruder head. While this process does provide on-demand capability for printing parts, to truly develop a self-sustaining, closed-loop on-orbit manufacturing process that will result in meaningfully less mass to launch and enabling space exploration, a means of recycling/reclaiming readily available materials will ultimately be required. NASA seeks launch packing solutions that can be composed of materials suitable for recyclable processing into 1.75mm filament and subsequently 3-D printed parts. This capability will significantly decrease current waste and substantially increase sustainability. The solution may be obtained using a variety of approaches, such as:

- Converting commonly used 3-D printing feedstocks into packing solutions, including but not limited foam or bags.
- Transforming traditional packing materials into 3-D Printing feedstock.
- Developing a technology that utilizes a novel approach to identify compatible materials for both packing solutions and 3-D Printing. For example, this could include such materials as netting, fabrics, structures, containers, etc.

Examples of traditional packing materials currently used for ISS, as well as commonly used feedstocks and types of 3-D Printed parts are provided below. These are intended to serve as examples rather than requirements. The proposal does not have to be limited to these materials:

- Foams currently used on ISS:
 - Plastazote (LD24FR & LD45FR).
 - Polyethylene.
 - Polyurethane.
 - PVDF.
 - PTFE film (for bubble wrap).
- Bagging materials currently used on ISS:
 - Pink Poly (not pink and white).
 - Llumaloy (good for ESD compatibility).
 - Tedlar (particularly for containment).
 - Kynar (positive flammability ratings).
- Common Feedstock Materials:
 - ABS.
 - PTFE.
 - PEAK.
 - Ultem.
- Examples of 3-D Printed Parts:
 - Common hand tools.
 - Handles, containers.
 - Clips.
 - Personal items such as grooming tools.
 - ‘Seat track’ strips.
 - Corresponding studs.

Phase I Deliverable is a Technical Feasibility Study and should provide:

- Demonstration of a close-looped system that provides launch packing solutions that can be recycled into 1.75mm filament for creating 3-D Printed parts without requiring any additional mass other than the shared packing/printing materials and process. The 3-D Printed part(s) must be able to be printed using 1.75mm filament feedstock via a Fused Deposition Melting (FDM) process.
- A materials assessment, which addresses such things as materials composition, flammability, toxicity, off-gassing, etc.
- Technology Readiness Level (TRL) rating from 2-5.
- A Systems Engineering and Proposed Design path for developing an ISS locker-sized hardware demonstration for functional testing at the completion of the Phase II contract.

The ultimate objective is to evolve this technology into a Phase II SBIR ISS Technology Demonstration payload.

H14.04 Optical components, sensors, and systems for ISS utilization

Lead Center: LaRC

The International Space Station (ISS) is an on-orbit research platform that provides a superior environment for human health and exploration, technology testing for enabling future exploration, research in basic life and physical science, and earth and space science as enunciated in the NASA Authorization ACT of 2010. This subtopic would focus on the utilization of ISS as a foremost test bed for test, operation, and validation of the functionality of advanced optical components, sensors and systems for enabling future exploration. The goal of this subtopic research is to satisfy the mission of the International Space Station (ISS) Program by advancing science and technology research and thereby significantly contributing to expand human knowledge, inspire and educate the next generation, foster the commercial development of space and demonstrate capabilities to enable future exploration missions beyond low Earth orbit (LEO) as discussed in the International Space Station (ISS) Researcher’s Guide is published by the NASA ISS Program Science Office. Under this subtopic, innovative research topics compatible to ISS test environment would address HEOMD core issues related to radiation protection, deep space habitat elements and analog missions.

This subtopic would take advantage of revolutionary and rapid advances that are taking place in optics, materials and processing disciplines. Development of sensors and systems using innovative sources, detectors, materials,

components and configurations for accomplishing new and/or improved performance, increased reliability and ruggedness, reduction in size, weight and power consumption (SWaP), and cost would advance HEOMD missions.

Topics of interest include but not limited to optical materials, optical components such high temperature and broadband windows and elements, active and passive sensing architectures, smart sensors and sensor suites including multifunctional aspects, monolithic or hybrid high operating temperature detectors and focal plane arrays, ISS compatible miniature remote sensing systems for characterization of hard targets, terrain mapping, deep space imaging (3-D and hyper spectral) sensors and systems, and precision, navigation, and timing systems.

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.

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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: (<http://science.nasa.gov/heliophysics>).

A major objective of SMD instrument development programs is to implement science measurement capabilities with smaller or more affordable spacecraft so development programs can meet multiple mission needs and therefore make the best use of limited resources. The rapid development of small, low-cost remote sensing and in situ instruments is essential to achieving this objective. For Earth Science needs, in particular, the subtopics reflect a focus on instrument development for airborne and Unmanned Aerial Vehicle (UAV) platforms. Astrophysics has a critical need for sensitive detector arrays with imaging, spectroscopy, and polarimetric capabilities, which can be demonstrated on ground, airborne, balloon, or suborbital rocket instruments. Heliophysics, which focuses on measurements of the sun and its interaction with the Earth and the other planets in the solar system, needs a significant reduction in the size, mass, power, and cost for instruments to fly on smaller spacecraft. Planetary Science has a critical need for miniaturized instruments with in situ sensors that can be deployed on surface landers, rovers, and airborne platforms.

For the 2012 program year, we are restructuring the Sensors, Detectors and Instruments Topic, rotating out, combining and retiring some of the subtopics. Please read each subtopic of interest carefully. One new subtopic, S1.09 Surface and Sub-surface Measurement Systems was added this year. This new subtopic solicits proposals that are for ground-based surface vehicles, and submerged systems. Systems that will provide near-term benefit in a ground-based application but that are ultimately intended for flight or mobile platforms are in scope. A key objective of this SBIR topic is to develop and demonstrate instrument component and subsystem technologies that reduce the risk, cost, size, and development time of SMD observing instruments and to enable new measurements. Proposals are sought for development of components, subsystems and systems that can be used in planned missions or a current technology program. Research should be conducted to demonstrate feasibility during Phase I and show a path towards a Phase II prototype demonstration. The following subtopics are concomitant with these objectives and are organized by technology.

S1.01 Lidar Remote Sensing Technologies

Lead Center: 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 NASAs requirements for remote sensing from space, advances are needed in state-of-the-art lidar technology with an emphasis on compactness, efficiency, reliability, lifetime, and high performance. Innovative lidar subsystem and component technologies that directly address the measurement of atmospheric constituents and surface topography of the Earth, Mars, the Moon, and other planetary bodies will be considered under this subtopic. Compact, high-efficiency lidar instruments for deployment on unconventional platforms, such as balloon, small sat, and CubeSat are also considered and encouraged.

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

- Backscattermeasures beam reflection from aerosols to retrieve the opacity of a gas.
- Rangingmeasures the return beams time-of-flight to retrieve distance.
- Dopplermeasures 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 2015 SBIR Program, NASA is soliciting the component and subsystem technologies described below.

Compact and rugged single-frequency continuous-wave and pulsed lasers operating between 0.3-mm and 2.05-mm wavelengths suitable for lidar. Specific wavelengths are of interest to match absorption lines or atmospheric transmission: 0.29-0.32-mm (ozone absorption), 0.532-mm, 1.0-mm, 1.57-mm (CO₂ line), 1.65-mm (methane line), and 2.05-mm (CO₂ 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 0.3-mm to 2.05-mm. 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 either at 1.6-mm or 2.0-mm wavelengths, 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.

Semiconductor lasers tunable in the 3-mm to 16-mm wavelength range with stable, narrow linewidth operation for applications in environmental gas and pollutant sensing, Earth and planetary atmospheric studies, and calibration of thermal infrared sensors. General requirements are for high power (>50mW), wavelength stability (<10MHz), and single-mode spectrum.

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.

Ka-band Power Amplifier for CubeSats:

- F = 35.7 GHz +/- 200MHz.
- Volume: <1U (10mmx10mmx10mm).
- Psat >32W.
- Gain > 35 dB.
- PAE > 20%.

Deployable Ka-band Antennas for CubeSats:

- F = 35.7 GHz +/- 200MHz.
- Aperture size = 0.75m.
- Gain > 45dB.
- Sidelobe ratio > 20dB.
- Stowed volume: <2.5U (25mmx10mmx10mm).
- 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 with better than d 0.01 dB/C thermal stability, Dicke switches with better than 30 dB isolation, phase modulators, and low loss isolators along with fully integrated state-of-art receiver systems operating at room and cryogenic temperatures.

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

Includes digitizers 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.

Local Oscillator technologies for THz instruments.

This can include GaN based frequency multipliers that can work in the 200-400 with better than 30% efficiency GHz range (output frequency) with input powers up to 1 W. Graphene based devices that can work as frequency multipliers in the frequency range of 1-3 THz with efficiencies in the 10% range and higher.

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

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.

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

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

Fast tuning, low-phase-noise, widely tunable, low-power, microwave synthesizers.

Used as reference source for Earth/planetary applications. The frequency tunability should be >=15% within the frequency range of 23 to 29 GHz. Power level <= 5 W, with radiation tolerance at least 100 krad, 300 krad preferable. Tuning speed <= 10 ms.

Development of 4 channels VHF (240-270 MHz) passive receiver for 6U Cubesat platforms.

Enables Root Zone Soil Moisture Measurements from LEO using the Follow-on military SatComm satellites as signals of opportunity transmitters

Development of innovative analogue/digital hardware designs for the implementation of distributed beamforming Synthetic Aperture Radar (SAR) architectures.

Enables beam steering over many array elements while reducing size, weight, and power compare to state-of-the-art.

Radars operating at 17.0 GHz +/- 150 MHz, >=6W transmit power meeting a detection capability with a range of 54km for a 20 square meter target.

The radar will be part of a Laser Hazard Reduction System (LHRS). The installed LHRS provides a means of detecting aircraft before they intersect a transmitted laser beam. Upon detecting an aircraft by the radar, the LHRS provides a signal so that laser beam be blocked to transmit.

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.

Development of structurally integrated/embedded airborne (P3, C130 aircrafts) antennas.

Enables mounting in non-traditional locations (e.g., doors, wing skins, fuselage panels and wing leading edges) covering 20 MHz-500 MHz bandwidth.

Analog to Digital (A/D) and Digital to Analog (D/A) Monolithic Integrated Circuit (MMIC) for P-band and L-band radar.

High efficiency, low power, high throughput.

S1.03 Sensor and Detector Technology for Visible, IR, Far IR and Submillimeter

Lead Center: JPL

Participating Center(s): ARC, GSFC, KSC, 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 $\text{NE}\Delta\text{T} < 20\text{mK}$, $\text{QE} > 30\%$ and dark currents $< 1.5 \times 10^{-6} \text{ A/cm}^2$ in the 5-14 μm infrared wavelength region. Array formats may be variable, 640 x 512 typical, with a goal to meet or exceed 2k X 2k pixel arrays. Evolve new technologies such as InAs/GaSb type-II strained layer super-lattices to meet these specifications.

New or improved technologies leading to measurement of trace atmospheric species (e.g., CO, CH₄, N₂O) 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, MgB₂) 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 KID arrays. Enables mega pixel arrays for mm to Far IR telescopes and spectrometers for astrophysics and earth observation.

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.

Development of an un-cooled (single element or array) infrared detector with an active area of 1x1 mm or greater, a sensitivity (D^*) of $10^9 \text{ cmHz}^{1/2}\text{W}^{-1}$ or greater, and a response speed of 10 kHz or greater in the 5 – 50 μm wavelength region. This new detector will be useful for the Climate Absolute Radiance and Refractivity Observatory (CLARREO).

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:

- IXO - (<http://htxs.gsfc.nasa.gov/index.html>).
- 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).

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 m²) 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 mm² to 10 x 10 mm². Focal plane mass must be minimized (2g/cm² 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, IMAP, GDC, DYNAMIC, MEDICI, 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:

- Self-calibrating scalar-vector magnetometer for future Earth and space science missions. Performance goals: dynamic range: $\pm 100,000$ nT, accuracy with self-calibration: 1 nT, sensitivity: 5 pT - Hz $^{-1/2}$ (max), max sensor unit size: 6 x 6 x 12 cm, max sensor mass: 0.6 kg, max electronics unit size: 8 x 13 x 5 cm, max electronics mass: 1 kg, and max power: 5 W operation, 0.5 W standby, including, but not limited to "sensors on a chip".
- High magnetic-field sensor that measures magnetic field magnitudes to 16 Gauss with an accuracy of 1 part in 105.
- Low-noise magnetic materials for advanced magnetometer sensors with performance equal to or better than those in the 6-81.3 Mo-Permalloy family.
- Deployable magnetic clean booms up to 50cm.
- 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.
- Long wire boom (≥ 50 m) deployment systems for the deployment of sensors attached to very lightweight tethers or antennae on spinning spacecraft.
- Small satellite rigid electric field booms: for three-axis stabilized spacecraft. Note for Cubesat applications: Full three-component measurement (six booms) must fit inside 6U Cubesat form factor, booms must be thin, rigid, and deploy to lengths ≥ 2 m, including sensors and harness.
- Small satellite wire booms: for spinning spacecraft. Two pairs of sensors attached to lightweight tethers or antennae. Note for Cubesat applications: Must deploy to ≥ 5 m and fit inside a 3U or larger Cubesat form factor.
- Development of tools to study spacecraft charging for the purpose of understanding effects on charged particle measurements, particularly at reduced energies.
- Radiation-hardened >200 Krads ASICs including Low-power multi-channel ADCs, DACs >16-bits and > 100MSPS, and >20 bits and >1MSPS.
- Low-cost, low-power, fast-stepping ($\leq 50\text{-}\mu\text{s}$), high-voltage power supplies 1V-6kV. High Voltage opto coupler components as a control element of HVPS, with >12KV isolation and >100 krad radiation tolerance.
- High efficiency (>2% or greater) conversion surfaces for energetic (1eV to 10KeV) neutral atom conversion to ions.
- High reliability cold electron emitters based on MCP or nano technology with emission surfaces 1-1000mm 2 and life time $> 20,000$.
- Solar Blind particle detectors less sensitive to light for particle detection in the energy Range 1KeV to 100MeV.
- Developing near real-time data-assimilative models and tools, for both solar quiet and active times, which allow for precise specification and forecasts of the space environment, beginning with solar eruptions and propagation, and including ionospheric electron density specification.

S1.06 In-Situ Sensors and Sensor Systems for Lunar and Planetary Science

Lead Center: JPL

Participating Center(s): ARC, GRC, GSFC, JSC, KSC, 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 Council's, Vision and Voyages for Planetary Science in the Decade 2013-2022 (<http://solarsystem.nasa.gov/2013decadal/>). Technologies that support NASA's New Frontiers and Discovery missions to various planetary bodies are of top priority.

In situ technologies are being sought to achieve much higher resolution and sensitivity with significant improvements over existing 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-pressure 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 - the proposers should demonstrate an understanding of the measurement requirements and be able to link those to instrument performance. 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:

- Miniaturized, high performance instrument suites for multidisciplinary applications.
- Spectrally resolved absorption and extinction of atmospheric aerosols (0.1 to 10 micron).
- High accuracy and precision atmospheric measurements of Nitrous Oxide, Ammonia, and Formaldehyde (>1 Hz).
- Novel measurement approaches for measurement of Carbon Dioxide (>1 ppm), Methane (5 ppb accuracy, 10 ppb precision), and Water Vapor (>0.5% precision).
- Small (<100 lbs) hyperspectral imagers: 350 to 2500 nanometers with signal to noise > 300 to 1.
- Sulfur based chemistry such as Sulfur Dioxide, Dimethyl Sulfide, Carbonyl Sulfide, Sulfate Aerosols.
- Precipitation - multiphase (0.1 mm to 20 mm with 5 % accuracy in three dimensions).
- Surface snow thickness (5 cm resolution).
- Aerosols and cloud particles (0.01 micron to 200 micron with 10% accuracy).
- Sun photometry measurements with accuracies of <1%.
- Volcanic ash (0.25 to 100 micron with 10 % accuracy).
- Three-dimensional wind measurement (1 mps accuracy/resolution at 10 Hz sampling).
- Miniature (< 7 lb) mass spectrometer with measurement range of 1 to 150 atomic mass units (amu) and resolution of 1 amu, able to detect molecular gas species of He, H₂, H₂O, N₂, O₂, Ar, CO₂, SO₂, OCS, H₂S, CH₄, NH₃ with sensitivity of 1 ppm.

S1.08 Surface & Sub-surface Measurement Systems**Lead Center: ARC****Participating Center(s): GSFC, JPL, KSC, LaRC, MSFC, SSC**

Surface & Sub-surface Measurement Systems are sought with relevance to future space missions such as Active Sensing of CO₂ 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).
- Suspended particle concentrations and spectra of mineral and biogenic (phytoplankton and detritus) components.
- Gases 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, suitable for Global Hawk deployment, for ocean surface and subsurface measurements such as conductivity, temperature, and depth.
- Miniature systems suitable for penetration of thin ice are highly desirable.
- Multi-wavelength, LIDAR-based, atmospheric ozone and aerosol profilers for continuous, simultaneous observations from multiple sites. Examples include three-band ozone measurement systems operating in the UV spectrum (e.g., 280-316 nm, possibly tunable), combined with visible or infrared systems for aerosols.
- Remote/unintended operation, minimum eye-hazards, and portability are desired.
- Miniaturized and 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. Innovations with future utility for other NASA programs (for example, Planetary Research) that can be matured in an Earth science role are also encouraged.

S1.09 Atomic Interferometry**Lead Center: JPL****Participating Center(s): GSFC**

Recent developments of laser control and manipulation of atoms have led to new types of precision inertial force and gravity sensors based on atom interferometry. Atom interferometers exploit the quantum mechanical wave nature of atomic particles and quantum gases for sensitive interferometric measurements. Ground-based laboratory experiments and instruments have already demonstrated beyond the state of the art performances of accelerometer, gyroscope, and gravity measurements. The microgravity environment in space provides opportunities for further drastic improvements in sensitivity and precision. Such inertial sensors will have great potential to provide new capabilities for NASA Earth and planetary gravity measurements, for spacecraft inertial navigation and guidance, and for gravitational wave detection and test of properties of gravity in space.

Currently the most mature development of atom interferometers as measurement instruments are those based on light pulsed atom interferometers with freefall cold atoms. There remain a number of technical challenges to infuse this technology in space applications. Some of the identified key challenges are (but not limited to):

- Compact high flux ultra-cold atom sources for free space atom interferometers (Example: $>1\times10^6$ total useful free-space atoms, <1 nK, Rb, K, Cs, Yb, Sr, and Hg. Performance and species can be defined by offerors).

Other related innovative methods and components for cold atom sources are of great interest, such as a highly compact and regulatable atomic vapor cell.

- Ultra-high vacuum technologies that allow completely sealed, non-magnetic enclosures with high quality optical access and the base pressure maintained $<1\times10^{-9}$ torr. Consideration should be given to the inclusion of cold atom sources of interest.
- Beyond the state-of-the-art photonic components at wavelengths for atomic species of interest, particularly at NIR and visible: efficient acousto-optic modulators (low rf power ~ 200 mW or less, low thermal distortion, $\sim 80\%$ or greater diffraction efficiency); efficient electro-optic modulators (low bias drift, residual AM, and return loss, fiber-coupled preferred), miniature optical isolators (~ 30 dB isolation or greater, ~ -2 dB loss or less), robust high-speed high-extinction shutters (switching time < 1 ms, extinction > 60 dB are highly desired).
- Flight qualifiable lasers of narrow linewidth and higher power for clock and cooling transitions of atomic species of interest. Cooling and trapping lasers: 10 kHz linewidth and ~ 1 W or greater total optical power. Compact clock lasers: 5×10^{-15} Hz/tau $^{1/2}$ near 1 s (wavelengths for Yb⁺, Yb, Sr clock transitions are of special interest).
- Analysis and simulation tool of a cold atom system in trapped and freefall states relevant to atom interferometer and clock measurements in space.

All proposed system performances can be defined by offerors with sufficient justification. Subsystem technology development proposals should clearly state the relevance, define requirements, relevant atomic species and working laser wavelengths, and indicate its path to a space-borne instrument.

S1.10 Cryogenic Systems for Sensors and Detectors

Lead Center: GSFC

Participating Center(s): ARC, JPL, KSC, 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 six 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:

- *Miniatrized/Efficient Cryocooler Systems* - Cryocooler systems viable for application on CubeSat 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 < 5 W respectively.
- *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 > 15 K).
 - Heat Switches.
 - 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.
- *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.
- *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.
- *Sub-Kelvin Cooling Technologies* - Contemporary ADR systems provide the highest cooling capacities and the lowest load temperatures of all sub-Kelvin techniques viable for space application. Cultivation of additional technology options are of interest. Candidate technologies for investigation may include closed cycle dilution cooling and/or alternative magnetic refrigeration techniques and cycles.
- *Continuous Flow Distributed Cooling Systems* - Distributed cooling provides increased lifetime of cryogen fluids for application on both the ground and spaceborne platforms. This has impacts on payload mass and volume for flight systems which translate into costs (either on the ground, during launch or in flight). Mission enabling components for use with distributed cooling systems are sought. Examples of such include cryo-valves and integral/non-integral cryocooler components.

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 as 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 ($> 1 \text{ m}$ diameter) optics.
- Polarization-insensitive coatings for large optics.
- Methods to measure the spectral reflectivity and polarization uniformity across large optics.

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 $\sim 140 \times 140$ 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/m² 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 optomechanical control. Large deployable multi-layer structures in support of sunshades for passive thermal control and 20m to 50m class planet finding external occulters are also relevant technologies. Potential architecture implementations must package into an existing launch volume, deploy and be self-aligning to the micron level. The target space environment is expected to be the Earth-Sun L2.

This subtopic solicits proposals to develop enabling, cost effective component and subsystem technology for deploying large aperture telescopes with low cost. Research areas of interest include:

- Precision deployable structures and metrology for optical telescopes (e.g., innovative active or passive deployable primary or secondary support structures).
- Architectures, packaging and deployment designs for large sunshields and external occulters.

In particular, important subsystem considerations may include:

- Innovative concepts for packaging fully integrated subsystems (e.g., power distribution, sensing, and control components).
- Mechanical, inflatable, or other precision deployable technologies.
- Thermally-stable materials (CTE < 1ppm) for deployable structures.
- Innovative systems, which minimize complexity, mass, power and cost.
- Innovative testing and verification methodologies.

The goal for this effort is to mature technologies that can be used to fabricate 16 m class or greater, lightweight, ambient or cryogenic flight-qualified observatory systems. Proposals to fabricate demonstration components and subsystems with direct scalability to flight systems through validated models will be given preference. The target launch volume and expected disturbances, along with the estimate of system performance, should be included in the discussion. Proposals with system solutions for large sunshields and external occulters will also be accepted. A successful proposal shows a path toward a Phase II delivery of demonstration hardware scalable to 5 meter diameter for ground test characterization.

Before embarking on the design and fabrication of complex space-based deployable telescopes, additional risk reduction in operating an actively controlled telescope in orbit is desired. To be cost effective, deployable apertures that conform to a cubesat (up to 3-U) or ESPA format are desired. Consequently, deployment hinge and latching concepts, buildable for these missions and scaleable to larger systems are desired. Such a system should allow <25 micron deployment repeatability and sub-micron stability for both thermal and mechanical on-orbit disturbances. A successful proposal would deliver a full-scale cubesat or ESPA ring compatible deployable aperture with mock optical elements.

Proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop the relevant subsystem technologies and to transition into future NASA program(s).

S2.03 Advanced Optical Systems and Fabrication/Testing/Control Technologies for EUV/Optical and IR Telescope

Lead Center: MSFC

Participating Center(s): JPL, GSFC

This subtopic solicits solutions in the following areas:

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

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

This subtopic's emphasis is to mature technologies needed to affordably manufacture, test or operate complete mirror systems or telescope assemblies. Section 3 contains a detailed discussion on specific technologies which need developing for each area.

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. An ideal Phase II project would further advance the technology to produce a space-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. The Phase II would also include a mechanical and thermal stability analysis.

Successful proposals will demonstrate an ability to manufacture, test and control ultra-low-cost optical systems that can meet flight 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

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.

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 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 a 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 potential UVO missions are normal incidence 4-meter (or larger) diameter 5 nm rms surface mirrors; and, active/passive align/control of normal-incidence imaging systems to achieve < 500 nm diffraction limit (< 40 nm rms wavefront error, WFE) performance. Additionally, recent analysis indicates that an Exoplanet mission, using an internal coronagraph, requires total telescope wavefront stability of less than 10 pico-meters per 10 minutes. Specifically needed for potential IR/Far-IR missions are normal incidence 12-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 less than \$1M to \$100K/m².

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

- Areal Cost < \$500k/m² (for UV/Optical).
- Areal Cost < \$100k/m² (for Infrared).
- Monolithic: 1 to 4 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).
- Thermally Stable < 10 pm/10 min (for Coronagraphy).
- Actuator Resolution < 1 nm rms (for UV/Optical).

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

Optical Components and Systems for potential UV/Optical missions

Potential UV/Optical missions require 4 to 8 or 16 meter monolithic or segmented primary mirrors with < 10 nm rms surface figures and < 10 pm per 10 min stability. Mirror areal density depends upon available launch vehicle capacities to Sun-Earth L2 (i.e., 15 kg/m² for a 5 m fairing EELV vs. 60 kg/m² for a 10 m fairing SLS). Regarding areal cost, it is necessary to keep the total cost of the primary mirror at or below \$100M. Thus, an 8-m class mirror (with 50 m² of collecting area) should have an areal cost of less than \$2M/m². And, a 16-m class mirror (with 200 m² of collecting area) should have an areal cost of less than \$0.5M/m².

Key technologies to enable such a mirror include new and improved:

- Mirror substrate materials and/or architectural designs.
- Processes to rapidly fabricate and test UVO quality mirrors.
- Mechanisms and sensors to align segmented mirrors to < 1 nm rms precisions.
- Thermal control to reduce wavefront stability to less than 10 pm rms per 10 min.
- Vibration isolation (> 140 db) to reduce phasing error to < 10 pm rms.

Also needed is ability to fully characterize surface errors and predict optical performance via integrated optomechanical modeling.

Potential solutions for substrate material/architecture include, but are not limited to: silicon carbide, nanolaminates or carbon-fiber reinforced polymer.

Potential solutions for new fabrication processes include, but are not limited to:

- 3-D printing.
- Additive manufacture.
- Direct precision machining.
- Rapid optical fabrication.
- Roller embossing at optical tolerances.
- Slumping or replication technologies to manufacture 1 to 2 meter (or larger) precision quality components.

Potential solutions for achieving the 10 pico-meter wavefront stability include, but are not limited to: metrology, passive and active control for optical alignment and mirror phasing; active vibration isolation; metrology, passive and active thermal control.

Optical Components and Systems for potential Infrared/Far-IR missions

Potential Infrared and Far-IR missions require 12 m to 16 m to 24 meter class segmented primary mirrors with $\sim 1 \mu\text{m}$ rms surface figures which operates at $< 10 \text{ K}$.

There are two primary challenges for such a mirror system:

- Areal Cost of $< \$100\text{K}$ per m^2 .
- Cryogenic Figure Distortion $< 100 \text{ nm rms}$

Fabrication, Test and Control of Advanced Optical Systems

While the “Optical Components and Systems for potential UV/Optical missions” and “Optical Components and Systems for potential Infrared/Far-IR missions” sections detail the capabilities need to enable potential future UVO and IR missions, it is important to note that this capability is made possible by the technology to fabricate, test and control optical systems. Therefore, this sub-topic also encourages proposals to develop such technology which will make a significant advance of a measurable metric.

S2.04 X-Ray Mirror Systems Technology, Coating Technology for X-Ray-UV-OIR, and Free-Form Optics

Lead Center: GSFC

Participating Center(s): JPL, MSFC

This subtopic solicits proposals in the following areas:

- Components, Systems, and Technologies of potential X-Ray missions.
- Coating technologies for X-Ray, EUV, 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 NASA's science mission needs and technical challenges specified under each category of section 3.

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 NASA's 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 m² 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/m².

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 from 1/2 to 6 cm.

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-obsured 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.

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 2015 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 115C 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* - Released March 2011. This decadal survey is considering technology needs. (http://solarsystem.nasa.gov/multimedia/download-detail.cfm?DL_ID=742).

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.

Radioisotope Power Conversion

Radioisotope technology enables a wide range of mission opportunities, both near and far from the Sun and hostile planetary environments including high energy radiation, both high and low temperature and diverse atmospheric chemistries. Technology innovations capable of advancing lifetimes, improving efficiency, highly tolerant to hostile environments are desired for all thermal to electric conversion technologies considered here. Specific systems of interest for this solicitation are listed below:

Stirling Power Conversion

Advances in, but not limited to, the following:

- System specific mass greater than 10 We/kg.
- Highly reliable autonomous control.

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).
- Lightweight solar array technologies applicable to solar electric propulsion missions. Current missions being studied require solar arrays that provide 1 to 20 kilowatts of power at 1 AU, are greater than 300 watts/kilogram specific power, can operate in the range of 0.7 to 3 AU, provide operational array voltages up to 300 volts and have a low stowed volume.

Note that submissions for thermoelectrics technologies, formerly solicited by SMD, are now being solicited by STMD.

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.

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:

- Propulsion systems with green propulsion.
- Micropumps w/ Mon-25/MMH.
- Iodine propellants.
- 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) and In-Space Electric Propulsion (ISP) are two 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 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/wiring 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 voltage, radiation hardened, high temperature power passive components.
- High power density/high efficiency power electronics and associated drivers for switching elements.
- Radiation hardened, 1200 V (or greater) SiC 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, and nano-wiring for low power 28 V distribution.
- 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 W.

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.

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.

S3.04 Unmanned Aircraft and Sounding Rocket Technologies

Lead Center: GSFC

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

Unmanned Aircraft System Technologies

Breakthrough technologies are sought that will enhance performance and utility of NASA's Airborne Science fleet with expanded use of unmanned aircraft systems (UAS). Novel airborne platforms incorporating tailored sensors and instrumentation suitable for supporting specific NASA Earth science research goals are encouraged. Additionally, innovative subsystem elements that will support existing or future UAS are desired. Concepts should include a clear outline of steps planned to complete all relevant NASA and FAA requirements. Potential concepts include:

- Novel Navigation Systems (terrain following for example).
- Autonomous Mission Planning.
- One month endurance small UAS for miniature (~2 lb) instrument packages scalable to larger platforms.
- Novel propulsion concepts that will expand the flight envelope.
- Small UAS in-situ cloud measurement capabilities.
- Autonomously Linking UAS.
- Novel flight management approaches such as dynamic soaring.
- Guided Dropsondes.
- Airspace monitoring system for small UAS operations.
- Modular air vehicle systems for optimization for specific missions.

- Systems for air/ash sample return from volcanic plumes.
- Miniaturized 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. 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.

S3.05 Guidance, Navigation and Control

Lead Center: GSFC

Participating Center(s): ARC, JPL, JSC

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 positioning, navigation, timing, attitude determination, and attitude control. 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 a range of spacecraft platform sizes, from large, to mid-size, to emerging smallsat-cubesat class spacecraft are desired.

Advances in the following areas are sought:

- Navigation systems - Autonomous onboard flight navigation sensors and algorithms incorporating a range of measurements from GNSS measurements, ground-based optical and RF tracking, and celestial navigation. Also relative navigation sensors enabling precision formation flying and astrometric alignment of a formation of vehicles relative to a background starfield.
- 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. Also lightweight, compact sensors and actuators that will enable pointing performance comparable to large platforms on lower cost, small spacecraft.

Proposals should address the following specific technology needs:

- Precision attitude reference sensors, incorporating optical, inertial, and x-ray measurements, leading to significant increase in accuracy and performance over the current state of the art.
- Autonomous navigation sensors and algorithms applicable to missions in HEO orbits, cis-lunar orbits, and beyond earth orbit. Techniques using above the constellation GNSS measurements, as well as measurements from celestial objects.
- Compact, low power attitude determination and control systems for small satellite platforms, including ESPA (EELV Secondary Payload Adapter) class spacecraft and smaller, university standard cubesat form factors.
- Relative navigation sensors for spacecraft formation flying and autonomous rendezvous with asteroids. Technologies applicable to laser beam steering and pulsed lasers for LIDAR.
- 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**

NASAs 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 two 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.

Planetary Balloons

Innovations in materials, structures, and systems concepts have enabled buoyant vehicles to play an expanding role in planning NASA's future Solar System Exploration Program. Balloons are expected to carry scientific payloads at 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. Proposals are sought in the following areas:

Power Systems for Titan Balloons

NASA is interested in Titan balloons that can fly at an altitude range of 5 to 10 km above the surface for at least 30 days. Innovative concepts are sought for power systems capable of providing 100 Watts of electric power continuously at 28 Volts for a 30 day mission for a total electrical energy output of 72 kW-hrs. The system must be capable of operating within the Titan environment at 85 to 95 K. The Titan atmosphere at this altitude range contains approximately 95% nitrogen and 5% methane gas which may be harvested as an in situ fuel source. Waste heat from the power source can be used to keep the balloon payload at a warm operating temperature to reduce electrical heating requirements. Consideration should also be given to define requirements (e.g., power needs) placed on the host spacecraft during the transit to Titan from Earth, which could be as long as 8 years, for storage and retention of the fuel and oxidizer components. 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. Proposers should include estimates of the mass and volume of their power system concept.

Steerable Antenna for Titan and Venus Telecommunications

Many concepts for Titan and Venus balloons require high gain antennas mounted on the balloon gondola to transmit data directly back to Earth. This approach requires that the antenna remain mechanically or electronically pointed at the Earth despite the motions experienced during balloon flight. A beacon signal from the Earth will be available to facilitate pointing. Innovative concepts are sought for such an antenna and pointing system with the following characteristics: dish antenna diameter of 0.8 m (or equivalent non-dish gain), total mass of antenna and pointing system of d 10 kg, power consumption for the steering system d 5 W (avg.), pointing accuracy d 0.5 deg (continuous), hemispheric pointing coverage (2π steradians), azimuthal and rotational slew rates ≥ 30 deg/sec. It is expected that a Phase I effort will involve a proof-of-concept experiment leading to a plan for full scale prototype fabrication and testing in Phase II. Phase II testing will need to include an Earth atmosphere balloon flight in the troposphere to evaluate the proposed design under real flight conditions.

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.
 - Thermal coatings with low absorptance, high emittance, and good electrical conductivity.
- 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 is user-friendly, integrates with all commonly used programs at NASA for mechanical, structural, thermal and optical analysis, allows full STOP analysis, changes performance predictions based on mechanical design changes, structural or thermal materials or analysis changes, and quickly predicts full system performance.
- Single-phased and two-phase mechanically pumped fluid systems with easily adaptable/reconfigurable architectures are needed in order to accommodate multiple heat sources and multiple heat sinks. In addition, missions with high sink temperatures require vapor compression systems with COP > 5 and high temperature lifts. Such systems must accommodate long duration missions (12+ years) in high radiation environments (e.g., Europa). Areas of focus include high performance working fluids with wide temperature ranges and low freeze points; novel evaporators/heat exchangers that promote isothermality over large areas; lightweight, reliable phase separators; long-life, energy efficient pumps for sub-cooled systems; long-life, energy efficient compressors for vapor compression systems; and miniaturization of pumps, compressors, and control valves.
- 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.

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 2015 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.

Additionally, the development of radiation hardened, high speed memory devices and advanced point-of-load power converters for high performance onboard processing systems is included as a goal.

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 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:

- Technologies enabling the use of COTS micropower/ultra-low power computing devices in highly reliable spacecraft avionics systems.
- Technologies enabling 3-D die stacking using die from different processes and foundries, enabling implementation of miniaturized, highly-reliable fault tolerant systems.
- Radiation hardened, high speed SDRAM memory devices for high performance onboard processing systems (focusing on DDR3 or newer technologies).
- Novel approaches for miniaturized, highly reliable point-of-load converters capable of providing core and I/O power for existing and emerging spaceflight processors and Field Programmable Gate Arrays (FPGAs). These should be capable of:
 - Accepting a nominal 5V input.

- Sourcing voltages as low as 1V at up to 5A.
- Providing peak efficiency exceeding 90%.
- Maintaining stability across a wide range of output loads while requiring a minimal number of external discrete components.
- Innovative approaches for single event effects mitigation utilizing non-RHBD (Radiation Hardened By Design) FPGA devices for performance (speed, power, mass) that is capable of meeting or exceeding traditional RHBD devices and leveraging commercially available devices.

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 (<http://solarsystem.nasa.gov/missions/index.cfm>) for mission information. See (<http://mars.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 115C 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 deg/sec).
- Improving the state-of-the-art in measurement accuracy/precision/resolution for the above sensor needs.
- Substantially reducing the amount of external processing needed by the host vehicle to calculate the measurements.
- Significantly reducing the impact of incorporating such sensors on the spacecraft in terms of Size, Weight, and Power (SWaP), spacecraft accommodation complexity, and/or cost.
- Providing sensors that are robust to environmental dust/sand/illumination effects.
- Mitigation technologies for dust/particle contamination of optical surfaces such as sensor optics, with possible extensibility to solar panels and thermal surfaces for Lunar, asteroid, and comet missions.

For all the aforementioned technologies, candidate solutions are sought that can be made compatible with the environmental conditions of deep spaceflight, the rigors of landing on planetary bodies both with and without atmospheres, and planetary protection requirements.

NASA is also looking for high-fidelity real-time simulation and stimulation of passive and active optical sensors for computer vision at update rates greater than 2 Hz to be used for signal injection in terrestrial spacecraft system test beds. These solutions are to be focused on improving system-level performance Verification and Validation during spacecraft assembly and test.

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

S4.02 Robotic Mobility, Manipulation and Sampling

Lead Center: JPL

Participating Center(s): 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.

Mobility technologies are needed to enable access to steep and rough terrain for planetary bodies where gravity dominates, such as the Moon and Mars. Tethered systems, non-wheeled systems, and marsupial systems are examples of mobility technologies that 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 needed. Manipulation technologies are needed to enable deployment of sampling tools and handling of samples. Small-body mission 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 material. A drill is needed to enable sample acquisition from the subsurface including rock cores to 3m depth and icy samples from deeper locations. Minimization of mass and ability to work reliably in the harsh mission environment are important characteristics for the tools.

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:

- Tethers and tether play-out and retrieval systems.
- Small body anchoring systems.

- Subsurface sampling systems.
- Low mass/power vision systems and processing capabilities to enable fast surface traverse.
- Abrading bit providing smooth surface preparation.
- 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-pressure is also required for deep atmospheric probes to planets. Proposals are sought for technologies that are suitable for remote sensing applications at cryogenic temperatures, and in-situ atmospheric and surface explorations in the high-temperature high-pressure environment at the Venusian surface (485°C, 93 atmospheres), or in low-temperature environments such as Titan (-180°C), Europa (-220°C), Ganymede (-200°C), Mars, the Moon, asteroids, comets and other small bodies. Also Europa-Jupiter missions may have a mission life of 10 years and the radiation environment is estimated at 2.9 Mega-rad total ionizing dose (TID) behind 0.1 inch thick aluminum. Proposals are sought for technologies that enable NASA's long duration missions to extreme wide-temperature and cosmic radiation environments. High reliability, ease of maintenance, low volume, low mass, and low out-gassing characteristics are highly desirable. Special interest lies in development of following technologies that are suitable for the environments discussed above:

- Wide temperature range precision mechanisms i.e., beam steering, scanner, linear and tilting multi-axis mechanisms.
- Radiation-tolerant/radiation hardened low-power low-noise mixed-signal mechanism control electronics for precision actuators and sensors.
- Wide temperature range feedback sensors with sub-arc-second/nanometer precision.
- Long life, long stroke, low power, and high torque/force actuators with sub-arc-second/nanometer precision.
- Long life Bearings/tribological surfaces/lubricants.
- High temperature energy storage systems.
- High-temperature actuators and gear boxes for robotic arms and other mechanisms.
- Low-power and wide-operating-temperature radiation-tolerant /radiation hardened RF electronics.

- Radiation-tolerant/radiation-hardened low-power/ultra-low-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/cm² 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).
- Squalene (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, 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 are tools that 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:

- Grid computing.
- Web services.
- Client-server models.
- 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.
 - 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 Algorithms and Tools for Science Data Processing, Discovery and Analysis, in State-of-the-Art Data Environments**Lead Center:** GSFC**Participating Center(s):** ARC, JPL, KSC, LaRC, MSFC, SSC

The size of NASA's observational data sets is growing dramatically as new missions come on line. In addition, NASA scientists continue to generate new models that regularly produce data sets of hundreds of terabytes or more. It is growing ever increasingly difficult to manage all of the data through its full lifecycle, as well as provide effective data analytical methods to analyze the large amount of data.

Using remote observation examples, 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. Other examples are 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). From the NASA climate

models, the MERRA reanalysis data set is approximately 200 TB, and MERRA2 will start generating even more data late in 2014.

This subtopic area seeks innovation and unique approaches to solve issues associated around the use of "Big Data" within NASA. The emphasis of this subtopic is on tools that leverage existing systems, interfaces, and infrastructure, where it exists and where appropriate. Reuse of existing NASA assets is strongly encouraged.

Specifically, innovations are being sought in the following areas:

- *Parallel Processing for Data Analytics* - Open source tools like the Hadoop Distributed File Systems (HDFS) have shown promise for use in simple MapReduce operations to analyze model and observation data. In addition to HDFS, there is a rapid emergence of an ecosystem of tools associated with high performance data analytics using cloud software packages, such as Hive, Impala, Spark, etc. The goal is to accelerate these types of open source tools for use with binary structured data from observations and model output using MapReduce or a similar paradigm.
- *High Performance File System Abstractions* - NASA scientists currently use a large number of existing applications for data analysis, such as GrADS, python scripts, and more, that are not compatible with an object storage environment. If data were stored within an object storage environment, these applications would not be able to access the data. Many of these applications would require a substantial amount of investment to enable them to use object storage file systems. Therefore, a file system abstraction, such as FUSE (file system in user space) is needed to facilitate the use of existing data analysis applications with an object storage environment. The goal is to make a FUSE-like file system abstraction robust, reliable, and highly performing for use with large NASA data sets.
- *Data Management of Large-Scale Scientific Repositories* - With increasing size of scientific repositories comes an increasing demand for using the data in ways that may never have been imagined when the repository was conceived. The goal is to provide capabilities for the flexible repurposing of scientific data, including large-scale data integration, aggregation, representation, and distribution to emerging user communities and applications.
- *Server Side Data Processing* - Large data repositories make it necessary for analytical codes to migrate to where the data are stored. In a densely networked world of geographically distributed repositories, tiered intermediation is needed. The goal is to provide support for migratable codes and analytical outputs as first class objects within a provenance-oriented data management cyberinfrastructure.
- *Techniques for Data Analysis and Visualization* - New methods for data analytics that scale to extremely large and geographically distributed data sets are necessary for data mining, searching, fusion, subsetting, discovery, visualization, and more. In addition, new algorithms and methods are needed to look for unknown correlations across large, distributed scientific data sets. The goal is to increase the scientific value of model and observation data by making analysis easier and higher performing. Among others, some of the topics of interest are:
 - Techniques for automated derivation of analysis products such as machine learning for extraction of features in large image datasets (e.g., volcanic thermal measurement, plume measurement, automated flood mapping, disturbance mapping, change detection, etc.).
 - Workflows for automated data processing, interpretation, and distribution.

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 ensure a successful 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 used for broad public dissemination or 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) or prevalent applications.

S5.04 Integrated Science Mission Modeling**Lead Center: JPL****Participating Center(s): GSFC**

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 models 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.
- Models of function or behavior of complex systems, at either the system or subsystem level. Such models should be capable of eliciting numerically accurate and robust estimates of system performance given appropriate environments and activity timelines, and could be tailored:
 - To support design efforts at early- to mid-phase.
 - To support verification and testing of systems that cannot be performed on actual as built systems.
 - To support the development of operational mission scenarios and the investigation and troubleshooting of on-orbit anomalies. As an example, the list of potential future missions includes a flagship UV-optical-IR, 10-m class space telescope with demanding performance requirements (e.g., milli-arcsecond pointing, picometer wavefront stability) driven by the goal to detect and characterize Earth-like exoplanets.
- Hi-fidelity performance models of remote sensing instruments that can easily be integrated with spacecraft and telescope models to form system-level performance models.
- 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.
- Modeling of failure modes and/or other risk mechanisms that enable meaningful assessment of performance, cost and schedule risk.

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.

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

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TOPIC: Z1 Advanced Power and Energy Storage Systems for Cross-Cutting Space Applications

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:

Solid State Power Generation

Thermoelectric and thermionic component materials will be investigated for the creation of electricity from thermal energy in space applications. There is particular interest in high Z materials and materials with low work functions applicable to thermionic energy conversion. The focus of the topic area will be to generate working devices by the end of an SBIR Phase II. Material performance and testing may be the focus of the Phase I activity as long as explicit discussion of eventual working device is included in the Phase I proposal and the intent of the effort is to use Phase II follow on effort to build and test the working system.

Modeling and Simulation / Modeling and Measurements

Innovative model development to will provide insight into design decisions and trade-offs for advanced propulsion and power systems are sought. The focus is on improving the correlation between experiments and predictions by developing and validating multi-scale physics-based models. The goal is to reduce the development time of future systems needed for space exploration.

Z1.01 Modeling and Measurements for Propulsion and Power

Lead Center: GRC

Participating Center(s): ARC, JPL, MSFC

To reduce the development time of advanced future systems needed for space exploration, physics-based modeling tools are sought for:

- Electrochemical systems such as batteries, fuel cells and electrolyzers.
- Nuclear power and nuclear power based propulsion systems.
- Microfluidic electrospray propulsion systems.

In each case, the emphasis is on determining performance-limiting features and identifying potential means to overcome limitations. Models should focus on aspects of the system where interactions of sub-systems or components is poorly understood and where development frequently relies on heuristics or iterative build and test cycles to settle on designs. Electro-chemistry models are sought that predict the rates of reaction, or side products of a reaction, predicated upon the thermodynamic or kinetic properties of electrode and electrolyte materials are needed. Nuclear systems models are required that model the fission reaction, heat transport, latent radiation, etc. in sufficient detail to predict design efficacy, evaluate engineering solutions, and reduce testing requirements. Creating interfaces between reactor models and engine system models, including radiation effects, and modeling nuclear thermal propulsion ground test engine exhaust filtering and containment are areas of particular interest. Physics based models are sought to predict flow properties of liquid metal or ionic liquids for microfluidic electrospray propulsion systems. Of particular interest are models that describe capillary flow forces as a function of micro-geometry, the characterization of end-to-end velocity profiles in a feed system, viscosity and velocity characterization as a function of thermal gradients, the boundary between flow characteristics determined by micro-fluidic capillary forces and flow characteristics determined by formation and operation of Taylor cones, and fluid properties under steady state and pulsed electric operation at the boundary of Taylor cones. Model validation will also be required; improved measurement techniques needed for validation are also of interest provided they are coupled with a modeling activity outlined above. Tools that exclusively model proprietary systems will not be considered for award.

Z1.02 Solid-State Thermal-to-Electric Power Generation

Lead Center: JPL

Participating Center(s): GRC, JSC

Future NASA missions require power generation capabilities beyond what can be easily supported using solar arrays or chemical fuel cells. Thermal-to-Electric materials and systems working in conjunction with nuclear systems have the potential to serve this need and to operate at distances from the Sun well beyond the limit of its useful energy. Existing Thermal-to-Electric materials and systems do not “trade well” with existing power generation options, e.g., fuel cells, due to poor efficiency and specific power, however their longevity of operation makes them attractive for many other mission spaces. In the last decade extensive research has gone into raising the figure of merit for thermoelectric materials, ZT, both new materials and new fabrication techniques that modify the morphology and atomic lattice of the materials, have been attempted with varying degrees of success. Simultaneously, work has been done on creating “coupled” systems similar to multi-junction solar arrays that produce greater efficiency than single layer systems. Although this research has resulted in significant advances at the basic materials level, these advances have yet to be transitioned to NASA RTGs. In fact the Mars Curiosity MMRTG utilized the same TE materials and reported the same system level performance, i.e., efficiency and specific power, as the SNAP 19 RTG launched in 1972 for Pioneer 10. Thermionic power conversion is a complimentary static approach which could extend power conversion efficiencies beyond thermoelectric limits to as high as 25% or more. Successful thermionic converters would enable power systems with the efficiency of dynamic systems (Rankine, Brayton and Stirling), but with no moving parts and the potential for high reliability. High waste heat rejection temperatures also lead to modest radiator area and mass. Thermionic converters received much attention in the 1960's-90's for solar and nuclear power, and were flown in space by the Russians in the 1990's. At the time, high-temperature low-work-function materials, precise gap maintenance, and space charge buildup proved problematic for the then state-of-art. Since the year 2000, major advances have been made in the highly relevant fields of nanotechnology, nanomaterials, MEMS, micromachining and fabrication, and new converter topologies. Proposals are thus solicited for application of these new ideas towards practical thermionic converters for nuclear and solar space power generation, and terrestrial topping cycles or energy harvesting.

This topic seeks to explore emerging capabilities in both Thermoelectric and Thermionic materials with an eye towards improving base system efficiencies and specific power of systems employing thermal to electric concepts. Proposals are solicited that focus on transitioning the improvements in bulk TE materials to system solutions for advanced power-generation and conversion technologies that will enable or enhance the capabilities of future science and human exploration 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). This topic will focus on:

- Advanced bulk materials enabling demonstration of high efficiency thermoelectric energy conversion (>15%) when using high grade space-qualified heat sources (> 1000 K).
- Advanced thermoelectric couple and module component technologies that will facilitate integration of new high performance materials into high reliability, high temperature long life systems.
- Advanced high temperature (>1500 K) thermionic materials demonstrating low work function (< 3 eV) and high Richardson coefficient (> 80 Amps/cm²-K²) to enable high efficiency (>25%) thermionic converters.
- Advanced thermionic converter designs leveraging modern approaches in nanotechnology, nanomaterials, microfabrication, and/or novel system topologies which demonstrate the potential for high conversion efficiency (> 25%).

Phase I products should include materials and proof-of-principle device-level demonstrations, test data, and conceptual system designs that incorporate the components advanced in Phase I and show a path to a successful Phase II project predicated on the criteria below.

Phase II should result in a working performance demonstrator at TRL 4 or greater, and should include a technology development plan for potential infusion into a flight system.

TOPIC: Z2 Lightweight Materials, Structures, and Advanced Manufacturing/Assembly

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 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 FY15 addresses large-scale polymer matrix composite (PMC) structures and materials, and concentrates on developing lightweight structures using advanced materials technologies and new manufacturing processes. Out of autoclave material systems and processing as well as joining technologies to enable 5 – 9 m diameter composite structures will be of interest. 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/directories/spacetech/home/index.html#.VCImYCSCam9>).

Z2.01 Large-Scale Polymer Matrix Composite (PMC) Structures, Materials, and Manufacturing Processes

Lead Center: MSFC

Participating Center(s): 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.

The subtopic will focus efforts to enable large (5 to 9 meter) diameter composite structures. Specific areas of interest include advances in PMC high performing resin/fiber material systems and associated out-of-autoclave processes for the manufacturing of large composite structures and innovative low cost, high reliability composite joint concepts/techniques. Proposals to each area will be considered separately:

- Advances in PMC high performing resin/fiber systems which can be cured via out of autoclave processes (such as resin infusion, or equivalent) which will yield large complex composite structures. Properties for this material system should use IM7/8552-1 or IM7/977-2 toughened epoxy systems as a baseline goal. Acceptable properties are key, but end-to-end manufacturing process evaluation should be considered to support scale-up including integration of modeling and potential automation of the processes.
- Innovative low cost, high reliability composite joining concepts/techniques for attaching large segmented structures together. 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. 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>).
- “Composite Cryotank Technologies & Demonstration.” (https://gcd.larc.nasa.gov/wp-content/uploads/2013/07/FS_CCTD_factsheet.pdf).

TOPIC: Z3 Entry, Descent, and Landing

The Entry, Descent and Landing topic area will focus on technologies that enable EDL for NASA’s challenging future planetary and Earth return missions. Functional areas, or subtopics, of interest include:

- *Engineering Instrumentation* - Sensors and sensor systems are needed, that will gather engineering data during EDL, for validating models, improving future missions, and generally advancing the state of the art. Sensors of interest include heatshield and backshell heating, pressure, radiometric and spectroscopic instruments, cameras for imaging critical events, and minimally-intrusive techniques such as wireless or acoustic systems. Key characteristics that are sought include: modularity; low mass, power, and volume; and minimal cost for the sensor system, which includes data acquisition, transfer, and storage.
- *Guidance and Control Techniques for EDL* - Advancements in hardware and software for autonomously guiding entry vehicles to specific landing sites will enable an increase in productive time on a planetary surface, or allow aggregation of surface assets. Achieving virtually pinpoint landings may require modified vehicle shapes, control methods that operate in extreme environments, or other hardware innovations. Accompanying numerical algorithms need to efficiently and robustly manipulate the vehicle system through the hypersonic, supersonic, and subsonic flight regimes.
- *Advanced Materials* - This subtopic seeks specific materials innovations that are unique to EDL, including thermal protection systems, multifunctional structures, and inflatable and deployable decelerator concepts.
- *Modeling and Simulation* - Innovative M&S tools that will provide insight into system and subsystem performance, design decisions, and trade-offs are sought. Physics-based models that can facilitate a move towards computational validation, or models grounded in flight data, are particularly of interest. The focus is on the reduction of overall development time and cost for advanced future systems needed for space exploration.

Z3.01 Wireless Cameras for Entry, Descent, and Landing Reconstruction**Lead Center: JPL****Participating Center(s): LaRC**

This subtopic seeks innovative solutions for the collection of high resolution, high frame rate, and low distortion imagery of key events and hardware during entry, descent, and landing. This would enable the capture of valuable forensic images for spacecraft events such as the deployment and inflation of parachutes, vehicle touchdown dynamics, and plume-ground interactions.

Because the intended usage of the camera system is during EDL, a series of spacecraft critical events, the camera system must operate on a non-interference basis with the rest of the spacecraft. Additionally, the use of wireless cameras allows the cameras to be optimally placed to capture imagery of key hardware that may be difficult to access with traditional wired cameras.

Camera Sensor Performance Targets:

- Format and Frame Rate Minimum: 1080p @ 30 fps (up to 100 fps).
- Array Format Minimum: 1920 x 1080 Pixels.
- Target Wavelength Range: 480nm - 800nm (TBR).
- Windowing: Yes.
- Color: Yes.
- Technology: CMOS or CCD.
- Temperature Range: -30°C to +40°C.

Camera Optical Performance Targets:

- Field of View: +/- 45 degrees off center-line.
- Focus: 0.5 m to infinity.

Supporting Avionics Functions:

- Ability to control the camera sensor.
- Ability to (near) real time, receive and store seconds to a few minutes of data at the above frame rates, then transmit the image data to the main entry vehicle computer.
- Distance from camera to storage device is between 0.5-10 meters.
- Unit volume no greater than 12.7 cm x 12.7 cm x 12.7 cm.

Phase I Deliverables - Include a camera system architecture design, and a testing and calibration plan. Constructing a breadboard unit would also be desired.

Phase II Deliverables - Include an engineering-level prototype system on which the testing and calibration from Phase I would have been completed, and a test/performance report.

TOPIC: Z4 Small Spacecraft Technology

This topic seeks innovative technologies for components and subsystems for small spacecraft ranging in size from cubesat-scale up to approximately 100 kilograms in mass. These spacecraft are intended for science, exploration, and other missions in Earth orbit and in regions of the inner solar system beyond Earth.

Proposals are sought for projects that can produce, by the end of Phase II, flight-quality hardware or at least proto-flight hardware for the designated components or subsystems that might then be integrated into spacecraft for technology demonstration flights. Several specific technology areas are of interest in this solicitation:

- Solar arrays, energy storage, and integrated power systems for small spacecraft. The primary power requirement is for electric propulsion systems although these spacecraft might also utilize significant electrical power for communications and payload operations.
- Navigation and attitude determination systems for small spacecraft operating beyond low-Earth orbit to provide precise knowledge of the spacecraft state (position, attitude, and rates in all axes) without reliance on the Global Positioning System or similar Earth-orbit references or planetary magnetic fields.
- Structural design concepts for small spacecraft that offer significant advantages over conventional structures in one or more of the following ways:
 - Reduce mass while maintaining adequate strength.
 - Provide thermal management features for the spacecraft such as enhanced heat transfer and heat rejection.
 - Provide radiation shielding to other spacecraft components.
 - Enhance the ease of assembly and integration of spacecraft.

Z4.01 Small Spacecraft in Deep Space: Power, Navigation, and Structures

Lead Center: ARC

This subtopic seeks innovative technologies for components and subsystems for small spacecraft ranging in size from cubesat-scale up to spacecraft of approximately 100 kilograms in mass. These spacecraft are intended for science, exploration, and other missions in Earth orbit and, in particular, for operations in other regions of the inner solar system beyond Earth.

For all technology areas outlined below, the components and subsystems must be tolerant of typical launch vehicle loads and environments and operationally tolerant of the thermal and radiation environment that exists, as a minimum, in earth orbit at any altitude above 300 km, in cis-lunar space including lunar orbit, and in heliocentric orbit at 1 Astronomical Unit (AU) from the sun. It is desirable that these components and subsystems also be operationally tolerant of the thermal and radiation environment that exists in interplanetary space ranging from 0.7 AU to at least to 3 AU from the sun and in orbit around Mars and Venus. Components and subsystems must also be resistant to the atomic oxygen environment in low-Earth orbit.

For all technology areas below, proposals are sought for projects that can produce, by the end of Phase II, flight-quality hardware or at least proto-flight hardware for the designated components or subsystems that might then be integrated into spacecraft for technology demonstration flights, initially in low-Earth orbit. Initial flight demonstrations are likely to employ 3-unit or 6-unit cubesat spacecraft. For convenience in integration, components and subsystems should be designed to fit a standard cubesat unit (10 by 10 by 10 centimeters), a fraction of that unit, or multiples of that unit. The desired Phase I deliverables include a detailed description and plan for development and fabrication of the hardware to be produced by the end of Phase II.

Proposals are sought in several technology areas outlined below. Proposers should clearly state the technology area addressed by their proposal. Proposers may submit more than one proposal but each individual proposal must address only one of the technology areas below.

Power Systems for Small Spacecraft

This area seeks innovative technologies for solar power generation and/or electrical energy storage systems for small spacecraft ranging in size from cubesat-scale up to spacecraft of approximately 100 kilograms in mass. The primary power requirement is for electric propulsion systems although these spacecraft might also utilize significant electrical power for communications and payload operations.

- Solar Array Systems: Solar array systems consisting of deployable panels or blankets with necessary structural support, mechanisms, and functional photovoltaic cell arrays. The arrays must be designed for unaided deployment in the space environment (micro-gravity and vacuum conditions) and provide for functional power generation. Innovations are sought in compact packaging of arrays for launch, reliable array deployment at a specified time after launch, and reliable power generation in space. Systems with low mass are desired but compact storage volume is the more important feature. The power generation goal for these systems is 100 to 500 watts per panel (power at beginning of life at 1 AU from the sun) for panels that can be packaged for launch within a volume of three cubesat units (3U) or less. Systems are sought which also incorporate the capability for rotation relative to the body of the spacecraft to allow the array to track the sun as the spacecraft moves through space.
- Energy Storage Systems: Batteries or other types of rechargeable energy storage systems with a capacity of 200 to 2000 watt-hours and with minimum volume and mass. Functional heat rejection requirements must also be addressed in the design and prototype hardware.
- Integrated Power Systems: Systems that include the solar array and energy storage as a system, ready for integration into a small spacecraft.

Navigation and Attitude Determination for Small Spacecraft beyond Earth Orbit

This area seeks innovative technologies for navigation and attitude determination systems for small spacecraft ranging in size from cubesat-scale up to spacecraft of approximately 100 kilograms in mass, operating beyond low-Earth orbit. The relevant systems are required to provide precise knowledge of the spacecraft state (position, attitude, and rates in all axes) without reliance on the Global Positioning System or similar Earth-orbit references or planetary magnetic fields. Any reliance on Earth based communications and tracking systems must take into account the limited power and other capabilities of small spacecraft operating at great distances from Earth. Novel concepts that minimize reliance on conventional navigation and tracking resources and techniques are desired.

The relevant navigation systems must be scaled for integration in small spacecraft with a target peak-power requirement of less than 100 watts and a volume of less than 3 cubesat units (approximately 10 by 10 by 30 centimeters) for the system. Lower volume, mass, and power usage is desirable. Requirements for heat rejection from the navigation system must be addressed in the design.

Structures for Small Spacecraft

This area seeks innovative technologies for structural designs for small spacecraft ranging in size from cubesat-scale up to spacecraft of approximately 100 kilograms in mass, for operation in and beyond Earth orbit. Structures for cubesats in the 3U, 6U and 12U size range are of particular interest. Proposed concepts should offer significant advantages over conventional aluminum or composite structures in one or more of the following ways:

- Reduce mass while maintaining adequate strength.
- Provide thermal management features for the spacecraft such as enhanced heat transfer and heat rejection.
- Provide radiation shielding to other spacecraft components.
- Enhance the ease of assembly and integration of spacecraft.

The recurring cost of the structures and materials proposed should be consistent with the low-cost goals of small spacecraft projects.

Proposals must focus on the design and fabrication of flight-quality or at least proto-flight structures that might then be integrated into small spacecraft for technology demonstration flights. Proposals that address general innovations in advanced manufacturing, structures, or materials are not appropriate for this subtopic.

NASA Small Spacecraft Technology Program:

- (http://www.nasa.gov/directorates/spacetech/small_spacecraft/index.html#.VEIDRySvybE).

Small Spacecraft Technology State of the Art Report:

- (http://www.nasa.gov/sites/default/files/files/Small_Spacecraft_Technology_State_of_the_Art_2014.pdf).

TOPIC: Z5 Assistive Free-Flyers

The Assistive Free-Flyers (AFF) topic area focuses on technology to enhance the capabilities and performance of small, free-flying robots that assist humans. AFF's can complement astronauts in space by performing tasks that are tedious, highly repetitive, dangerous or long-duration. AFF's can also provide side-by-side assistance to astronauts by carrying tools/materials, providing procedure support, etc.

AFF's can potentially be applied to a wide variety of tasks including in-flight maintenance, spacecraft health-management, environmental monitoring surveys (air quality, radiation, lighting, sound levels, etc.), and automated logistics management (inventory, inspection, etc.)

AFF's can be used when humans are present to off-load routine work, to increase human productivity, and to handle contingencies. AFF's can also be used when humans are not present, such as during "pre-deployment" and quiescent periods, to perform spacecraft caretaking. In particular, AFF's could be used to enable mobile monitoring, maintenance, and repair of spacecraft before, and between, crews.

Z5.01 Payload Technologies for Assistive Free-Flyers

Lead Center: ARC

Participating Center(s): JPL, JSC

The objective of this subtopic is to develop technology that can be integrated as external payloads on assistive free-flyers (AFF). AFFs are small free-flying robots that assist humans in exploration, surveillance, inspection, mapping, and other work. Current AFFs include space free-flyers, micro UAVs, drones, etc. A key characteristic of AFFs is that they can perform assistive tasks while co-located in human environments. On the International Space Station (ISS), for example, the SPHERES robots have shown how AFF's can perform environment surveys, inspection, and crew support.

During 2015-2017, STMD will develop a new AFF as part of the Human Exploration Telerobotics 2 (HET-2) project. This new robot will carry out inventory, sound monitoring, and other routine tasks on the ISS. Proposals are sought to create AFF payloads that can be integrated for application-specific functions, or that can provide general capability enhancements in three areas:

- Sensor Payloads - Compact sensors that can be used for environment monitoring, including detection of combustibles, air quality (CO₂ levels), illumination (light spectrum), radiation, etc.
- Logistics Devices - Devices that facilitate automated logistics management, particularly inventory scanners (RFID, barcode, etc.) and mechanisms to support tagging/tracking.
- Appendages - Mechanisms that can be used for docking/perching, prodding/pushing, etc. This includes deployable structures, universal end-effectors (e.g., jamming granular gripper), and devices incorporating gecko or electrostatic adhesion.

Deliverables to NASA:

- Identify scenarios and use cases.
- Develop concepts.
- Construct prototypes.
- Perform technology demos.

Proposals are highly-encouraged that leverage the SPHERES engineering units and HET-2 free-flyers at the NASA Ames Research Center. Phase II efforts should deliver documentation and sufficient units to support future research/testing on ISS.

TOPIC: Z6 Advanced Metallic Materials and Processes Innovation

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.

Z6.01 Advanced Metallic Materials and Processes Innovation

Lead Center: MSFC

Participating Center(s): JPL, LaRC

This subtopic seeks innovative processes and development of metallic material systems. This subtopic has an emphasis 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, inconels, 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.

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.

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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): GRC, KSC, LaRC

As small satellites have become more capable of performing valuable missions for both government and commercial customers, there has been significant growth in both the quantity and quality of Nano and Micro Satellite missions. Currently these satellites can only be launched affordably as secondary payloads; but the number of these missions has outpaced available ride share opportunities. This limitation makes it difficult for small satellite missions to launch when needed and to attain the desired orbit with an acceptable risk.

A dedicated access to space also allows new and emerging technologies that increase capability and/or decrease costs to be demonstrated and qualified. Additive manufacturing is one example of such a technology. Technologies that are demonstrated and validated at the nano/micro scale can also be robustly infused into large launch vehicles where loads are not as severe.

Low cost, dedicated launch vehicles are required that will robustly meet the nano/micro satellite launch needs. This subtopic solicits technology proposals for propulsion stages of such a launcher. Specifically, the subtopic requests proposals for propulsion design tools and stages for application as booster stages, upper stages or orbit insertion stages. Stage concepts are sought that can be demonstrated within the schedule and budget of a Phase II STTR project with the following goals and constraints:

- Accepted proposals will be limited to stages that are applicable to existing or proposed architectures for orbital launch vehicles.
- A sub-orbital flight test is expected in Phase II. Additionally, the path from the sub-orbital flight test to orbital capability must be clearly defined.
- Demonstrations other than a sub-orbital flight test will be considered. However anything less than a sub-orbital flight test will require the documentation of the explicit path, including test plans and cost data, to an orbital-capable stage.
- Payload capabilities in the 5-50 kg range are targeted.
- Small launch vehicles are targeting total launch costs (fixed, reoccurring and range costs) in the \$1-2 million range. Proposed stages should demonstrate costs that fit within this range.

Phase I activities should develop the data necessary to assert with confidence that the proposed technology solution has a clear path to meet the goal an affordable orbital launch vehicle. Phase II activities will include sub-orbital stage flight-testing for verification of functionality as well as substantiation of cost projections for the orbital stage.

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 Harvesting Technology Development

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, novel energy harvesting technologies are critical toward supporting future power generation systems to begin to meet these challenges. This subtopic addresses the potential for deriving power from waste rocket engine heat, warm soil, liquids (water, oils, hydraulic fluids), kinetic motion, piezoelectric materials, or various naturally occurring energy sources, etc. Development of energy harvesting (both capture and conversion) technologies would also address the national need for novel new energy systems and alternatives to reduce energy consumption.

Areas of special focus for this subtopic include consideration of:

- Innovative technologies for the efficient capture and/or conversion of acoustic, kinetic, 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 and conversion 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 and conversion 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 to capture and convert. 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 harvesting 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.

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): ARC, 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.

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 Resource Robotic**Lead Center:** KSC**Participating Center(s):** ARC, LaRC

Using resources in space is the first step towards human self-sufficiency while expanding its presence into the Solar System. The use of robotics for In-Situ Resource Utilization (ISRU) in outer space on various planetary bodies is essential since ISRU requires large quantities of local regolith that must be acquired and processed by capable machines. In some cases this will happen prior to crew arrival on site, or it will take place at a remote destination where the crew cannot spend much time due to radiation exposure limits or other constraints. In addition, communications latencies at remote locations such as Asteroids mandate autonomous robotics applications.

The first step towards using resources derived from small bodies in space, Mars, Mars Moons and Earth's Moon, such as water, volatiles, metals and organic compounds, is to visit a target body, prospect it with sample acquisition devices and subsequently do characterization of these samples. This data will feed into eventual missions and methods for using resources in outer space by mining the ore on these target bodies and then transforming it into useful products via In-Situ Resource Utilization (ISRU) and advanced manufacturing techniques such as Additive Manufacturing and Construction. For these reasons, resource prospecting, identification and sampling regolith for characterization are priorities in this sub-topic.

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.

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 Communications Systems**Lead Center:** GRC**Participating Center(s):** GSFC

Future missions require networked comms systems that can support greater levels of autonomy and possess cognizance of the local environmental conditions and awareness of the state of other assets in the comms network for enhanced reach back and data delivery. ACS offer potential to improve overall system performance through automated sensing of local and system level conditions, rapid analysis and responsive configuration control.

Innovations are sought to enable an ACS to:

- Learn through experience to enhance adaptability to nominal and anomalous operations.
- Establish self-configurable network connections.
- Exchange information autonomously.
- Sense local conditions and dynamically maximize performance.
- Mitigate system-level effect of outages, delays, disruptions and interference.
- Leverage capabilities of flexible receivers, software-defined radios (SDRs), cognitive radios, network routers and storage, and ground assets to increase system-level autonomy, capacity and efficiency.

Potential deliverables may include a demo of ACS concept(s), enhanced comms component(s) through a clever innovation, or prototype of an element that enables a higher level of automation, performance, or efficiency at the system level.

State of the Art

Current spaceflight transceivers perform comms and some navigation functions. SDRs are reconfigurable. Use of GPS for location determination is becoming common. However, most transceivers, SDRs and ground assets operate independently under closely coordinated control. They are not yet cognitive of their local environmental conditions or the overall comms network capabilities and status, and unable to learn and improve.

Compelling need for this Subtopic

NASA SMD and HEOMD conduct robotic and human missions from low Earth orbit to deep space, in spacecraft as varied as constellations of CubeSats to human-rated orbiters and landers. The Space Communications and Navigation (SCaN) Program provides infrastructure, technologies and standards enable these missions. ACS offers the potential to sense and exploit knowledge of local and system-wide capabilities and conditions for efficient use of available comms network assets and maximum performance.

STMD/NASA/NARP/National Goals

SCaN Goals include: To implement a networked communication and navigation infrastructure across space; and to evolve its infrastructure to provide the highest data rates feasible for both robotic and human exploration missions.

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.
- 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 Gas Sensing Technology Advancements for Spacesuits**Lead Center: JSC**

Space suit life support systems are critically necessary for the successful support of the International Space Station (ISS) and future human space exploration missions for in-space micro-gravity EVA and planetary surface operations. NASA has experienced a history of failures with the existing carbon dioxide (CO₂) gas sensor for the current Extravehicular Mobility Unit (EMU) due to excess moisture in the suit. In addition, NASA is presently developing an Advanced EMU (AEMU) for exploration missions. These missions will require a robust, lightweight, and maintainable Portable Life Support System (PLSS). The PLSS attaches to the space suit pressure garment and provides approximately an 8 hour supply of oxygen for breathing, suit pressurization, ventilation; humidity, trace- contaminant, carbon dioxide (CO₂) removal; and a thermal control system for crew member metabolic heat rejection. Innovative technologies and technology advancements are needed for the partial pressure gas sensors in the PLSS. Therefore, based on current and future EVA applications, advanced CO₂ gas sensing methods are needed that can tolerate ~100% oxygen, direct water contact (Relative Humidity 0-100%), 3-23.5 psia operating pressures, and CO₂ ranges of 0-30mmHg. Additional attributes needed include low mass and volume, low maintenance, and radiation hardened or radiation tolerant. Integration of other sensing capabilities such as ammonia (NH₃ 0-50 ppm) and oxygen (0-100%) is desirable.

T6.02 Space Weather**Lead Center: GSFC****Participating Center(s): JSC**

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. 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. 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. 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. Investigations that take an integrated approach, combining observation, theory and modeling, will be preferred. Those submitting proposals are urged to take advantage of relevant available observations (such as those from SDO, STEREOs, ACE, MAVEN, MSL/RAD, LRO, etc). The potential outcome will benefit all NASA missions, both robotic and manned, current and future. The goal is in line with NASA's Living with a Star Program (<http://lws.gsfc.nasa.gov>) and Human Research Roadmap (<http://humanresearchroadmap.nasa.gov/>).

TOPIC: T7 Human Exploration Destination Systems

Reserved for future Solicitations.

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

Participating Center(s): GSFC, LaRC

This subtopic is focused on developing and demonstrating technologies for both orbital and in situ compositional analysis and mapping that can be proposed to future planetary missions. Technologies that can increase instrument resolution, precision and sensitivity or achieve new and innovative scientific measurements are solicited. For example missions, see (<http://science.hq.nasa.gov/missions>). For details of the specific requirements see the National Research 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. Improved technologies for the handling and fine manipulation of solid or powdered surface samples that could be coupled to robotic arm- or body-mounted analytical instruments.

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. Advantages of the proposed technology compared to the competition. 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 Visible to Far-Infrared Absolute Radiance Developments**Lead Center:** LaRC**Participating Center(s):** GSFC

This solicitation seeks to advance the state of the art in absolute radiance measurements in the visible through the far-infrared (0.3 - 50 μm wavelength). Technologies to increase accuracy, precision, and sensitivity of absolute radiance measurements are desired. These wavelengths are of specific interest to remote sensing applications for both Earth science and planetary exploration missions.

Areas of interest include:

- Develop detector technologies to improve absolute radiance measurements in the infrared (1 - 50 μm wavelength) by increasing sensitivity, decreasing noise levels, and reducing or removing cooling requirements.
- Study and thoroughly characterize the non-linearities present in infrared detectors, specifically pyroelectric and mercury cadmium telluride (MCT), in the 5 - 50 μm wavelength region.
- Develop detector technologies to improve absolute radiance measurements in the visible to near infrared (0.3 - 8 μm wavelength).
- Develop novel compact lightweight high performance blackbody calibration source that may be enabled by recent developments in high emissivity surface treatments.
- Develop revolutionary compact, lightweight, and high performing infrared spectrometer (5 - 50 μm wavelength).

Proposals should specifically address one or more of the previously listed areas and include:

- Advantages and improvements of the proposed technology relative to current standards.
- Relevance of the technology to NASA's science goals.

Phase I deliverables - Feasibility study and documentation of clear path to working prototype in Phase II for hardware topics or complete report characterizing infrared detector non-linearities

Phase II deliverables - Working prototype hardware with thorough documentation of development and complete testing and characterization results

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 system bodies must meet increasingly ambitious objectives requiring highly reliable “soft landing”, “precision landing”, and “hazard avoidance” capabilities. Robotic missions to the Moon and Mars demand landing at pre-designated sites of high scientific value near hazardous terrain features, such as escarpments, 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 5 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.
- Ultra compact or micro-chip lasers generating 0.2 mJ - 2 mJ in 1.0 μm – 1.6 μm wavelength range. Laser pulse width must be less than 5 nsec and its beam quality better than 2.0 M². The laser must operate at greater than 20 Hz, preferably adjustable to over 50 Hz.
- 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.
- Non-mechanical laser beam steering devices capable of 2-axis pointing laser beams over +/- 25 degrees angle.

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****Participating Center(s): JPL, JSC**

The objective of this subtopic is to develop information technologies that enable robots to better support space exploration. Improving robot information technology (algorithms and software) is critical to improving the capability, flexibility, and performance of future 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 intelligent robots is directly linked to the quality and capability of the information technologies 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. This does NOT include user interfaces for direct teleoperation / purely manual control, telepresence, or virtual reality. The primary objective is to enable more effective and efficient interaction with robots remotely operated with discrete commands or supervisory control.
- Mobile robot navigation for operations in man-made (inside the International Space-Station) and unstructured environments (asteroids, 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 advanced on-board sensors, perception algorithms and software.
- Robot software architecture that supports adjustable autonomy, on-board health management and prognostics, automated data triage, data management, and data distribution (middleware). The primary objective is to facilitate the creation, extensibility and maintenance of complex robot systems.

Deliverables to NASA:

- Identify scenarios and use cases.
- Define specifications based on design trades.
- Develop concepts to address use cases.
- Build and test prototype systems.
- Perform technology demonstrations.

T11.02 Computational Simulation and Engineering**Lead Center: JPL****Computational Optimization**

Proposals are solicited for developing numerical methods and tools that enable robust continuous and discrete optimization as well as uncertainty quantification for physics based computational models. There are many different optimization methods and implementations of some of these methods are available in commercial and open-source form. These methods typically use a “function call” to evaluate a performance model to be optimized. We seek proposals to develop new methods and tools for developing an integrated performance model that represents the behavior of a system (or component) by integrating multi-disciplinary performances. We are not interested in discipline-specific performance models (e.g., a FEA model of a solar panel dynamics). We are interested in model representations that capture different physical phenomena in a system (e.g., structural, dynamic, thermal, geometry, etc.). Our objective is to enable automated and/or human-in-the-loop optimization of complex, multi-disciplinary system models. We are also interested in uncertainty quantification of these models. Methods or tools that leverage discipline-specific, commercial packages that are commonly used in engineering design at NASA and other relevant fields (e.g., DoD, automotive, aerospace, etc.) are of high interest.

The integrated performance model should clearly demonstrate how it may be used to first evaluate performance against different requirements and then improved (automated or human-guided) to give an optimal performance (in a weighted sum manner) against the different requirements. Intrinsic in this is the parameterization of the discipline-specific aspects of the performance model and exposing the parameters for optimization. In Phase I, it is expected that the proposer will demonstrate integration of at least two different disciplines. One of these disciplines should be geometry via Computer Aided Design software. If successful, Phase II will mature the work-flow and develop integration with a number of different discipline specific tools. Given the maturity of discipline specific tools, we expect the TRL level at the end of Phase II to be 4-6.

Virtual Worlds

Proposals are solicited for development of computational tools that enable rapid demonstration of mission concepts. The intent of such a tool is to enable non-experts in animation to rapidly build mission scenarios and visually express their concepts in a virtual world. These tools should enable full 3-D visualization by importing of CAD parts of electromechanical systems (e.g., rovers, landers, orbiters), environment models (height field maps with textures for terrain, star maps and planetary bodies), animation functionality to show temporal progression and movement of appropriate objects in the scene. The tool should support animation of flexible bodies (e.g., solar panel vibrations) along with articulation of components. The tool should feature a ray-tracing engine for good quality visualization with shadowing, ambient lighting, etc. The tool should also be able to demonstrate terrain artifacts such as rocks, dust and ejecta as both static and dynamic objects. An example of a static artifact may be a rock pile that does not move during the animation while a dynamic artifact may be dust rising from a lander thruster interaction with terrain. Note that the emphasis is on visualization and not necessarily on the physics of the problem. However, the tool should have API for integration with physics engines (e.g., ODE, Bullet, Proprietary Code) so that physics simulations can be used to control temporal progression of a scene. There should also be a functionality to write simple scripts for animating the virtual entities. There should be an avenue for developing a library of animation objects (e.g., rovers, terrains and locations) for re-use in later concept developments. The tools should be cross platform and enable development of animations or movies. The tool should take advantage of graphics processors or enable use of cluster computers for fast rendering of complex scenes. Alternately, the tool could feature a server-based functionality where the front-end user-interactions are through a webpage (using Java, HTML or other alternatives) and the computations are remotely conducted. Support for multiple concurrent users for content creating is desired. Ease of user interaction is key to the success of the tools. It is expected that at the end of Phase I, the performer will deliver an architecture document that captures the full intent of the tool. Similarly, performer will deliver software prototype of the implementation of the tool. It is expected that the software at the end of Phase I will be a prototype and may not have all features implemented or debugged. Performer will identify options for desired licensing options for the software to be developed for Phase II. At the end of Phase II, the performer will deliver all source code associated with the tool and verification test cases demonstrating all the proposed features within the software. The performer will also deliver a document summarizing the installation and usage of the tool and appropriate licensing options. In case of use of any third party software (e.g., open-source code) in this effort, the performer will deliver an acknowledgement that they have complied with appropriate licensing agreements. The anticipated TRL level at the end of Phase II is 5-6.

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):** JSC

This subtopic seeks new and innovative technologies in structural health monitoring (SHM), integrated vehicle health management (IVHM) systems, their corresponding analysis tools, and smart materials. Advanced structural composites and sensors with the potential to enable or enhance distributed damage detection for aerospace vehicles and spacecraft are sought. Example systems should allow for detection of damage states including corrosion, electrostatic discharge, delamination, cracking, microcracking, porosity, fiber breakage, impact damage, micrometeoroid orbital debris impacts on orbit, and general material property degradation due to aging. The innovative introduction of smart aspects to composite structures, for example, autonomous healing, shape memory, or piezoelectricity, is of interest. Such structures could allow for the realization of the mass reduction that composite materials have promised for spacecraft through enhanced damage tolerance. The addition of multi-functionality would be an asset towards improving overall system efficiency.

NASA is evaluating advanced composite structures due to their relatively high strength, light weight, and potential low production cost. Currently, damage tolerance concerns require that much thicker and heavier composite structures be manufactured to compensate for potential damage, and therefore the weight savings that composites promise has not yet been achieved. Smart sensor systems and smart structural composites could address this issue of damage tolerance, thereby allowing composites to be far lighter. Development of advanced technologies is required to improve the capability to better detect damage during manufacture and lifetime. Determining the extent of damage and/or autonomous healing of damage will also reduce the complexity of composite maintenance and increase performance lifetime and reliability.

This STTR seeks to enable the creation of smart composite systems and smart sensor systems for extended structural life monitoring and/or self-repair. Primary material systems for this STTR can include metals, but it is highly desirable to target carbon composite structures. Inclusion of smart or enhanced materials such as piezoelectric, shape memory, and self-healing will be highly advantageous. Other potential sensors are: Surface Acoustic Wave (SAW)-based sensors, passive wireless sensor-tags, flexible sensors for highly curved surfaces direct-write film sensors, and others. Sensor systems can include sensors that can be applied post-manufacture of the structure. All systems will provide information about location and extent of the structural deficiency. It is not required but considered highly advantageous to directly relate to a measurable material property such as remaining material strength, density, etc.

Suitable target structures include but are not limited to primary and secondary structures, including vehicle, habitat module, and pressure vessel structures. Target structures may be relevant to either existing or future aerospace vehicles and spacecraft. SHM and IVHM systems applicable to the International Space Station are especially of interest, though the scope of the solicitation is not limited to this application. This subtopic is not intended for materials coupon-level work only; proposed systems should have a targeted demonstrator structure identified as a deliverable.

In Phase I, composite samples or prototype sensor systems will be fabricated and tested to demonstrate basic functionality of the material or sensor system. The targeted demonstrator structure will be identified, and critical test environments and associated performance predictions will be defined relative to the final operating environment. Deliverables include composite samples, sensors, associated test data, predictions, and lessons learned.

In Phase II, while full-scale demonstrators are not required, scaled-up systems will be built in application-appropriate geometries. Demonstrators will be tested in a simulated operational environment for demonstrate of performance in critical areas. Further scale-up requirements will be defined, and performance predictions will made for subsequent development phases. Deliverables will include samples and the associated test data, sensor hardware and predictions.

T12.02 High Temperature Materials and Sensors for Propulsion Systems

Lead Center: GRC

Advanced materials, structures and sensors are crosscutting technologies which are essential in the design, development and health maintenance/detection needs of components and subsystems that will be needed in future generations of aeronautics and space propulsion and power systems. Materials will require multiple or tailored functions that are designed to meet specific mission needs. Lightweight, high temperature, environmentally stable and multifunctional materials and reliable structures will be needed to meet the challenges of future aerospace systems. Improved temperature capability enables increased thermodynamic efficiency and improved performance.

- Develop innovative approaches to enhance the durability, processability, performance and reliability of advanced high temperature materials (metals, ceramics, polymers, high-strength fibers, composites, nanostructured materials and coatings to improve environmental durability).
- Develop and demonstrate hierarchical assembly of nano and microstructures to give ultra-lightweight materials with unique thermal, electrical, and/or mechanical properties.
- Multifunctional materials and structures as a means to reduce component weight.
- Physics based modeling tools that capture the modes of materials degradation in the extreme environments found in propulsion systems.

Innovative smart sensing methods and measurement techniques that can reliably assess component health in the harsh environments experienced in aerospace engines and vehicles that go beyond the limits of current sensing technology. Interest is in:

- Sensors and systems with a fast response, able to be used at high temperatures, low volume and weight, be minimally intrusive and possess high accuracy and reliability.
- Development of nano-sensor technology allowing sensors that are smaller, more energy efficient and the ability to provide more sensitive health assessments.
- Approaches to measure strain, temperature, heat flux, deflection, acoustics and/or acceleration of structural components.
- Integration of sensors into systems (wireless, wired or fiber optic).

T12.03 Advanced Bladder Materials for Inflatable Habitats

Lead Center: JSC

This subtopic solicits advanced bladder materials for use in inflatable structures. Inflatable structures are a solution for increasing the volume and decreasing the weight and launch package for habitats, airlocks, and potentially other crewed vessels. Ideal bladder materials are low permeability gas barriers, durable over time, and do not degrade due to effects such as cold flow. Low permeability bladder materials that can withstand extreme cold temperatures (-90 °F), recover, and then deploy at low temperatures (-30 °F and -50 °F) while still maintaining low permeability rates (goal of 1.5 cc/100in²/day/atm), are of particular interest. Multi-functional materials (self-healing, flame resistant, puncture resistant...) are also of interest, however, cold flexure is of prime concern. The bladder materials should also be low mass (goal of <6 oz./yd²) and be able to be manufactured into complex shapes (such as dual curvature). Developments can include material development and testing, and/or demonstration of manufacturing techniques.

Phase I and/or Phase II deliverables should include material identification and/or development, and bladder materials flexure tested at various temperatures (such as room temperature, -30 °F, and -50 °F) and then permeability tested at room temperature. In addition, bladder materials can be lightly packed and folded and then taken to even colder temperatures (for example; -90 °F, -75 °F, and/or -60 °F) for an extended period of time (24 hours to a few months), allowed to recover, unfolded at cold temperatures (-30 °F and -50 °F) and then permeability tested at room temperature. Bladder materials should demonstrate the ability to be manufactured into complex shapes. The colder temperature the bladder materials can withstand (cold storage and deployment) and still meet the permeability goal, after recovery, the better the results.

T12.04 Experimental and Analytical Technologies for Additive Manufacturing**Lead Center: MSFC****Participating Center(s): ARC, GRC, JSC, LaRC**

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.

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.

What is the compelling need for this Subtopic?

Additive manufacturing is largely an emerging technology that shows great promise for the defense, energy, aerospace, medical and commercial sectors. 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.

The technology enabling to further utilization and certification for aerospace components. Almost all NASA Centers have capability in additive manufacturing and will benefit from this technology. This technology will accelerate growth in commercial development.

STMD/NASA/NARP/National - The subtopic is highly consistent with the technology objectives within the Strategic Space Technology Investment Plan and the NASA's technology roadmaps. The subtopic is also closely aligned with the National Manufacturing Initiative and the Materials Genome Initiative.

TOPIC: T13 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.
- 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 Advanced Propulsion System Ground Test and Launch Technology

Lead Center: SSC

Participating Center(s): KSC, MSFC

Rocket propulsion development is enabled by rigorous ground testing to mitigate the risk inherent in spaceflight. As next generation propulsion systems are developed matching/related advancements in test technologies to appropriately test the new propulsion systems as well as more overall advancements in test technologies are also required. This subtopic area seeks to develop advanced ground test component and systems technologies to reduce cost and schedule, to improve reliability and quality, and to increase safety in Rocket Propulsion Testing. Many of these types of technologies may also have benefit for launch operations. Specific technologies of interest:

- Innovative Facility Components. Efficient generation of high temperature ($>2500^{\circ}\text{R}$), high flowrate ($<60 \text{ lb/sec}$) hydrogen, devices for measurement of pressure, temperature, strain and radiation in a high temperature and/or radiation environment, Development of innovative rocket test facility components (e.g., valves, flowmeters, actuators, tanks, etc.) for ultra-high pressure ($>8000 \text{ psi}$), high flow rate ($>100 \text{ lbm/sec}$) and cryogenic environments. Robust and reliable component designs which are oxygen compatible and can operate efficiency in high vibro-acoustic, environments.
- Advanced Test Facility Monitoring. Embedded sensor systems to provide advanced diagnostics to monitor test facility parameters includes high-speed, simultaneous heat flux, temperature, pressure, strain and near-field acoustics. This includes remote monitoring of vacuum line, gas leaks and fire, where the use of wireless/self-powered sensors to eliminate power and data wires would be beneficial. 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.
- Advanced Test Imaging & Analysis. Advanced test imaging technologies providing ultra-high dynamic imaging ranges with frame rates suitable for high speed event reconstruction. The proposed innovative systems must be capable of imaging at better than 500 frames/sec, IRIG-B compatible, and with ultra-high contrast ratio. The image data must also be transferred and recorded in real time, remote from the camera optics. It must also be capable of recovering from saturated pixels from very bright objects. Ability to analyze object speed and trajectory through stereo imaging is highly desirable.

Phase I will develop feasibility studies, validate system concepts and possibly produce prototypes. Phase II will development prototype hardware and validate the technology readiness for meeting ground and launch propulsion test requirements.

TOPIC: T14 Thermal Management Systems

Reserved for future Solicitations.

TOPIC: T15 Aeronautics

Reserved for future Solicitations.

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	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.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of scaling requirements.

		made for subsequent development phases.	Prototype implementations developed.	
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 Handling & 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	Cryogenic Purge Gas Recovery and Reclamation	H10.01
			Affordable Nano/Micro Launch Propulsion Stages	T1.01
TA	STR Technology Area (TA) Level 1 Description	STR Technology Area (TA) Level 2 Description	Subtopic Description	Subtopic
TA02	2.0.0 In-Space Propulsion Technologies	2.1.0 Chemical Propulsion	In-Space Chemical Propulsion	H2.01
			Spacecraft Technology for Sample Return Missions	S4.03
		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
		2.4.0 Supporting Technologies	Cryogenic Fluid Management for In-Space Transportation	H2.04

TA	STR Technology Area (TA) Level 1 Description	STR Technology Area (TA) Level 2 Description	Subtopic Description	Subtopic
<u>TA03</u>	<u>3.0.0 Space Power and Energy Storage</u>	3.1.0 Power Generation	Space Nuclear Power Systems	H8.01
			Solid Oxide Fuel Cells and Electrolyzers	H8.02
			Advanced Photovoltaic Systems	H8.03
			Power Generation and Conversion	S3.01
			Energy Harvesting Technology Development	T3.01
			Small Spacecraft in Deep Space: Power, Navigation, and Structures	Z4.01
		3.2.0 Energy Storage	Terrestrial and Planetary Balloons	S3.06
		3.4.0 Cross Cutting Technology	Power Electronics and Management, and Energy Storage	S3.03
			Solid-State Thermal-to-Electric Power Generation	Z1.02
TA	STR Technology Area (TA) Level 1 Description	STR Technology Area (TA) Level 2 Description	Subtopic Description	Subtopic
<u>TA04</u>	<u>4.0.0 Robotics, Telerobotics and Autonomous Systems</u>	4.1.0 Sensing & Perception	Payload Technologies for Assistive Free-Fliers	Z5.01
		4.3.0 Manipulation	Robotic Mobility, Manipulation and Sampling	S4.02
			Regolith Resource Robotic	T4.02
		4.4.0 Human-Systems Integration	Mobility Subsystem, Manipulation Subsystem, and Human System Interaction	H6.01
		4.5.0 Autonomy	Unmanned Aircraft Systems Technology	A2.02
			Fault Management Technologies	S5.05

			Dynamic Servoelastic (DSE) Network Control, Modeling and Optimization	T4.01
			Information Technologies for Intelligent and Adaptive Space Robotics	T11.01
		4.7.0 RTA Systems Engineering	Contamination Control and Planetary Protection	S4.05
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
			Flight Dynamics and Navigation Technology	H9.03
			Slow and Fast Light	S3.08
		5.4.0 Position, Navigation, and Timing	Guidance, Navigation and Control	S3.05
		5.5.0 Integrated Technologies	Intelligent Communication Systems	H9.02
			Autonomous Communications Systems	T5.01
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 Monitoring for Spacecraft Cabins	H3.01
			International Space Station (ISS) Demonstration of Improved Exploration Technologies	H14.02
			Bioregenerative Technologies for Life Support	H3.02
			Spacecraft Cabin Atmosphere Quality and Thermal Management	H3.03

		6.2.0 Extravehicular Activity Systems	Space Suit Pressure Garment and Airlock Technologies EVA Space Suit Pressure Garment Systems EVA Space Suit Power, Avionics, and Software Systems Gas Sensing Technology Advancements for Spacesuits	H4.01 H4.02 H4.03 T6.01
		6.3.0 Human Health and Performance	Measurements of Net Ocular Blood Flow Unobtrusive Workload Measurement Technology for Monitoring Muscle Protein Synthesis and Breakdown in Spaceflight	H12.01 H12.02 H12.03
		6.5.0 Radiation	Radiation Shielding Systems Space Weather	H11.01 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	Regolith ISRU for Mission Consumable Production	H1.01
			International Space Station (ISS) Utilization	H14.01
		7.2.0 Sustainability & Supportability	Recycling/Reclamation of 3-D Printer Plastic Including Transformation of Launch Package Solutions into 3-D Printed Parts	H14.03
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	Proximity Glare Suppression for Astronomical Coronagraphy	S2.01

		Sensor and Detector Technology for Visible, IR, Far IR and Submillimeter	S1.03
		Advanced Optical Systems and Fabrication/Testing/Control Technologies for EUV/Optical and IR Telescope	S2.03
		Detector Technologies for UV, X-Ray, Gamma-Ray and Cosmic-Ray Instruments	S1.04
		Particles and Field Sensors and Instrument Enabling Technologies	S1.05
		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
		Command, Data Handling, and Electronics	S3.09
		Technologies for Planetary Compositional Analysis and Mapping	T8.01
	8.2.0 Observations	Precision Deployable Optical Structures and Metrology	S2.02
		Unmanned Aircraft and Sounding Rocket Technologies	S3.04
		X-Ray Mirror Systems Technology, Coating Technology for X-Ray-UV-OIR, and Free-Form Optics	S2.04
	8.3.0 Sensor Systems	Optical components, sensors, and systems for ISS utilization	H14.04
		Lidar Remote Sensing Technologies	S1.01

			Microwave Technologies for Remote Sensing	S1.02
			Atomic Interferometry	S1.09
			Cryogenic Systems for Sensors and Detectors	S1.10
			Visible to Far-Infrared Absolute Radiance Developments	T8.02
TA	STR Technology Area (TA) Level 1 Description	STR Technology Area (TA) Level 2 Description	Subtopic Description	Subtopic
TA09	9.0.0 Entry, Descent and Landing Systems	9.1.0 Aeroassist & Entry	Ablative Thermal Protection Systems Technologies, Sensors and NDE Methods	H7.01
		9.2.0 Descent	Diagnostic Tools for High Velocity Testing & Analysis	H7.02
		9.3.0 Landing	Wireless Cameras for Entry, Descent, and Landing Reconstruction	Z3.01
		9.4.0 Vehicle Systems Technology	Navigation and Hazard Avoidance Sensor Technologies	T9.01
TA	STR Technology Area (TA) Level 1 Description	STR Technology Area (TA) Level 2 Description	Subtopic Description	Subtopic
TA10	10.0.0 Nanotechnology	10.1.0 Engineered Materials and Structures	Structural Efficiency-Hybrid Nanocomposites	A1.01

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	Quiet Performance	A1.04
			Physics-Based Conceptual Aeronautics Design Tools	A1.05
			Efficient Propulsion & Power	A1.07
			Integrated Science Mission Modeling	S5.04
			Modeling and Measurements for Propulsion and Power	Z1.01
		11.3.0 Simulation	Computational Simulation and Engineering	T11.02
		11.4.0 Information Processing	Earth Science Applied Research and Decision Support	S5.02
			Algorithms and Tools for Science Data Processing, Discovery and Analysis, in State-of-the-Art Data Environments	S5.03

TA	STR Technology Area (TA) Level 1 Description	STR Technology Area (TA) Level 2 Description	Subtopic Description	Subtopic
TA12	12.0.0 Materials, Structures, Mechanical Systems and Manufacturing	12.1.0 Materials	Extreme Temperature Structures	H5.02
			Extreme Environments Technology	S4.04
			Advanced Structural Health Monitoring	T12.01
			High Temperature Materials and Sensors for Propulsion Systems	T12.02
			Advanced Bladder Materials for Inflatable Habitats	T12.03
			Large-Scale Polymer Matrix Composite (PMC) Structures, Materials, and Manufacturing Processes	Z2.01
		12.2.0 Structures	Deployable Structures	H5.01
			Multifunctional Materials and Structures	H5.03
		12.3.0 Mechanical Systems	Vertical Lift	A1.06
			Advanced NDE Modeling and Analysis	H13.01
		12.4.0 Manufacturing	Experimental and Analytical Technologies for Additive Manufacturing	T12.04
		12.5.0 Cross-Cutting	Low Emissions Propulsion and Power	A1.03
			NDE Sensors	H13.02
			Advanced Metallic Materials and Processes Innovation	Z6.01

TA	STR Technology Area (TA) Level 1 Description	STR Technology Area (TA) Level 2 Description	Subtopic Description	Subtopic
<u>TA13</u>	13.0.0 Ground and Launch Systems Processing	13.1.0 Technologies to Optimize the Operational Life-Cycle	Advanced Propulsion System Ground Test and Launch Technology	<u>T13.01</u>
		13.3.0 Technologies to Increase Reliability and Mission Availability	Flight Test and Measurements Technologies	<u>A2.01</u>
TA	STR Technology Area (TA) Level 1 Description	STR Technology Area (TA) Level 2 Description	Subtopic Description	Subtopic
<u>TA14</u>	14.0.0 Thermal Management Systems	14.2.0 Thermal Control Systems	Thermal Control Systems	<u>S3.07</u>

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