

National Aeronautics and Space Administration

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

Program Solicitations

**Opening Date: July 6, 2007
Closing Date: September 6, 2007**

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

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2007 NASA SBIR/STTR Program Solicitations

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, the three program phases, and information for submitting responsive proposals is contained herein. The 2007 Solicitation period for Phase 1 proposals begins July 6, 2007, and ends September 6, 2007.

The purposes of the SBIR/STTR programs, as established by law, are to stimulate technological innovation in the private sector; to strengthen the role of SBCs in meeting Federal research and development needs; to increase the commercial application of these research results; and to encourage participation of socially and economically disadvantaged persons and women-owned small businesses.

Technological innovation is vital to the performance of the NASA mission and to the Nation's prosperity and security. To be eligible for selection, a proposal must present an innovation that meets the technology needs of existing NASA programs and projects as described herein and has significant potential for successful commercialization. Commercialization encompasses the transition of technology into products and services for NASA mission programs, other Government agencies and non-Government markets.

NASA considers every technology development investment dollar critical to the ultimate success of NASA's mission and strives to ensure that the research topic areas described in this solicitation are in alignment with its Mission Directorate high priorities technology needs. In addition, the solicitation is structured such that SBIR/STTR investments are complementary to other NASA technology investments. NASA'S ultimate objective is to achieve infusion of the technological innovations developed in the SBIR/STTR program into its Mission Directorates programs and projects.

The 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.

Subject to the availability of funds, approximately 250 SBIR and 30 STTR Phase 1 proposals will be selected for negotiation of fixed-price contracts in November 2007. Historically, the ratio of Phase 1 proposals to awards is approximately 8:1 for SBIR and 5:1 for STTR, and approximately 40% of the selected Phase 1 contracts are selected for Phase 2 follow-on efforts.

NASA will not accept more than 10 proposals to either program from any one company 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 via the Internet at <http://sbir.nasa.gov> and include all relevant documentation. Unsolicited proposals will not be accepted.

1.2 Program Authority and Executive Order

SBIR: This Solicitation is issued pursuant to the authority contained in P.L. 106-554 in accordance with policy directives issued by the Small Business Administration. The current law authorizes the program through September 30, 2008.

STTR: This Solicitation is issued pursuant to the authority contained in P.L. 107-50 in accordance with policy directives issued by the Small Business Administration. The current law authorizes the program through September 30, 2009.

Executive Order: This Solicitation complies with Executive Order 13329 (issued February 24, 2004) directing Federal agencies that administer the SBIR and STTR programs to encourage innovation in manufacturing related research and development consistent with the objectives of each agency and to the extent permitted by law.

1.3 Program Management

The Innovative Partnerships Program Office under the Office of the NASA Associate Administrator 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 provides the overall procurement management for the programs. All of the NASA centers actively participate in the SBIR/STTR program 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.

NASA research and technology areas to be solicited are identified annually by 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 of Mission Directorate research topic descriptions.

The STTR Program Solicitation is aligned with needs associated with the core competencies of the NASA Centers as described in Section 9.2. As of 2007, the NASA Jet Propulsion Laboratory (JPL) will participate in the management of the STTR Program and, therefore, is not available to respond to the NASA STTR Program as a Research Institution.

Information regarding the Mission Directorates and the NASA Centers can be obtained at the following web sites:

NASA Mission Directorates	
Aeronautics Research	http://www.aeronautics.nasa.gov/
Exploration Systems	http://www.exploration.nasa.gov/
Science	http://science.hq.nasa.gov/
Space Operations	http://www.hq.nasa.gov/osf/

NASA Centers	
Ames Research Center (ARC)	http://www.nasa.gov/centers/ames/home/index.html
Dryden Flight Research Center (DFRC)	http://www.nasa.gov/centers/dryden/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.

1.4.1 Phase 1. The purpose of Phase 1 is to determine the scientific, technical, and commercial merit and feasibility of the proposed innovation, and the quality of the SBC's performance. Phase 1 work and results should provide a sound basis for the continued development, demonstration and delivery of the proposed innovation in Phase 2 and follow-on efforts. Successful completion of Phase 1 objectives is a prerequisite to consideration for a Phase 2 award.

Proposals must conform to the format described in Section 3.2. Evaluation and selection criteria are described in Section 4.1. NASA is solely responsible for determining the relative merit of proposals, their selection for award, and judging the value of Phase 1 results.

Maximum value and period of performance for Phase 1 contracts:

Phase 1 Contracts	SBIR	STTR
Maximum Contract Value	\$ 100,000	\$ 100,000
Maximum Period of Performance	6 months	12 months

1.4.2 Phase 2. The purpose of Phase 2 is the development, demonstration and delivery of the innovation. Only SBCs awarded Phase 1 contracts are eligible for Phase 2 funding agreements. Phase 2 projects are chosen as a result of competitive evaluations based on selection criteria provided in Section 4.2.

The maximum value for SBIR/STTR Phase 2 contracts is \$600,000 with a maximum period of performance of 24 months.

On active Phase 2 awards, NASA may execute the option to fund a limited number of Phase 2 awardees for "Phase 2 Enhancement" (Phase 2-E) to encourage transition of SBIR/STTR projects into NASA programs and projects. The objective of the Phase 2-E option is to incentivize Phase 3 awards by providing a cost share extension of the Phase 2 contract. This extension will assist a NASA program/project or third party investor, accelerate and/or enhance the infusion of the Phase 2 research into a NASA application or into a commercial product. Under this option, NASA will match with SBIR/STTR funds up to \$150,000 of non-SBIR/non-STTR investment (Phase 3 contract) from a NASA project, NASA contractor, or third party commercial investor. A letter of commitment will be required from the Phase 3 funding source and must substantiate intent to provide funding for further development, including a brief statement of why the resulting Phase 2 Enhancement is needed to support this effort. If exercised, this option allows the extension of the existing Phase 2 project for up to 4 months to perform additional research. The total cumulative award for the Phase 2 contract plus the Phase 2-E matching funds will not exceed \$750,000.00 of SBIR/STTR funding. The non-SBIR contribution is not limited, since it is regulated under the guidelines for Phase 3 awards. All Phase 2-E option applications are subject to review and acceptance by the NASA SBIR/STTR Selection Official. Additional details, including how to apply for the Phase 2 enhancement, will be provided as part of the Phase 2 negotiation process.

1.4.3 Phase 3. NASA may award Phase 3 contracts for products or services with non-SBIR/STTR funds. The competition for SBIR/STTR Phase 1 and Phase 2 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 3 project is not required to conduct another competition in order to satisfy those statutory provisions. Phase 3 work may be for products, production, services, R/R&D, or any combination thereof. A Federal agency may enter into a Phase 3 agreement at any time with a Phase 1 or Phase 2 awardee.

There is no limit on the number, duration, type, or dollar value of Phase 3 awards made to a business concern. There is no limit on the time that may elapse between a Phase 1 or Phase 2 and a Phase 3 award. The small business size limits for Phase 1 and Phase 2 awards do not apply to Phase 3 awards.

1.5 Eligibility Requirements

1.5.1 Small Business Concern. Only firms qualifying as SBCs, as defined in Section 2.16, are eligible to participate in these programs. Socially and economically disadvantaged and women-owned SBCs are particularly encouraged to propose.

STTR: SBCs must submit a cooperative research agreement with a Research Institution (RI).

1.5.2 Place of Performance. For both Phase 1 and Phase 2, the R/R&D must be performed in the United States (Section 2.21). 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. Prior to award, approval by the Contracting Officer for such specific condition(s) must be in writing.

1.5.3 Principal Investigator. The primary employment of the Principal Investigator (PI) must be with the SBC under the SBIR Program, while under the STTR Program the PI may be employed by either the SBC or RI. Primary employment means that more than half of the PI's total employed time (including all concurrent employers, consulting, and self-employed time) is spent with the SBC. 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, the offeror must explain how these requirements will be met if the proposal is selected for contract negotiations that may lead to an award. U.S. Citizenship is not a requirement for selection.

REQUIREMENTS	SBIR	STTR
Primary Employment	PI must be with the SBC	PI must 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.	If the PI is not an employee of the SBC, the offeror must describe the management process to ensure SBC control of the project.
Co-Principal Investigators	Not Acceptable	Not Acceptable
Misrepresentation of Qualifications	Will result in rejection of the proposal or termination of the contract	Will result in rejection of the proposal or termination of the contract
Substitution of PIs	Must receive advanced written approval from NASA	Must receive advanced written approval from NASA

1.6 General Information

1.6.1 Solicitation Distribution. This 2007 SBIR/STTR Program Solicitation is available via the NASA SBIR/STTR Website (<http://sbir.nasa.gov>). SBCs are encouraged to check this website for program updates and information. Any updates or corrections to the Solicitation will be posted there. If the SBC has difficulty accessing the Solicitation, contact the Help Desk (Section 1.6.2).

1.6.2 Means of Contacting NASA SBIR/STTR Program

- (1) NASA SBIR/STTR Website: <http://sbir.nasa.gov>
- (2) The websites of the NASA Mission Directorates and the NASA Centers as listed in Section 1.3 provide information on NASA plans and mission programs relevant to understanding the topics/subtopics and needs described in Section 9.

- (3) Help Desk. Contact via:

e-mail: sbir@reisys.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.

- (4) NASA SBIR/STTR Program Manager. Specific information requests that could not be answered by the Help Desk should be mailed or e-mailed to:

Dr. Gary C. Jahns, Program Manager
NASA SBIR/STTR Program Management Office
MS 202A-3, Ames Research Center
Moffett Field, CA 94035-1000
Gary.C.Jahns@nasa.gov

1.6.3 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 1 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 Commercialization

Commercialization is a process of developing markets and producing and delivering products or services for sale (whether by the originating party or by others). As used here, commercialization includes both Government and non-Government markets.

2.3 Cooperative Research or Research and Development (R/R&D) Agreement

A financial assistance mechanism used when substantial Federal programmatic involvement with the awardee during performance is anticipated by the issuing agency. The Cooperative R/R&D Agreement contains the responsibilities and respective obligations of the parties.

2.4 Cooperative Research or 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 at least 40 percent of the work (amount requested, including cost sharing if any, less fee if any) is performed by the SBC and at least 30 percent of the work is performed by the RI.

2.5 Essentially Equivalent Work

The “scientific overlap,” which occurs when (1) substantially the same research is proposed for funding in more than one contract proposal or grant application submitted to the same Federal agency; (2) substantially the same research is submitted to two or more different Federal agencies for review and funding consideration; or (3) a specific research objective and the research design for accomplishing an objective are the same or closely related in two or more proposals or awards, regardless of the funding source.

2.6 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.

2.7 HUBZone-Owned SBC

"HUBZone" is an area that is located in one or more of the following:

- A qualified census tract (as defined in section 42(d)(5)(C)(i)(1) of the Internal Revenue Code of 1986);
- A qualified "non-metropolitan county" that is: not located in a metropolitan statistical area (as defined in section 143(k)(2)(B) of the Internal Revenue Code of 1986), and
 - in which the median household income is less than 80 percent of the non-metropolitan State median household income, or
 - that based on the most recent data available from the Secretary of Labor, has an unemployment rate that is not less than 140 percent of the statewide average unemployment rate for the State in which the county is located;
- Lands within the external boundaries of an Indian reservation.

To participate in the HUBZone Empowerment Contracting Program, a concern must be determined to be a "qualified HUBZone small business concern." A firm can be found to be a qualified HUBZone concern, if:

- It is small,
- It is located in a "historically underutilized business zone" (HUBZone),
- It is owned and controlled by one or more U.S. Citizens, and
- At least 35% of its employees reside in a HUBZone.

2.8 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.

2.9 Innovation

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.

2.10 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 2.14), ideas, designs, know-how, business, technical and research methods, and 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.

2.11 Principal Investigator (PI)

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

2.12 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(5) of the Stevenson-Wydler Technology Innovation Act of 1980, or (3) a nonprofit college or university.

Note: The Jet Propulsion Laboratory is not available to respond to the NASA STTR Program as a Research Institution.

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

Any activity that is (1) a systematic, intensive study directed toward greater knowledge or understanding of the subject studied, (2) a systematic study directed specifically toward applying new knowledge to meet a recognized need, or (3) a systematic application of knowledge toward the production of useful materials, devices, systems, or methods, including the 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).

2.14 SBIR/STTR Technical Data

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

2.15 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.

2.16 Small Business Concern (SBC)

An SBC is one that, at the time of award of Phase 1 and Phase 2 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.

2.17 Socially and Economically Disadvantaged Individual

A member of any of the following groups: African American, Hispanic American, Native American, Asian-Pacific American, Subcontinent-Asian American, other groups designated from time to time by SBA to be socially disadvantaged, or any other individual found to be socially and economically disadvantaged by SBA pursuant to Section 8(a) of the Small Business Act, 15 U.S.C. 637(a).

2.18 Socially and Economically Disadvantaged Small Business Concern

A socially and economically disadvantaged SBC is one that is: (1) at least 51 percent owned by (i) an Indian tribe or a native Hawaiian organization: or, (ii) one or more socially and economically disadvantaged individuals; and (2) whose management and daily business operations are controlled by one or more socially and economically disadvantaged individuals. See 13 CFR Parts 124.103 and 124.104.

2.19 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.

2.20 Technology Readiness Level (TRLs)

Technology Readiness Level (TRLs) are 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) or in a simulated environment in which a valid test can be conducted.

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 B.

2.21 United States

Means 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.

2.22 Women-Owned Small Business

A women-owned SBC is one that is at least 51 percent owned by a woman or women who also control and operate it. "Control" in this context means exercising the power to make policy decisions. "Operate" in this context means being actively involved in the day-to-day management.

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 may be submitted only under that one subtopic within each program. An offeror may not submit more than 10 proposals to each of the SBIR or STTR programs, and may submit more than one 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.

STTR: All Phase 1 proposals must provide sufficient information to convince NASA that the proposed SBC/RI cooperative effort represents a sound approach for converting technical information resident at the RI into a product or service that meets a need described in a Solicitation research topic.

Contract Deliverables. All Phase 1 contracts shall require the delivery of interim and final reports that present (1) the work and results accomplished, (2) the scientific, technical and commercial merit and feasibility of the proposed innovation and Phase 1 results, (3) its relevance and significance to one or more NASA needs (Section 9), and (4) the strategy for development and transition of the proposed innovation and Phase 1 results into products and services for NASA mission programs and other potential customers. Phase 1 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.

Phase 2 contracts require the deliverable of interim and final reports. The delivery of a prototype unit, software package, or a complete product or service, for NASA testing and utilization is highly desirable and, if proposed, must be described and listed as a deliverable in the proposal. The Phase 2 reports shall present (1) the work and results accomplished, (2) the scientific, technical and commercial merit and feasibility of the proposed innovation and Phase 2 results, (3) its relevance and significance to one or more NASA needs (Section 9), and (4) the progress towards transitioning the proposed innovation and Phase 2 results into follow-on investment, development, testing and utilization for NASA mission programs and other potential customers.

Report deliverables for Phase 1 and Phase 2 shall be submitted electronically via the SBIR/STTR website. NASA requests the submission of report deliverables in PDF format. Other acceptable formats are MS Word, MS Works, and WordPerfect.

3.2 Phase 1 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, 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.

Page Limitation. A Phase 1 proposal shall not exceed a total of 25 standard 8 1/2 x 11 inch (21.6 x 27.9 cm) pages inclusive of the technical content and the required forms. Proposal items required in Section 3.2.2 will be included within this total. 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 should be 1.0 inch (2.5 cm).

Proposals exceeding the 25-page limitation will be rejected during administrative screening.

Web site references, product samples, videotapes, slides, or other ancillary items will not be considered during the review process. Offerors are requested not to use the entire 25-page allowance unless necessary.

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.

3.2.2 Format Requirements. All required items of information must be covered in the proposal. 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,
- (2) Proposal Summary (Form B),
- (3) Budget Summary (Form C),
- (4) Technical Content (11 parts in order as specified in Section 3.2.4, **not to exceed 22 pages for SBIR and 21 pages for STTR – see box below**), including all graphics, with a table of contents,
- (5) Briefing Chart (Not included in the 25-page limit and must not contain proprietary data).

STTR: Each STTR proposal must also contain a Cooperative R/R&D Agreement between the SBC and RI following the required items listed above. The agreement is included as part of the 25-page limit.

3.2.3 Forms

3.2.3.1 Cover Sheet (Form A). A sample Cover Sheet form is provided in Section 8. 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.

3.2.3.2 Proposal Summary (Form B). A sample Proposal Summary form is provided in Section 8. The offeror shall provide complete information for each item and submit Form B as required in Section 6.

Technical Abstract: Summary of the offeror's proposed project is limited to 200 words and shall summarize the implications of the approach and the anticipated results of both Phase 1 and Phase 2 including an assessment of technology readiness levels (TRLs) at the end of the Phase 1 contract. *If the technical abstract is judged to be non responsive to the subtopic, the proposal will be rejected without further evaluation.*

Technology Taxonomy: Selections for the technology taxonomy are limited to technologies supported or relevant to the specific proposal. The listing of technologies for the taxonomy is provided in Appendix C.

Potential NASA and non-NASA commercial applications of the technology must also be presented.

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

3.2.3.3 Budget Summary (Form C). The offeror shall complete the Budget Summary, following the instructions provided with the form (Section 8). The total requested funding for the Phase 1 effort shall not exceed \$100,000. 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 budget

is fair and reasonable. The government is not responsible for any monies expended by the applicant before award of any contract.

Property. Proposed costs for materials may be included. "Materials" means property that may be incorporated or attached to a deliverable end item or that may be consumed or expended in performing the contract. It includes assemblies, components, parts, raw materials, and small tools that may be consumed in normal use. Any purchase of equipment or products under an SBIR/STTR contract using NASA funds should be American-made to the extent possible. NASA will not fund the purchase of equipment, instrumentation, or facilities under SBIR/STTR contracts as a direct cost (Section 5.15).

Travel. Travel is an acceptable cost when it is part of accomplishing the work proposed in Phase 1. Proposed travel must be described as to its purpose and benefits in proving technical feasibility, and is subject to negotiation and approval by the Contracting Officer and COTR at the time of award.

Profit. A profit or fee may be included in the proposed budget as noted in Section 5.10.

Cost Sharing. See Section 5.9.

3.2.4 Technical Content. This part of the submission shall not contain any budget data and must consist of all eleven parts listed below in the given order. All parts must be numbered and titled; parts that are not applicable must be noted as "Not Applicable."

Part 1: Table of Contents. The technical content shall begin with a brief table of contents indicating the page numbers of each of the parts of the proposal. The required table of contents is provided below:

Phase 1 Table of Contents

Part 1:	Table of Contents.....	Page #
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 2 or Future R/R&D	
Part 8:	Company Information and Facilities	
Part 9:	Subcontracts and Consultants	
Part 10:	Potential Post Applications	
Part 11:	Similar Proposals and Awards	

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 1 R/R&D effort including the technical questions that must be answered to determine the feasibility of the proposed innovation.

Part 4: Work Plan. Include a detailed description of the Phase 1 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. At least 40 percent of the work (amount requested including cost sharing, less fee, if any) is to be performed by the SBC as the prime contractor, and at least 30 percent of the work is to be performed by 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. At the offeror's option, this section may include bibliographic references.

Part 6: Key Personnel and Bibliography of Directly Related Work. Identify key personnel involved in Phase 1 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 1 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 substitute 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 (Section 1.5.3), and indicate the extent to which other proposals recently submitted or planned for submission in 2007 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.

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 1 and Phase 2). Discuss the significance of the Phase 1 effort in providing a foundation for the Phase 2 R/R&D effort and for follow-on development, application and commercialization efforts (Phase 3).

Part 8: Company Information and Facilities. Provide adequate information to allow the evaluators to assess the ability of the offeror to carry out the proposed Phase 1 and projected Phase 2 and Phase 3 activities. The offeror should describe the relevant facilities and equipment, their availability, and those to be acquired, to support the proposed activities. *NASA will not fund the purchase of equipment, instrumentation, or facilities under Phase 1 contracts as a direct cost.* Special tooling may be allowed. (Section 5.15)

The capability of the offeror to perform the proposed activities and to accomplish the commercialization of the proposed innovation and R/R&D results must be presented. Qualifications of the offeror in performing R/R&D activities and technology commercialization must be presented.

Note: Government wide SBIR and STTR policies prohibit the use of any SBIR/STTR award funds for the use of Government equipment and facilities. This does not preclude an SBC from utilizing a Government facility or Government equipment, but any charges for such use cannot be paid for with SBIR/STTR funds (SBA SBIR Policy Directive, Section 9 (f)(3)). In rare and unique circumstances, the SBA may issue a case-by-case waiver to this provision after review of an agency's written justification. NASA cannot guarantee that a waiver from this policy can be obtained from SBA.

If a proposed project or product demonstration requires the use of unique Government facilities or equipment to be funded by the SBIR program, then the offeror must provide a) a letter 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 b) a statement, signed by the appropriate Government official at the facility, verifying that it will be available for the required effort. The proposal should also include relevant information on the funding source(s) private, internal, or other Government. Failure to provide this explanation and the site manager's written authorization of use may invalidate any proposal selection. If the offeror proposes the use of SBIR/STTR funds for Government equipment or facilities, this explanation will be provided to SBA during the Agency waiver process.

Additional information on the use of NASA facilities, facility programs, and equipment is available at <http://sbir.nasa.gov/SBIR/facilities.html>.

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 required. Documentation of subcontract costs must be made available during negotiations to substantiate the budget estimate.

Subcontractors' and consultants' work must be performed in the United States. The following restrictions apply to the use of subcontracts/consultants:

SBIR	STTR
The proposed subcontracted business arrangements must not exceed one-third of the research and/or analytical work (amount requested including cost sharing if any, less fee, if any).	The proposed subcontracted business arrangements with individuals or organizations other than the RI must not exceed 30 percent of the work (amount requested including cost sharing if any, less fee, if any).

Part 10: Potential Post Applications (Commercialization). The Phase 1 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 11: Similar Proposals and Awards. A firm may elect to submit proposals for essentially equivalent work to other Federal program solicitations (Section 2.5). Firms may also choose to resubmit previously unsuccessful Phase 1 proposals to NASA. However, it is unlawful to receive funding for essentially equivalent work already funded under any Government program. The Office of Inspector General has full access to all proposals

submitted to NASA. The offeror must inform NASA of related proposals and awards and clearly state whether the SBC has submitted currently active proposals for similar work under other Federal Government program solicitations or intends to submit proposals for such work to other agencies. For all such cases, the following information is required:

- (1) The name and address of the agencies to which proposals have been or will be submitted, or from which awards have been received (including proposals that have been submitted to previous NASA SBIR Solicitations);
- (2) Dates of such proposal submissions or awards;
- (3) Title, number, and date of solicitations under which proposals have been or will be submitted or awards received;
- (4) The specific applicable research topic for each such proposal submitted or award received;
- (5) Titles of research projects;
- (6) Name and title of the PI/project manager for each proposal that has been or will be submitted, or from which awards have been received;
- (7) If resubmitting to NASA, please briefly describe how the proposal has been changed and/or updated since it was last submitted.

Note: All eleven (11) parts of the technical proposal must be included. 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.

3.2.5 Cooperative R/R&D Agreement (Applicable for STTR proposals only). The Cooperative R/R&D Agreement (not to be confused with the Allocation of Rights Agreement, Section 4.1.4) is a single-page document electronically submitted and endorsed by the SBC and RI. A model agreement is provided, or firms can create their own custom agreement. The Cooperative R/R&D Agreement should be submitted as required in Section 6. This agreement counts toward the 25-page limit.

3.2.6 Prior Awards Addendum (Applicable for SBIR awards only). If the SBC has received more than 15 Phase 2 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 2. The addendum is not included in the 25-page limit and content should be limited to information requested above. Offerors are encouraged to use spreadsheet format.

3.2.7 Briefing Chart. A one-page briefing chart is required to assist in the ranking and advocacy of proposals prior to selection. It is not counted against the 25-page limit, and *must not* contain any proprietary data. An example chart is provided in Appendix A.

3.3 Phase 2 Proposal Requirements

3.3.1 General Requirements. The Phase 1 contract will serve as a request for proposal (RFP) for the Phase 2 follow-on project. Phase 2 proposals are more comprehensive than those required for Phase 1. Submission of a Phase 2 proposal is in accordance with Phase 1 contract requirements and is voluntary. NASA assumes no responsibility for any proposal preparation expenses.

A competitive Phase 2 proposal will clearly and concisely (1) describe the proposed innovation relative to the state of the art and the market, (2) address Phase 1 results relative to the scientific, technical merit and feasibility of the proposed innovation and its relevance and significance to the NASA needs as described in Section 9, and (3) provide the planning for a focused project that builds upon Phase 1 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.

Page Limitation. A Phase 2 proposal shall not exceed a total of 50 standard 8 1/2 x 11 inch (21.6 x 27.9 cm) pages. All items required in Section 3.3.2 will be included within this total. 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 should be 1.0 inch (2.5 cm). **Proposals exceeding the 50-page limitation may be rejected during administrative screening.**

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.

3.3.2 Format Requirements. All required items of information must be covered in the proposal. 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,
- (2) Proposal Summary (Form B),
- (3) Budget Summary (Form C),
- (4) Technical Content (11 Parts in order as specified in Section 3.3.4), including all graphics, and starting with a table of contents,
- (5) Briefing Chart (Not included in the 50-page limit and must not contain proprietary data).

STTR: Each STTR proposal must also contain a Cooperative R/R&D Agreement between the SBC and RI following the required items listed above. The agreement is included as part of the 50-page limit.

3.3.3 Forms

3.3.3.1 Cover Sheet (Form A). A sample copy of the Cover Sheet is provided in Section 8. 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.

3.3.3.2 Proposal Summary (Form B). A sample Proposal Summary form is provided in Section 8. The offeror shall provide complete information for each item and submit Form B as required in Section 6.

Technical Abstract: Summary of the offeror's proposed project is limited to 200 words and shall summarize the implications of the approach and the anticipated results of both Phase 1 and Phase 2 including an assessment of technology readiness levels (TRLs) at the end of the Phase 2 contract. *If the technical abstract is judged to be non responsive to the subtopic, the proposal will be rejected without further evaluation.*

Technology Taxonomy: Selections for the technology taxonomy are limited to technologies supported or relevant to the specific proposal. The listing of technologies for the taxonomy is provided in Appendix C.

Potential NASA and non-NASA commercial applications of the technology must also be presented.

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

3.3.3.3. Budget Summary (Form C). The offeror shall complete the Budget Summary, following the instructions provided with the form (Section 8), not to exceed \$600,000. 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 budget is fair and reasonable. The Government is not responsible for any monies expended by the applicant before award of any funding agreement.

Property. Proposed costs for materials may be included. "Materials" means property that may be incorporated or attached to a deliverable end item or that may be consumed or expended in performing the contract. It includes assemblies, components, parts, raw materials, and small tools that may be consumed in normal use. Any purchase of equipment or products under an SBIR/STTR contract using NASA funds should be American-made to the extent possible. NASA will not fund the purchase of equipment, instrumentation, or facilities under SBIR/STTR contracts as a direct cost (Section 5.15).

Travel. Travel is an acceptable cost when it is part of accomplishing the work proposed in Phase 2. Proposed travel must be described as to its purpose and benefits in conducting the research and development, and is subject to negotiation and approval by the Contracting Officer and COTR.

Deliverables. All proposed deliverables (other than reports) must be listed. This may include a prototype unit, software package, or a complete product or service, for NASA testing and utilization.

Profit. A profit or fee may be included in the proposed budget as noted in Section 5.10.

Cost Sharing. See Section 5.9.

Requirement for Approved Accounting System. Offerors should note that in order to receive progress payments under a Phase 2 contract, an offeror must have in place, prior to award, an accounting system that in the Defense Contract Audit Agency's (DCAA) opinion is adequate for accumulating costs. An approved accounting system can track costs to final cost objectives and segregate costs between direct and indirect. If you currently do not have an adequate accounting system, it is recommended that you take action to implement such a system. The lack of an adequate accounting system may preclude you from receiving a Phase 2 contract or may cause extended delays in award. For more information about cost proposals and accounting standards, please see the DCAA publication entitled "Information for Contractors" which is available at <http://www.dcaa.mil/dcaap7641.90.pdf>.

3.3.4 Technical Proposal. This part of the submission shall not contain any budget data and must consist of all eleven parts listed below in the given order. All parts must be numbered and titled; parts that are not applicable must be noted as "Not Applicable."

Part 1: Table of Contents. The technical content shall begin with a brief table of contents indicating the page numbers of each of the parts of the proposal. The required table of contents is provided below:

Phase 2 Table of Contents

Part 1:	Table of Contents.....	Page #
Part 2:	Identification and Significance of the Innovation and Results of the Phase 1 Proposal	
Part 3:	Technical Objectives	
Part 4:	Work Plan	
Part 5:	Related R/R&D	
Part 6:	Key Personnel	
Part 7:	Phase 3 Efforts, Commercialization and Business Planning	
Part 8:	Company Information and Facilities	
Part 9:	Subcontracts and Consultants	
Part 10:	Potential Post Applications	
Part 11:	Similar Proposals and Awards	

Part 2: Identification and Significance of the Innovation and Results of the Phase 1 Proposal

Drawing upon Phase 1 results, 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;
- (3) the proposed innovation relative to the state of the market and 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 2 research and technical approach.

Part 4: Work Plan. Provide a detailed work plan defining specific tasks, performance schedules, project milestones, and deliverables.

Part 5: Related R/R&D. Describe R/R&D related to the proposed work and affirm that the stated objectives have not already been achieved and that the same development is not presently being pursued elsewhere under contract to the Federal Government.

Part 6: Key Personnel. Identify the key technical personnel for the project, confirm their availability for Phase 2, and discuss their qualifications in terms of education, work experience, and accomplishments relevant to the project.

Part 7: Phase 3 Efforts, Commercialization and Business Planning. Present a plan for commercialization (Phase 3) 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 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 temporal competitive advantage, and achieve planned commercialization.

Part 8: Company Information and Facilities. Describe the capability of the offeror to carry out Phase 2 and Phase 3 activities, including its organization, operations, number of employees, R/R&D capabilities, and experience in technological innovation, commercialization and other areas relevant to the work proposed.

This section shall also provide adequate information to allow evaluators to assess the ability of the SBC to carry out the proposed Phase 2 activities. The offeror should describe the relevant facilities and equipment currently available, and those to be purchased, to support the proposed activities. NASA will not fund the acquisition of equipment, instrumentation, or facilities under Phase 2 contracts as a direct cost. Special tooling may be allowed. (Section 5.15)

Note: Government-wide SBIR and STTR policies prohibit the use of any SBIR/STTR award funds for the use of Government equipment and facilities. This does not preclude an SBC from utilizing a Government facility or Government equipment, but any charges for such use cannot be paid for with SBIR/STTR funds (SBA SBIR Policy Directive, Section 9 (f)(3)). In rare and unique circumstances, SBA may issue a case-by-case waiver to this provision after review of an agency's written justification. NASA cannot guarantee that a waiver from this policy can be obtained from SBA.

If a proposed project or product demonstration requires the use of unique Government facilities or equipment that will be funded with SBIR dollars, the offeror must provide a) a letter 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 b) a statement, signed by the appropriate Government official at the facility, verifying that it will be available for the required effort. The proposal should also include relevant information on the funding source(s) private, internal, or other Government. Failure to provide this explanation and the site manager's written authorization of use may invalidate any proposal selection. If the offeror proposes the use of SBIR/STTR funds for Government equipment or facilities, this explanation will be provided to SBA during the Agency waiver process.

Additional information on the use of NASA facilities, facility programs, and equipment is available at <http://sbir.nasa.gov/SBIR/facilities.html>.

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 required. Documentation of subcontract costs must be made available during negotiations to substantiate the budget estimate.

Subcontractors' and consultants' work must be performed in the United States. The following restrictions apply to the use of subcontracts/consultants:

SBIR Phase 2 Proposal

A minimum of one-half of the work (contract cost less profit) must be performed by the proposing SBC.

STTR Phase 2 Proposal

A minimum of 40 percent of the work must be performed by the proposing SBC and 30 percent by the RI.

Part 10: Potential Post Applications (Commercialization). Building upon Section 3.3.4, Part 7, further specify the potential NASA and commercial applications of the innovation and the associated potential customers, such as NASA mission programs and projects, within target markets. Potential NASA applications

include the projected utilization of proposed contract deliverables (e.g., prototypes, test units, software) and resulting products and services by NASA organizations and contractors.

Part 11: Similar Proposals and Awards. If applicable, provide updated material (Reference Phase 1 Proposal Requirements, Part 11).

3.3.5 Capital Commitments Addendum Supporting Phase 2 and Phase 3. Describe and document capital commitments from non-SBIR/STTR sources or from internal SBC funds for pursuit of Phase 2 and Phase 3. Offerors for Phase 2 contracts are strongly urged to obtain non-SBIR/STTR funding support commitments for follow-on Phase 3 activities and additional support of Phase 2 from parties other than the proposing firm. Funding support commitments must show that a specific, substantial amount will be made available to the firm to pursue the stated Phase 2 and/or Phase 3 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 Phase 3 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 2 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 2 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 2 proposal. This addendum will not be counted against the 50-page limitation.

3.3.6 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 *must not* contain any proprietary data. An example chart is provided in Appendix A.

3.4 SBA Data Collection Requirement

Each SBC applying for a Phase 2 award is required to update the appropriate information in the Tech-Net database for any of its prior Phase 2 awards. In addition, upon completion of Phase 2, the SBC is required to update the appropriate information in the Tech-Net database and is requested to update the information annually thereafter for a minimum period of five years. For complete information on what to enter, go to <http://technet.sba.gov>.

4. Method of Selection and Evaluation Criteria

All Phase 1 and 2 proposals will be evaluated and judged on a competitive basis. Proposals will be initially screened to determine responsiveness. Proposals passing this initial screening will be technically evaluated by NASA personnel to determine the most promising technical and scientific approaches. Each proposal will be judged 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 Phase 1 Proposals

Proposals judged 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 evaluated by evaluators with knowledge of the subtopic area.

4.1.1 Evaluation Process. Proposals should provide all information needed for complete evaluation. Evaluators will not seek additional information. Evaluations will be performed by NASA scientists and engineers. 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 1 Evaluation Criteria. NASA plans to select for award those proposals offering the best value to the Government and the Nation. 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 judged 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. 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 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 be shown to be adequate and any reliance on external sources, such as Government Furnished Equipment or Facilities, addressed (Section 5.15).

Factor 3. Effectiveness of the Proposed Work Plan

The work plan will be reviewed for its comprehensiveness, effective use of available resources, cost management and proposed schedule for meeting the Phase 1 objectives. The methods planned to achieve each objective or task should be discussed in detail.

STTR: The clear delineation of the 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 or 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 funding sources, existing and projected commitments for Phase 3 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.

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 1 proposals, Technical Merit carries more weight than Commercial Merit.

4.1.3 Selection. Proposals recommended for award 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 as well as overall NASA priorities, program balance and available funding. The Source Selection Official has the final authority for choosing the specific proposals for contract negotiation.

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.

4.1.4 Allocation of Rights Agreement (STTR awards only). After being selected for Phase 1 contract negotiations, but before the contract starts, the offeror shall 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.

4.2 Phase 2 Proposals

4.2.1 Evaluation Process. The Phase 2 evaluation process is similar to the Phase 1 process. NASA plans to select for award those proposals offering the best value to the Government and the Nation. Each proposal will be reviewed by NASA scientists and engineers and by qualified experts outside of NASA as needed. In addition, those proposals with high technical merit will be reviewed for commercial merit. NASA may use a peer review panel to evaluate commercial merit. Panel membership may include non-NASA personnel with expertise in business development and technology commercialization.

4.2.2 Evaluation Factors. The evaluation of Phase 2 proposals under this Solicitation will apply the following factors:

Factor 1. Scientific/Technical Merit and Feasibility

The proposed R/R&D effort will be evaluated on its innovativeness, originality, and potential technical value, including the degree to which Phase 1 objectives were met, the feasibility of the innovation, and whether the Phase 1 results indicate a Phase 2 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 be shown to be adequate and any reliance on external sources, such as Government Furnished Equipment or Facilities, addressed (Section 5.15).

Factor 3. Effectiveness of the Proposed Work Plan

The work plan will be reviewed for its comprehensiveness, effective use of available resources, cost management and proposed schedule for meeting the Phase 1 objectives. The methods planned to achieve each objective or task should be discussed in detail.

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 3 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 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.

4.2.3 Evaluation and Selection. 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 numerical scores of 85 percent or higher will be evaluated and rated for their commercial potential using the criteria listed in Factor 4 and by applying the same adjectival ratings as set forth for Phase 1 proposals. Where technical evaluations are essentially equal in potential, cost to the Government may be considered in determining successful offerors. For Phase 2 proposals, commercial merit is a critical factor.

Recommendations for award 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.

Note: Companies with Prior NASA SBIR/STTR Awards

NASA has instituted a comprehensive commercialization survey/data gathering process for companies with prior NASA SBIR/STTR awards. Information received from SBIR/STTR awardees completing the survey is kept confidential, and will not be made public except in broad aggregate, with no company-specific attribution.

Responding to the survey is strictly voluntary. However, the SBIR/STTR Source Selection Official does see the information contained within the survey as adding to the program's ability to use past performance in decision making as well as providing a database of SBIR/STTR results for management.

If you have not completed a survey, or if you would like to update a previously submitted response, please go on line at <http://sbir.nasa.gov/SBIR/survey.html>.

4.3 Debriefing of Unsuccessful Offerors

After Phase 1 and Phase 2 selection decisions have been announced, debriefings for unsuccessful 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. They are intended to acquaint the offeror with perceived strengths and weaknesses of the proposal and perhaps identify constructive future action by the offeror.

Debriefings will not disclose the identity of the proposal evaluators, proposal scores, the content of, or comparisons with, other proposals.

4.3.1 Phase 1 Debriefings. For Phase 1 proposals, debriefings will be automatically e-mailed to the designated business official within 60 days of the selection announcement. If you have not received your debriefing by this time, contact the SBIR/STTR Program Support Office at sbir@reisys.com.

4.3.2 Phase 2 Debriefings. To request debriefings on Phase 2 proposals, offerors must request via e-mail to the SBIR/STTR Program Support Office at sbir@reisys.com within 60 days after selection announcement. Late requests will not be honored.

5. Considerations

5.1 Awards

5.1.1 Availability of Funds. Both Phase 1 and Phase 2 awards are subject to availability of funds. NASA has no obligation to make any specific number of Phase 1 or Phase 2 awards based on this Solicitation, and may elect to make several or no awards in any specific technical topic or subtopic.

SBIR	STTR
<ul style="list-style-type: none"> ➤ NASA plans to announce the selection of approximately 250 proposals resulting from this Solicitation, for negotiation of Phase 1 contracts with values not exceeding \$100,000. Following contract negotiations and awards, Phase 1 contractors will have up to 6 months to carry out their programs, prepare their final reports, and submit Phase 2 proposals. ➤ NASA anticipates that approximately 40 percent of the successfully completed Phase 1 projects from the SBIR 2007 Solicitation will be selected for Phase 2. Phase 2 agreements will be fixed-price contracts with performance periods not exceeding 24 months and funding not exceeding \$600,000. 	<ul style="list-style-type: none"> ➤ NASA plans to announce the selection of approximately 30 proposals resulting from this Solicitation, for negotiation of Phase 1 contracts with values not exceeding \$100,000. Following contract negotiations and awards, Phase 1 contractors will have up to 12 months to carry out their programs, prepare their final reports, and submit Phase 2 proposals. ➤ NASA anticipates that approximately 40 percent of the successfully completed Phase 1 projects from the STTR 2007 Solicitation will be selected for Phase 2. Phase 2 agreements will be fixed-price contracts with performance periods not exceeding 24 months and funding not exceeding \$600,000.

5.1.2 Contracting. Fixed-price contracts will be issued for both Phase 1 and Phase 2 awards. Simplified contract documentation is employed; however, SBCs selected for award can reduce processing time by examining the procurement documents, submitting signed representations and certifications, and responding to the Contracting Officer in a timely manner. NASA will make a Phase 1 model contract and other documents available to the public on the NASA SBIR/STTR Website (<http://sbir.nasa.gov>) at the time of the selection announcement. **From the time of proposal selection until the award of a contract, all communications shall be submitted electronically to NSSC-contactcenter@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.

5.2 Phase 1 Reporting

Interim progress reports are required as described in the contract. These reports shall document progress made on the project and activities required for completion to provide NASA the basis for determining whether the payment is warranted.

A final report must be submitted to NASA upon completion of the Phase 1 R/R&D effort in accordance with applicable contract provisions. It shall elaborate the project objectives, work carried out, results obtained, and assessments of technical merit and feasibility. The final report shall include a single-page summary as the first page, in a format provided in the Phase 1 contract, identifying the purpose of the R/R&D effort and describing the findings and results, including the degree to which the Phase 1 objectives were achieved, and whether the results justify Phase 2 continuation. The potential applications of the project results in Phase 3 either for NASA or commercial purposes shall also be described. The final project summary is to be submitted without restriction for NASA publication.

All reports are required to be submitted electronically via the SBIR/STTR Website.

5.3 Payment Schedule for Phase 1

The exact payment terms will be included in the contract, but payments are normally authorized as follows: one-third at the time of award, one-third at project mid-point after award, and the remainder upon acceptance of the final report and any other deliverables by NASA.

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 Cover (Form A) and the Proposal Summary (Form B). Other proposal data is considered to be proprietary to the offeror, and NASA will protect it from public disclosure to the extent permitted by law including the Freedom of Information Act.

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 access to proposals to other NASA contractor and subcontractor personnel. NASA will provide access to such data only under contracts that contain an appropriate Handling of Data clause that requires the contractors to fully protect the information from unauthorized use or disclosure.

5.6 Final Disposition of Proposals

The Government retains ownership of proposals accepted for evaluation, and such proposals will not be returned to the offeror. Copies of all evaluated Phase 1 proposals will be retained for a minimum of one year after the Phase 1 selections have been made. Successful proposals will be retained in accordance with contract file regulations.

5.7 Proprietary Information in the Proposal Submission

Information contained in unsuccessful proposals will remain the property of the applicant. The Government may, however, retain copies of all proposals. Public release of information in any proposal submitted will be subject to existing statutory and regulatory requirements. 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 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 Cover (Form A), the Proposal Summary (Form B), and the Briefing Chart should not contain proprietary information.

5.8 Limited Rights Information and Data

Rights to data used in, or first produced under, any Phase 1 or Phase 2 contract are specified in the clause at FAR 52.227-20, Rights in Data--SBIR/STTR Program. The clause provides for rights consistent with the following:

5.8.1 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. These 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.

5.8.2 Proprietary Data. When data that is required to be delivered under an SBIR/STTR contract qualifies as "proprietary," i.e., either data developed at private expense that embody trade secrets or are commercial or financial and confidential or privileged, or computer software developed at private expense that is a trade secret, the contractor, if the contractor desires to continue protection of such proprietary data, shall not deliver such data to the Government, but instead shall deliver form, fit, and function data.

5.8.3 Non Disclosure Period. For a period of 4 years after acceptance of all items to be delivered under this 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.

5.8.4 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.

5.8.5 Patents. The contractor may normally elect title to any inventions made in the performance of an SBIR/STTR contract. The Government receives a nonexclusive license to practice or have practiced for or on behalf of the Government each such invention throughout the world. Small business concerns normally may retain the principal worldwide patent rights to any invention developed with Government support. The Government receives a royalty-free license for Federal Government use, reserves the right to require the patent holder to license others in certain circumstances, and requires that anyone exclusively licensed to sell the invention in the United States must normally manufacture it domestically.

In accordance with the Patent Rights Clause (FAR 52.227-11), SBIR/STTR contractors must disclose all subject inventions, which means 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 disclosed, the contractor has 2 years to decide whether to elect title. If the contractor fails to do so within the 2-year time period, 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 allowable time to file a patent.

Costs associated with patent applications are not allowable.

5.8.6 Invention Reporting. Awardees must report inventions to the awarding agency within 2 months of the inventor's report to the awardee. The reporting of inventions should be accomplished in accordance with the negotiated contract.

5.9 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.

STTR: If cost sharing is proposed, then these added funds shall be included in the 40/30 work percentage distribution and reflected in the Summary Budget (Form C).

5.10 Profit or Fee

Both Phase 1 and Phase 2 contracts may include a reasonable profit. The reasonableness of proposed profit is determined by the Contracting Officer during contract negotiations. Reference FAR 15.404-4.

5.11 Joint Ventures and Limited Partnerships

Both joint ventures and limited partnerships are permitted, provided the entity created qualifies as an SBC in accordance with the definition in Section 2.16. 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 25-page limit for the Phase 1 proposal.

5.12 Similar 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 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 acknowledge or report similar or duplicate efforts can lead to the termination of contracts or civil or criminal penalties.

5.13 Contractor Commitments

Upon award of a contract, the contractor will be required to make certain legal commitments through acceptance of numerous clauses in the Phase 1 contract. The outline of this section illustrates the types of clauses that will be included. This is not a complete list of clauses to be included in Phase 1 contracts, nor does it contain specific wording of these clauses. Copies of complete provisions will be made available prior to contract negotiations.

5.13.1 Standards of Work. Work performed under the contract must conform to high professional standards. Analyses, equipment, and components for use by NASA will require special consideration to satisfy the stringent safety and reliability requirements imposed in aerospace applications.

5.13.2 Inspection. Work performed under the contract is subject to Government inspection and evaluation at all reasonable times.

5.13.3 Examination of Records. The Comptroller General (or a duly authorized representative) shall have the right to examine any directly pertinent records of the contractor involving transactions related to the contract.

5.13.4 Default. The Government may terminate the contract if the contractor fails to perform the contracted work.

5.13.5 Termination for Convenience. The contract may be terminated by the Government at any time if it deems termination to be in its best interest, in which case the contractor will be compensated for work performed and for reasonable termination costs.

5.13.6 Disputes. Any dispute concerning the contract that cannot be resolved by mutual agreement shall be decided by the Contracting Officer with right of appeal.

5.13.7 Contract Work Hours. The contractor may not require a non-exempt employee to work more than 40 hours in a work week unless the employee is paid for overtime.

5.13.8 Equal Opportunity. The contractor will not discriminate against any employee or applicant for employment because of race, color, religion, age, sex, or national origin.

5.13.9 Affirmative Action for Veterans. The contractor will not discriminate against any employee or applicant for employment because he or she is a disabled veteran or veteran of the Vietnam era.

5.13.10 Affirmative Action for Handicapped. The contractor will not discriminate against any employee or applicant for employment because he or she is physically or mentally handicapped.

5.13.11 Officials Not to Benefit. No member of or delegate to Congress shall benefit from an SBIR or STTR contract.

5.13.12 Covenant Against Contingent Fees. No person or agency has been employed to solicit or to secure the contract upon an understanding for compensation except bona fide employees or commercial agencies maintained by the contractor for the purpose of securing business.

5.13.13 Gratuities. The contract may be terminated by the Government if any gratuities have been offered to any representative of the Government to secure the contract.

5.13.14 Patent Infringement. The contractor shall report to NASA each notice or claim of patent infringement based on the performance of the contract.

5.13.15 American-Made Equipment and Products. Equipment or products purchased under an SBIR or STTR contract must be American-made whenever possible.

5.13.16 Export Control Laws. The contractor shall comply with all U.S. export control laws and regulations, including the International Traffic in Arms Regulations (ITAR) and the Export Administration Regulations (EAR). Offerors are responsible for ensuring that all employees who will work on this contract are eligible under export control and International Traffic in Arms (ITAR) regulations. 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 and ITAR regulations 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.

5.14 Additional Information

5.14.1 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 are controlling.

5.14.2 Evidence of Contractor Responsibility. 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.

5.14.3 Central Contractor Registration: Offerors should be aware of the requirement to register in the Central Contractor Registration (CCR) database prior to contract award. **To avoid a potential delay in contract award, offerors are strongly encouraged to register prior to submitting a proposal.**

The CCR database 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 the CCR database, all mandatory information, which includes the DUNS or DUNS+4 number, and a CAGE code, must be validated in the CCR system. 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 CCR registration process.

The DoD has established a goal of registering an applicant in the CCR database within 48 hours after receipt of a complete and accurate application via the Internet. However, registration of an applicant submitting an application through a method other than the Internet may take up to 30 days. Therefore, offerors that are not registered should consider applying for registration immediately upon receipt of this solicitation. Offerors and contractors may obtain information on CCR registration and annual confirmation requirements via the Internet at <http://www.ccr.gov> or by calling 888-CCR-2423 (888-227-2423).

5.14.4 Software Development Standards: Offerors proposing projects involving the development of software should comply with the requirements of NASA Procedural Requirements (NPR) 7150.2, "NASA Software Engineering Requirements" available online at <http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7150&s=2>.

5.15 Property and Facilities

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. An SBC will furnish its own facilities to perform the proposed work as an indirect cost to the contract. Special tooling required for a project may be allowed as a direct cost.

When an SBC cannot furnish its own facilities to perform required tasks, an SBC may propose to acquire the use of available non Government facilities. Rental or lease costs may be considered as direct costs as part of the total funding for the project. If unique requirements force an offeror to acquire facilities under a NASA contract, they will be purchased as Government Furnished Equipment (GFE) and will be titled to the Government.

An offeror may propose the use of unique or one-of-a-kind Government facilities if essential for the research.

If a proposed project or product demonstration requires the use of unique Government facilities or equipment that will be funded with SBIR dollars, the offeror must provide a) a letter 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 b) a statement, signed by the appropriate Government official at the facility, verifying that it will be available for the required effort. The proposal should also include relevant information on the funding source(s) private, internal, or other Government. Failure to provide this explanation and the site manager's written authorization of use may invalidate any proposal selection. If the offeror proposes the use of SBIR/STTR funds for Government equipment or facilities, this explanation will be provided to SBA during the Agency waiver process.

Additional information on the use of NASA facilities, facility programs, and equipment is available at <http://sbir.nasa.gov/SBIR/facilities.html>.

5.16 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.

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. 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.

For successful proposal submission, SBCs must complete all three forms online, upload their technical proposal in an acceptable format, and have the Business Official 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 for Phase 1 and 3.3.4 for Phase 2.

STTR: The Research Institution is required to electronically endorse the Cooperative 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, and the briefing chart must be submitted via the Submissions EHB located on the NASA SBIR/STTR website.

- (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) Firms must also upload a briefing chart, which is not included in the page count (See Sections 3.2.7 and 3.3.6).

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

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. Other acceptable formats are MS Works, MS Word, and WordPerfect. Note: Due to PDF difficulties with non-standard fonts, Unix and TeX users should output technical proposal files in DVI format.

Graphics. For reasons of space conservation and simplicity the offeror is encouraged, but not required, to embed graphics within the document. For graphics submitted as separate files, the acceptable file formats (and their respective extensions) are: Bit-Mapped (.bmp), Graphics Interchange Format (.gif), JPEG (.jpg), PC Paintbrush (.pcx), WordPerfect Graphic (.wpg), and Tagged-Image Format (.tif). Embedded animation or video 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. Proposals can be uploaded multiple times with each new upload replacing the previous version. An e-mail will be sent acknowledging each successful upload. An example is provided below:

Sample E-mail for Successful Upload of Technical Proposal

Subject: Successful Upload of Technical Proposal

Upload of Technical Document for your NASA SBIR/STTR Proposal No. _____

This message is to confirm the successful upload of your technical proposal document for:

*Proposal No. _____
(Uploaded File Name/Size/Date)*

Please note that any previous uploads are no longer considered as part of your submission.

This e-mail is NOT A RECEIPT OF SUBMISSION of your entire proposal

IMPORTANT! The Business Official or an authorized representative must electronically endorse the proposal in the Electronic Handbook using the "Sign Proposal" step. Upon endorsement, you will receive an e-mail that will be your official receipt of proposal submission. .

Thank you for your participation in NASA's SBIR/STTR program.

NASA SBIR/STTR Program Support Office

You may upload the technical proposal multiple times but only the final uploaded and electronically endorsed version will be considered for review.

6.3 Deadline for Phase 1 Proposal Receipt

All Phase 1 proposal submissions must be received no later than 5:00 p.m. EDT on Thursday, September 6, 2007, via the NASA SBIR/STTR Website (<http://sbir.nasa.gov>). The server/electronic handbook will not be available for Internet submissions after this deadline. **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), Form B, Form C, and the uploaded technical proposal and 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. An example is provided below:

Sample E-mail for Official Confirmation of Receipt of Full Proposal:

Subject: Official Receipt of your NASA SBIR/STTR Proposal No. _____

Confirmation No. _____

This message is to acknowledge electronic receipt of your NASA SBIR/STTR Proposal No. _____.

Your proposal, including the forms and the technical document, has been received at the NASA SBIR/STTR Support Office.

SBIR/STTR 2007 Phase I xx.xx-xxxx (Title)

Form A completed on:

Form B completed on:

Form C completed on:

Technical Proposal Uploaded on:

File Name:

File Type:

File Size:

Briefing Chart completed on:

Proposal endorsed electronically by:

This is your official confirmation of receipt. Please save this email for your records, as no other receipt will be provided. The official selection announcement is currently scheduled for November 16, 2007, and will be posted via the SBIR/STTR website (<http://sbir.nasa.gov>).

Thank you for your participation in the NASA SBIR/STTR program.

NASA SBIR/STTR Program Support Office

6.5 Withdrawal of Proposals

Proposals may be withdrawn via the electronic handbook system hosted on the NASA SBIR/STTR Website (<http://sbir.nasa.gov>) with an endorsement by the designated SBC Official.

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 Manager at the address listed below:

Dr. Gary C. Jahns, Program Manager
 NASA SBIR/STTR Program Management Office
 MS 202A-3, Ames Research Center
 Moffett Field, CA 94035-1000
Gary.C.Jahns@nasa.gov

The copy of any protest shall be received by the NASA SBIR/STTR Program Manager within one day of filing a protest with the GAO.

7. Scientific and Technical Information Sources

7.1 NASA Websites

General information relating to scientific and technical information at NASA is available via the following web sites:

NASA Strategic Plan: <http://www.nasa.gov/about/budget/index.html>

NASA Organizational Structure: <http://www.nasa.gov/centers/hq/organization/index.html>

NASA Innovative Partnerships Program: <http://www.ipp.nasa.gov/>

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.sba.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, an agency of the Department of Commerce, is the Federal Government's largest central resource for government-funded scientific, technical, engineering, and business related information. For information about their various services and fees, call or write:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Phone: 703-605-6585
URL: <http://www.ntis.gov>

8. Submission Forms and Certifications

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Form A – SBIR Cover Sheet

1. PROPOSAL NUMBER: Subtopic Number **07** - _ _ . _ _ _ _ _
2. SUBTOPIC TITLE:
3. PROPOSAL TITLE:
4. SMALL BUSINESS CONCERN (SBC):
 NAME:
 MAILING ADDRESS:
 CITY/STATE/ZIP:
 PHONE: FAX:
 EIN/TAX ID: DUNS + 4: CAGE CODE:
 NUMBER OF EMPLOYEES:
5. AMOUNT REQUESTED \$ _____ DURATION: _____ MONTHS
6. CERTIFICATIONS: OFFEROR CERTIFIES THAT:

As defined in Section 1 of the Solicitation, the offeror certifies:

- | | | |
|---|-----|----|
| a. The Principal Investigator is “primarily employed” by the organization as defined in the SBIR Solicitation | Yes | No |
|---|-----|----|

As defined in Section 2 of the Solicitation, the offeror qualifies as a:

- | | | |
|--|-----|----|
| b. SBC | Yes | No |
| Number of employees: _____ | | |
| c. Socially and economically disadvantaged SBC | Yes | No |
| d. Women-owned SBC | Yes | No |
| e. HUBZone-owned SBC | Yes | No |

As defined in Section 3.2.4 Part 11 of the Solicitation indicate if

- | | | |
|---|-----|----|
| f. Work under this project has been submitted for Federal funding only to the NASA SBIR Program | Yes | No |
| g. Funding has been received for work under this project by any other Federal grant, contract, or subcontract | Yes | No |

As described in Section 3 of this solicitation, the offeror meets the following requirements completely:

- | | | |
|---|-----|----|
| h. All 11 parts of the technical proposal are included in part order | Yes | No |
| i. Subcontracts/consultants proposed? | Yes | No |
| i) If yes, limits on subcontracts/consultants met | Yes | No |
| j. Government equipment or facilities required (cannot use SBIR funds)? | Yes | No |
| i) If yes, signed statement enclosed in Part 8 | Yes | No |
| ii) If yes, non-SBIR funding source identified in Part 8? | Yes | No |

In accordance with Section 5.13.16 of the Solicitation as applicable

- | | | |
|--|-----|----|
| k. The offeror will comply with export control regulations | Yes | No |
|--|-----|----|

7. ACN NAME: E-MAIL:
8. I understand 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.
9. ENDORSEMENT BY SBC OFFICIAL:
- | | |
|------------|---------|
| NAME: | TITLE: |
| PHONE: | E-MAIL: |
| SIGNATURE: | DATE: |

NOTICE: 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.

Guidelines for Completing SBIR Cover Sheet

Complete Cover Sheet Form A electronically.

1. **Proposal Number:** This number does not change. The proposal number consists of the four-digit subtopic number and four-digit system-generated number.
2. **Subtopic Title:** Enter the title of the subtopic that this proposal will address. Use abbreviations as needed.
3. **Proposal Title:** Enter a brief, descriptive title using no more than 80 keystrokes (characters and spaces). Do not use the subtopic title. Avoid words like "development" and "study."
4. **Small Business Concern:** Enter the full name of the company submitting the proposal. If a joint venture, list the company chosen to negotiate and receive contracts. If the name exceeds 40 keystrokes, please abbreviate.

Address:	Address where mail is received
City, State, Zip:	City, 2-letter State designation (i.e. TX for Texas), 9-digit Zip code (i.e. 20705-3106)
Phone, Fax:	Number including area code
EIN/Tax ID:	Employer Identification Number/Taxpayer ID
DUNS + 4:	9-digit Data Universal Number System plus a 4-digit suffix given by parent concern
CAGE Code:	Commercial Government and Entity Code (Issued by Central Contractor Registration (CCR))

5. **Amount Requested:** Proposal amount from Budget Summary. The amount requested should not exceed \$100,000 (see Sections 1.4.1, 5.1.1).

Duration: Proposed duration in months. The requested duration should not exceed 6 months (see Sections 1.4.1, 5.1.1).

6. **Certifications:** Answer Yes or No as applicable for 6a, 6b, 6c, 6d, 6e, 6f, 6h (see the referenced sections for definitions).
 - 6g. SBCs should choose "No" to confirm that work under this project has not been funded under any other Federal grant, contract or subcontract.
 - 6i. Subcontracts/consultants proposed? By answering yes, the SBC certifies that subcontracts/consultants have been proposed and arrangements have been made to perform on the contract, if awarded.
 - i) If yes, limits on subcontracting and consultants met: By answering yes, the SBC certifies that business arrangements with other entities or individuals do not exceed one-third of the work (amount requested including cost sharing if any, less fee, if any) and is in compliance with Section 3.2.4, Part 9.
 - 6j. Government furnished equipment required? By answering yes, the SBC certifies that unique, one-of-a-kind Government Furnished Facilities or Government Furnished Equipment are required to perform the proposed activities (see Sections 3.2.4 Part 8, 3.3.4 Part 8, 5.15). By answering no, the SBC certifies that no such Government Furnished Facilities or Government Furnished Equipment is required to perform the proposed activities.
 - i) If yes, signed statement enclosed in Part 8: By answering yes, the SBC certifies that a statement describing the uniqueness of the facility and its availability to the offeror at specified times, signed by the appropriate Government official, is enclosed in the proposal.
 - ii) If yes, non-SBIR funding source identified in Part 8: By answering yes, the SBC certifies that it has a confirmed, non-SBIR funding source for whatever charges may be incurred when utilizing the required Government facility.
 - 6k. Offerors are responsible for ensuring compliance with export control and International Traffic in Arms (ITAR) regulations. All employees who will work on this contract must be eligible under these regulations or the offeror must have in place a valid export license or technical assistance agreement. Violations of these regulations can result in criminal or civil penalties.

7. **ACN Name and E-mail:** Name and e-mail address of Authorized Contract Negotiator.
8. **Endorsement of this form certifies understanding of this statement.**
9. **Endorsement:** An official of the firm must electronically endorse the proposal cover.

Form B – SBIR Proposal Summary

Subtopic Number

1. Proposal Number **07** - _ _ . _ _ _ _ _ _ .
2. Subtopic Title
3. Proposal Title
4. Small Business Concern
Name:
Address:
City/State:
Zip:
Phone:
5. Principal Investigator/Project Manager
Name:
Address:
City/State:
Zip:
Phone:
E-mail:
6. Estimated Technology Readiness Level (TRL) or TRL Range upon completion of contract:
7. Technical Abstract (Limit 2,000 characters, approximately 200 words)
8. Potential NASA Application(s): (Limit 1,500 characters, approximately 150 words)
9. Potential Non-NASA Application(s): (Limit 1,500 characters, approximately 150 words)
10. Technology Taxonomy (Select only the technologies relevant to this specific proposal)

Guidelines for Completing SBIR Proposal Summary

Complete Proposal Summary Form B electronically.

1. **Proposal Number:** Same as Cover Sheet.
2. **Subtopic Title:** Same as Cover Sheet.
3. **Proposal Title:** Same as Cover Sheet.
4. **Small Business Concern:** Same as Cover Sheet.
5. **Principal Investigator/Project Manager:** Enter the full name of the PI/PM and include all required contact information.
6. **Technology Readiness Level (TRL):** Provide the estimated Technology Readiness Level (TRL) or TRL Range upon completion of contract. See Section 2.20 and Appendix B for TRL definitions.
7. **Technical Abstract:** Summary of the offeror's proposed project in 200 words or less. The abstract must not contain proprietary information and must describe the NASA need addressed by the proposed R/R&D effort.
8. **Potential NASA Application(s):** Summary of the direct or indirect NASA applications of the innovation, assuming the goals of the proposed R/R&D are achieved. Limit your response to 150 words or 1,500 characters, whichever is less.
9. **Potential Non-NASA Application(s):** Summary of the direct or indirect NASA applications of the innovation, assuming the goals of the proposed R/R&D are achieved. Limit your response to 150 words or 1,500 characters, whichever is less.
10. **Technology Taxonomy:** Selections for the Technology Taxonomy are limited to technologies supported or relevant to the specific proposal.

Form C – SBIR Budget Summary

PROPOSAL NUMBER:

SMALL BUSINESS CONCERN:

DIRECT LABOR:

Category	Hours	Rate	Cost \$
----------	-------	------	------------

TOTAL DIRECT LABOR:

(1) \$ _____

OVERHEAD COST

_____ % of Total Direct Labor or \$ _____

OVERHEAD COST:

(2) \$ _____

OTHER DIRECT COSTS (ODCs):

Category	Cost \$
----------	------------

TOTAL OTHER DIRECT COSTS:

(3) \$ _____

Explanation of ODCs

(1)+(2)+(3)=(4)

SUBTOTAL:

(4) \$ _____

GENERAL & ADMINISTRATIVE (G&A) COSTS

_____ % of Subtotal or \$ _____

G&A COSTS:

(5) \$ _____

(4)+(5)=(6)

TOTAL COSTS

(6) \$ _____

ADD PROFIT or SUBTRACT COST SHARING
(As applicable)

PROFIT/COST SHARING:

(7) \$ _____

(6)+(7)=(8)

AMOUNT REQUESTED:

(8) \$ _____

PHASE 1 DELIVERABLES: Upon selection, SBCs will be required to submit mandatory deliverables such as progress reports, final report and New Technology report as per their contract. Samples of all required contract deliverables are available in the NASA SBIR/STTR Firms Library via the NASA SBIR/STTR Website (<http://sbir.nasa.gov>). If your firm is proposing any additional deliverables, list them below:

Deliverable	Quantity	Project Delivery Milestone
_____	_____	_____
_____	_____	_____
_____	_____	_____

AUDIT AGENCY: If a Federal agency has ever audited your accounting system, please identify the agency, office location, and contact information below:

Agency: _____ Office/Location: _____
 Phone: _____ Email: _____

Guidelines for Preparing SBIR Budget Summary

Complete Budget Summary Form C electronically.

The offeror electronically submits to the Government a pricing proposal of estimated costs with detailed information for each cost element, consistent with the offeror's cost accounting system.

This summary does not eliminate the need to fully document and justify the amounts requested in each category. Such documentation should be contained, as appropriate, in the text boxes provided on the electronic form.

Firm: Same as Cover Sheet.

Proposal Number: Same as Cover Sheet.

Direct Labor: Enter labor categories proposed (e.g., Principal Investigator/Project Manager, Research Assistant/Laboratory Assistant, Analyst, Administrative Staff), labor rates and the hours for each labor category.

Overhead Cost: Specify current rate and base. Use current rate(s) negotiated with the cognizant Federal auditing agency, if available. If no rate(s) has (have) been negotiated, a reasonable indirect cost (overhead) rate(s) may be requested for Phase 1 for acceptance by NASA. Show how this rate is determined. The offeror may use whatever number and types of overhead rates are in accordance with the firm's accounting system and approved by the cognizant Federal negotiating agency, if available. Multiply Direct Labor Cost by the Overhead Rate to determine the Overhead Cost.

Example: A typical SBC might have an overhead rate of 30 percent. If the total direct labor costs proposed are \$50,000, the computed overhead costs for this case would be $.3 \times 50,000 = \$15,000$, if the base used is the total direct labor costs.

or provide a number for total estimated overhead costs to execute the project.

Note: If no labor overhead rate is proposed and the proposed direct labor includes all fringe benefits, you may enter "0" for the overhead cost line.

Other Direct Costs (ODCs):

- Materials and Supplies: Indicate types required and estimate costs.
- Documentation Costs or Page Charges: Estimate cost of preparing and publishing project results.
- Subcontracts: Include a completed budget including hours and rates and justify details. (Section 3.2.4, Part 9.)
- Consultant Services: Indicate name, daily compensation, and estimated days of service.
- Computer Services: Computer equipment leasing is included here.

List all other direct costs that are not otherwise included in the categories described above.

Explanations of all items identified as ODCs must be provided under "Explanation of ODCs." Offeror should include the basis used for estimating costs (vendor quote, catalog price, etc.) For example, if "Materials" is listed as an ODC, include a description of the materials, the quantity required and basis for the proposed cost.

Note: NASA will not fund the purchase of capital equipment or supplies that are not to be delivered to the government or consumed in the production of a prototype. The cost of capital equipment should be depreciated and included in G&A if appropriate.

Subtotal (4): Sum of (1) Total Direct Labor, (2) Overhead and (3) ODCs

General and Administrative (G&A) Costs (5): Specify current rate and base. Use current rate negotiated with the cognizant Federal negotiating agency, if available. If no rate has been negotiated, a reasonable indirect cost (G&A) rate may be requested for acceptance by NASA. Show how this rate is determined. If a current negotiated rate is

not available, NASA will negotiate a reasonable rate with the offeror. Multiply (4) subtotal (Total Direct Cost) by the G&A rate to determine G&A Cost.

or provide an estimated G&A costs number for the proposal.

Total Costs (6): Sum of Items (4) and (5). Note that this value will be used in verifying the minimum required work percentage for the SBC.

Profit/Cost Sharing (7): See Sections 5.9 and 5.10. Profit to be added to total budget, shared costs to be subtracted from total budget, as applicable.

Amount Requested (8): Sum of Items (6) and (7), not to exceed \$100,000.

Deliverables and Audit Information (9):

Deliverables: List any additional deliverables, if applicable. Include the deliverable name, quantity (include unit of measurement, i.e., 2 models or 1.5 lbs. of material), and the proposed delivery milestone (i.e., end of contract). This section should only be completed if the offeror is proposing a deliverable in addition to the mandatory deliverables (progress report, final report and New Technology Report).

Audit Agency: Complete the “Contact Information” section if your firm’s accounting system has been audited by a Federal agency. Provide the agency name, the office branch or location, and the phone number and/or email.

SBIR Check List

For assistance in completing your Phase 1 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 25 8.5 x 11 inch pages (Section 3.2.1).
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. The 1 page briefing chart does not include any proprietary data (Section 3.2.7)
6. Certifications in Form A are completed.
7. Proposed funding does not exceed \$100,000. (Sections 1.4.1, 5.1.1).
8. Proposed project duration should not exceed 6 months. (Sections 1.4.1, 5.1.1).
9. Entire proposal including Forms A, B, and C submitted via the Internet.
10. Form A electronically endorsed by the SBC Official.
11. **Proposals must be received no later than 5:00 p.m. EDT on Thursday, September 6, 2007** (Section 6.3).

Form A – STTR Cover Sheet

1. PROPOSAL NUMBER: **07** - _ _ . _ _ _ _ _
2. RESEARCH TOPIC:
3. PROPOSAL TITLE:
4. SMALL BUSINESS CONCERN (SBC) RESEARCH INSTITUTION (RI)
 NAME: NAME:
 ADDRESS: ADDRESS:
 CITY/STATE/ZIP: CITY/STATE/ZIP :
 PHONE: FAX: PHONE: FAX:
 EIN/TAX ID: EIN/TAX ID:
 DUNS + 4: CAGE CODE:
5. AMOUNT REQUESTED: \$ _____ DURATION: _____ MONTHS
6. CERTIFICATIONS: THE ABOVE SBC CERTIFIES THAT:

As defined in Section 2 of the Solicitation, the offeror qualifies as a:

- | | | |
|--|-----|----|
| a. SBC | Yes | No |
| Number of employees: _____ | | |
| b. Socially and economically disadvantaged SBC | Yes | No |
| c. Woman-owned SBC | Yes | No |
| d. HUBZone-owned SBC | Yes | No |

As described in Section 2.12 of the Solicitation, the partnering institution qualifies as a:

- | | | |
|------------------------------------|-----|----|
| e. FFRDC | Yes | No |
| f. Nonprofit research institute | Yes | No |
| g. Nonprofit college or university | Yes | No |

As described in Section 3 of the Solicitation, the offeror meets the following requirements completely:

- | | | |
|---|-----|----|
| h. Cooperative Agreement signed by the SBC and RI enclosed | Yes | No |
| i. All eleven parts of the technical proposal included in part order | Yes | No |
| j. Subcontracts/consultants proposed? (Other than the RI) | Yes | No |
| i) If yes, limits on subcontracts/consultants met | Yes | No |
| k. Government equipment or facilities required (cannot use STTR funds)? | Yes | No |
| i) If yes, signed statement enclosed in Part 8 | Yes | No |
| ii) If yes, non-STTR funding source identified in Part 8? | Yes | No |
| l. A signed Allocation of Rights Agreement will be available for the Contracting Officer at time of selection | Yes | No |

As defined in Section 3.2.4 of the Solicitation, indicate if:

- | | | |
|---|-----|----|
| m. Work under this project has been submitted for funding only to the NASA STTR Program | Yes | No |
| n. Funding has been received for work under this project by any other Federal grant, contract, or subcontract | Yes | No |

In accordance with Section 5.13.16 of the Solicitation as applicable

- | | | |
|--|-----|----|
| o. The offeror will comply with export control regulations | Yes | No |
|--|-----|----|

7. ACN NAME: E-MAIL:
8. The SBC will perform ____% of the work and the RI will perform ____% of the work of this project.
9. I understand 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.
10. ENDORSEMENT BY SBC OFFICIAL:
- | | |
|------------|---------|
| NAME: | TITLE: |
| PHONE: | E_MAIL: |
| SIGNATURE: | DATE: |

NOTICE: 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.

Guidelines for Completing STTR Cover Sheet

Complete Cover Sheet Form electronically.

1. Proposal Number: This number does not change. The proposal number consists of the program year (i.e. 04) and unique four-digit system-generated number.
2. Research Topic: NASA research topic number and title (Section 9).
3. Proposal Title: A brief, descriptive title, avoid words like "development of" and "study of," and do not use acronyms or trade names.
4. Small Business Concern: Full name and address of the company submitting the proposal. If a joint venture, list the company chosen to negotiate and receive contracts. If the name exceeds 40 keystrokes, please abbreviate.

Research Institution: Full name and address of the research institute.

Mailing Address: Address where mail is received
City, State, Zip: City, 2-letter State designation (i.e. TX for Texas), 9-digit Zip code (i.e. 20705-3106)
Phone, Fax: Number including area code
EIN/TAX ID: Employer Identification Number/Taxpayer ID
DUNS + 4: 9-digit Data Universal Number System plus a 4-digit suffix given by parent concern
CAGE Code: Commercial Government and Entity Code (Issued by Central Contractor Registration (CCR))
5. Amount Requested: Proposal amount from Budget Summary. The amount requested should not exceed \$100,000 (see Sections 1.4.1, 5.1.1).

Duration: Proposed duration in months. The requested duration should not exceed 12 months (see Sections 1.4.1, 5.1.1).
6. Certifications: Answer Yes or No as applicable for 6a, 6b, 6c, 6d, 6e, 6f, 6g, 6i, 6l (see Section 2 for definitions).
 - 6h. Cooperative Agreement signed by the SBC and RI: By answering yes, the SBC/RI certifies that a Cooperative Agreement signed by both SBC and RI is enclosed in the proposal (see Sections 3.2.2, 3.2.5).
 - 6j. Subcontracts/consultants proposed? By answering yes, the SBC/RI certifies that subcontracts/consultants have been proposed and arrangements have been made to perform on the contract, if awarded.
 - i) If yes, limits on subcontracting and consultants met: By answering yes, the SBC/RI certifies that business arrangements with other entities or individuals do not exceed 30 percent of the work (amount requested including cost sharing if any, less fee, if any) and is in compliance with Section 3.2.4, Part 9.
 - 6k. Government furnished equipment required? By answering yes, the SBC/RI certifies that unique, one-of-a-kind Government Furnished Facilities or Government Furnished Equipment are required to perform the proposed activities (see Sections 3.2.4 Part 8, 3.3.4 Part 8, 5.15). By answering no, the SBC/RI certifies that no such Government Furnished Facilities or Government Furnished Equipment are required to perform the proposed activities.
 - i) If yes, signed statement enclosed in Part 8: By answering yes, the SBC/RI certifies that a statement describing the uniqueness of the facility and its availability to the offeror at specified times, signed by the appropriate Government official, is enclosed in the proposal.
 - ii) If yes, non-SBIR funding source identified in Part 8. By answering yes, the SBC certifies that it has confirmed, non-SBIR funding source for whatever charges may be incurred when utilizing the required Government facility.
 - 6n. SBCs should choose "No" to confirm that work under this project has not been funded under any other Federal grant, contract or subcontract.
 - 6o. Offerors are responsible for ensuring compliance with export control and International Traffic in Arms (ITAR) regulations. All employees who will work on this contract must be eligible under these regulations or the offeror must have in place a valid export license or technical assistance agreement. Violations of these regulations can result in criminal or civil penalties.
7. ACN Name and E-mail: Name and e-mail address of Authorized Contract Negotiator.

8. Proposals submitted in response to this Solicitation must be jointly developed by the SBC and the RI, and at least **40 percent** of the work (amount requested including cost sharing, less fee, if any) is to be performed by the SBC as the prime contractor, and at least **30 percent** of the work is to be performed by the RI (see Section 3.2.4).
9. Endorsement of this form certifies understanding of this statement.
10. Endorsements: An official of the firm must electronically endorse the proposal cover.

Form B – STTR Proposal Summary

1. Proposal Number **07** - _ _ . _ _ _ _ _ _ _ _
2. Research Topic:
3. Proposal Title:
4. Small Business Concern
Name:
Address:
City/State:
Zip:
Phone:
5. Research Institution
Name:
Address:
City/State:
Zip:
Phone:
6. Principal Investigator/Project Manager:
7. Estimated Technology Readiness Level (TRL) or TRL Range upon completion of contract:
8. Technical Abstract (Limit 2,000 characters, approximately 200 words)
9. Potential NASA Application(s): (Limit 1,500 characters, approximately 150 words)
10. Potential Non-NASA Application(s): (Limit 1,500 characters, approximately 150 words)
11. Technology Taxonomy (Select only the technologies relevant to this specific proposal)

Guidelines for Completing STTR Proposal Summary

Complete Form B electronically.

1. **Proposal Number:** Same as Cover Sheet
2. **Research Topic:** Same as Cover Sheet.
3. **Proposal Title:** Same as Cover Sheet.
4. **Small Business Concern:** Same as Cover Sheet.
5. **Research Institution:** Same as Cover Sheet.
6. **Principal Investigator/Project Manager:** Enter the full name of the PI/PM and include all required contact information.
7. **Technology Readiness Level (TRL):** Provide the estimated Technology Readiness Level (TRL) or TRL Range upon completion of contract. See Section 2.20 and Appendix B for TRL definitions.
8. **Technical Abstract:** Summary of the offeror's proposed project in 200 words or less. The abstract must not contain proprietary information and must describe the NASA need addressed by the proposed R/R&D effort.
9. **Potential NASA Application(s):** Summary of the direct or indirect NASA applications of the innovation, assuming the goals of the proposed R/R&D are achieved. Limit your response to 150 words or 1,500 characters, whichever is less.
10. **Potential Non-NASA Application(s):** Summary of the direct or indirect NASA applications of the innovation, assuming the goals of the proposed R/R&D are achieved. Limit your response to 150 words or 1,500 characters, whichever is less.
11. **Technology Taxonomy:** Selections for the Technology Taxonomy are limited to technologies supported or relevant to the specific proposal.

Form C – STTR Budget Summary

PROPOSAL NUMBER:

SMALL BUSINESS CONCERN:

DIRECT LABOR:

Category	Hours	Rate	Cost \$
----------	-------	------	------------

TOTAL DIRECT LABOR:

(1)

\$ _____

OVERHEAD COST

_____ % OF TOTAL DIRECT LABOR OR \$ _____

OVERHEAD COST:

(2)

\$ _____

OTHER DIRECT COSTS (ODCs) including RI budget:

Category	Cost \$
----------	------------

TOTAL OTHER DIRECT COSTS:

(3)

\$ _____

Explanation of ODCs

(1)+(2)+(3)=(4)

SUBTOTAL:

(4)

\$ _____

GENERAL & ADMINISTRATIVE (G&A) COSTS

_____ % of Subtotal or \$ _____

G&A COSTS:

(5)

\$ _____

(4)+(5)=(6)

TOTAL COSTS

(6)

\$ _____

ADD PROFIT or SUBTRACT COST SHARING PROFIT/COST SHARING:

(As applicable)

(7)

\$ _____

(6)+(7)=(8)

AMOUNT REQUESTED:

(8)

\$ _____

PHASE 1 DELIVERABLES: Upon selection, SBCs will be required to submit mandatory deliverables such as progress reports, final report and New Technology Report as per their contract. Samples of all required contract deliverables are available in the NASA SBIR/STTR Firms Library via the NASA SBIR/STTR Website (<http://sbir.nasa.gov>). If your firm is proposing any additional deliverables, list them below:

Deliverable	Quantity	Project Delivery Milestone
_____	_____	_____
_____	_____	_____
_____	_____	_____

AUDIT AGENCY: If a Federal agency has ever audited your accounting system, please identify the agency, office location, and contact information below:

Agency: _____	Office/Location: _____
Phone: _____	Email: _____

Guidelines for Preparing STTR Budget Summary

Complete Summary Budget Form C electronically.

The offeror electronically submits to the Government a pricing proposal of estimated costs with detailed information for each cost element, consistent with the offeror's cost accounting system.

This summary does not eliminate the need to fully document and justify the amounts requested in each category. Such documentation should be contained, as appropriate, in the text boxes provided on the electronic form.

Small Business Concern - Same as Cover Sheet.

Principal Investigator/Project Manager - Same as Cover Sheet.

Direct Labor - Enter labor categories proposed (e.g., Principal Investigator/Project Manager, Research Assistant/Laboratory Assistant, Analyst, Administrative Staff), labor rates and the hours for each labor category.

Overhead Cost - Specify current rate and base. Use current rate(s) negotiated with the cognizant Federal auditing agency, if available. If no rate(s) has (have) been audited, a reasonable indirect cost (overhead) rate(s) may be requested for Phase 1 for acceptance by NASA. Show how this rate is determined. The offeror may use whatever number and types of overhead rates are in accordance with the firm's accounting system and approved by the cognizant Federal negotiating agency, if available. Multiply Direct Labor Cost by the Overhead Rate to determine the Overhead Cost.

Example: A typical SBC might have an overhead rate of 30%. If the total direct labor costs proposed are \$50,000, the computed overhead costs for this case would be $.3 \times 50,000 = \$15,000$, if the base used is the total direct labor costs.

or provide a number for total estimated overhead costs to execute the project.

Note: If no labor overhead rate is proposed and the proposed direct labor includes all fringe benefits, you may enter "0" for the overhead cost line.

Other Direct Costs (ODCs) -

Include total cost for the Research Institution. Note that the proposal should include sufficient information from the Research Institution to determine how their budget was calculated.

- Materials and Supplies: Indicate types required and estimate costs.
- Documentation Costs or Page Charges: Estimate cost of preparing and publishing project results.
- Subcontracts: Include a completed budget including hours and rates and justify details. (Section 3.2.4, Part 9.)
- Consultant Services: Indicate name, daily compensation, and estimated days of service.
- Computer Services: Computer equipment leasing is included here.

List all other direct costs that are not otherwise included in the categories described above.

Explanations of all items identified as ODCs must be provided under "Explanation of ODCs." Offeror should include the basis used for estimating costs (vendor quote, catalog price, etc.) For example, if "Materials" is listed as an ODC, include a description of the materials, the quantity required and basis for the proposed cost.

Note: NASA will not fund the purchase of capital equipment or supplies that are not to be delivered to the government or consumed in the production of a prototype. The cost of capital equipment should be depreciated and included in G&A if appropriate.

Subtotal (4) - Sum of (1) Total Direct Labor, (2) Overhead and (3) ODCs

General and Administrative (G&A) Costs (5)- Specify current rate and base. Use current rate negotiated with the cognizant Federal negotiating agency, if available. If no rate has been negotiated, a reasonable indirect cost (G&A) rate may be requested for acceptance by NASA. If a current negotiated rate is not available, NASA will negotiate a reasonable rate with the offeror. Multiply (4) subtotal (Total Direct Cost) by the G&A rate to determine G&A Cost.

or provide an estimated G&A costs number for the proposal.

Total Costs (6) - Sum of Items (4) and (5). Note that this value will be used in verifying the minimum required work percentage for the SBC and RI.

Profit/Cost Sharing (7) - See Sections 5.9 and 5.10. Profit to be added to total budget, shared costs to be subtracted from total budget, as applicable.

Amount Requested (8) - Sum of Items (6) and (7), not to exceed \$100,000.

Deliverables and Audit Information (9):

Deliverables: List any additional deliverables, if applicable. Include the deliverable name, quantity (include unit of measurement, i.e., 2 models or 1.5 lbs. of material), and the proposed delivery milestone (i.e., end of contract). This section should only be completed if the offeror is proposing a deliverable in addition to the mandatory deliverables (progress report, final report and New Technology Report).

Audit Agency: Complete the "Contact Information" section if your firm's accounting system has been audited by a Federal agency. Provide the agency name, the office branch or location, and the phone number and/or email.

Model Cooperative R/R&D Agreement

By virtue of the signatures of our authorized representatives, _____ (Small Business Concern), _____ and _____ (Research Institution) have agreed to cooperate on the _____ (Proposal Title) Project, in accordance with the proposal being submitted with this agreement.

This agreement shall be binding until the completion of all Phase 1 activities, at a minimum. If the _____ (Proposal Title) Project is selected to continue into Phase 2, the agreement may also be binding in Phase 2 activities that are funded by NASA, then this agreement shall be binding until those activities are completed. The agreement may also be binding in Phase 3 activities that are funded by NASA.

After notification of Phase 1 selection and prior to contract release, we shall prepare and submit, if requested by NASA, an **Allocation of Rights Agreement**, which shall state our rights to the intellectual property and technology to be developed and commercialized by the _____ (Proposal Title) Project. We understand that our contract cannot be approved and project activities may not commence until the **Allocation of Rights Agreement** has been signed and certified to NASA.

Please direct all questions and comments to _____ (Small Business Concern representative) at _____ (Phone Number)

Signature

Name/title

Small Business Concern

Signature

Name/title

Research Institution

Small Business Technology Transfer (STTR) Program Model Allocation of Rights Agreement

This Agreement between _____, a small business concern organized as a _____ under the laws of _____ and having a principal place of business at _____, ("SBC") and _____, a research institution having a principal place of business at _____, ("RI") is entered into for the purpose of allocating between the parties certain rights relating to an STTR project to be carried out by SBC and RI (hereinafter referred to as the "PARTIES") under an STTR funding agreement that may be awarded by NASA to SBC to fund a proposal entitled "_____ " submitted, or to be submitted, to by SBC on or about _____, 200__.

1. Applicability of this Agreement.

(a) This Agreement shall be applicable only to matters relating to the STTR project referred to in the preamble above.

(b) If a funding agreement for STTR project is awarded to SBC based upon the STTR proposal referred to in the preamble above, SBC will promptly provide a copy of such funding agreement to RI, and SBC will make a sub-award to RI in accordance with the funding agreement, the proposal, and this Agreement. If the terms of such funding agreement appear to be inconsistent with the provisions of this Agreement, the Parties will attempt in good faith to resolve any such inconsistencies.

However, if such resolution is not achieved within a reasonable period, SBC shall not be obligated to award nor RI to accept the sub-award. If a sub-award is made by SBC and accepted by RI, this Agreement shall not be applicable to contradict the terms of such sub-award or of the funding agreement awarded by NASA to SBC except on the grounds of fraud, misrepresentation, or mistake, but shall be considered to resolve ambiguities in the terms of the sub-award.

(c) The provisions of this Agreement shall apply to any and all consultants, subcontractors, independent contractors, or other individuals employed by SBC or RI for the purposes of this STTR project.

2. Background Intellectual Property.

(a) "Background Intellectual Property" means property and the legal right therein of either or both parties developed before or independent of this Agreement including inventions, patent applications, patents, copyrights, trademarks, mask works, trade secrets and any information embodying proprietary data such as technical data and computer software.

(b) This Agreement shall not be construed as implying that either party hereto shall have the right to use Background Intellectual Property of the other in connection with this STTR project except as otherwise provided hereunder.

(1) The following Background Intellectual Property of SBC may be used nonexclusively and, except as noted, without compensation by RI in connection with research or development activities for this STTR project (if "none" so state): _____;

(2) The following Background Intellectual Property of RI may be used nonexclusively and, except as noted, without compensation by SBC in connection with research or development activities for this STTR project (if "none" so state): _____;

(3) The following Background Intellectual Property of RI may be used by SBC nonexclusively in connection with commercialization of the results of this STTR project, to the extent that such use is reasonably necessary for practical, efficient and competitive commercialization of such results but not for commercialization independent of the commercialization of such results, subject to any rights of the Government therein and upon the condition that SBC pay to RI, in addition to any other royalty including any royalty specified in the following list, a royalty of _____% of net sales or leases made by or under the authority of SBC of any product or service that embodies, or the manufacture or normal use of which entails the use of, all or any part of such Background Intellectual Property (if "none" so state):

3. Project Intellectual Property.

(a) "Project Intellectual Property" means the legal rights relating to inventions (including Subject Inventions as defined in 37 CFR § 401), patent applications, patents, copyrights, trademarks, mask works, trade secrets and any other legally protectable information, including computer software, first made or generated during the performance of this STTR Agreement.

(b) Except as otherwise provided herein, ownership of Project Intellectual Property shall vest in the party whose personnel conceived the subject matter, and such party may perfect legal protection in its own name and at its own expense. Jointly made or generated Project Intellectual Property shall be jointly owned by the Parties unless otherwise agreed in writing. The SBC shall have the first option to perfect the rights in jointly made or generated Project Intellectual Property unless otherwise agreed in writing.

(1) The rights to any revenues and profits, resulting from any product, process, or other innovation or invention based on the cooperative shall be allocated between the SBC and the RI as follows:

SBC Percent: _____ RI Percent: _____

(2) Expenses and other liabilities associated with the development and marketing of any product, process, or other innovation or invention shall be allocated as follows: the SBC will be responsible for _____ percent and the RI will be responsible for _____ percent.

(c) The Parties agree to disclose to each other, in writing, each and every Subject Invention, which may be patentable or otherwise protectable under the United States patent laws in Title 35, United States Code. The Parties acknowledge that they will disclose Subject Inventions to each other and the Agency within two months after their respective inventor(s) first disclose the invention in writing to the person(s) responsible for patent matters of the disclosing Party. All written disclosures of such inventions shall contain sufficient detail of the invention, identification of any statutory bars, and shall be marked confidential, in accordance with 35 U.S.C. § 205.

(d) Each party hereto may use Project Intellectual Property of the other nonexclusively and without compensation in connection with research or development activities for this STTR project, including inclusion in STTR project reports to the AGENCY and proposals to the AGENCY for continued funding of this STTR project through additional phases.

(e) In addition to the Government's rights under the Patent Rights clause of 37 CFR § 401.14, the Parties agree that the Government shall have an irrevocable, royalty free, nonexclusive license for any Governmental purpose in any Project Intellectual Property.

(f) SBC will have an option to commercialize the Project Intellectual Property of RI, subject to any rights of the Government therein, as follows—

(1) Where Project Intellectual Property of RI is a potentially patentable invention, SBC will have an exclusive option for a license to such invention, for an initial option period of _____ months after such invention has been reported to SBC. SBC may, at its election and subject to the patent expense reimbursement provisions of this section, extend such option for an additional _____ months by giving written notice of such election to RI prior to the expiration of the initial option period. During the period of such option following notice by SBC of election to extend, RI will pursue and maintain any patent protection for the invention requested in

writing by SBC and, except with the written consent of SBC or upon the failure of SBC to reimburse patenting expenses as required under this section, will not voluntarily discontinue the pursuit and maintenance of any United States patent protection for the invention initiated by RI or of any patent protection requested by SBC. For any invention for which SBC gives notice of its election to extend the option, SBC will, within _____ days after invoice, reimburse RI for the expenses incurred by RI prior to expiration or termination of the option period in pursuing and maintaining (i) any United States patent protection initiated by RI and (ii) any patent protection requested by SBC. SBC may terminate such option at will by giving written notice to RI, in which case further accrual of reimbursable patenting expenses hereunder, other than prior commitments not practically revocable, will cease upon RI's receipt of such notice. At any time prior to the expiration or termination of an option, SBC may exercise such option by giving written notice to RI, whereupon the parties will promptly and in good faith enter into negotiations for a license under RI's patent rights in the invention for SBC to make, use and/or sell products and/or services that embody, or the development, manufacture and/or use of which involves employment of, the invention. The terms of such license will include: (i) payment of reasonable royalties to RI on sales of products or services which embody, or the development, manufacture or use of which involves employment of, the invention; (ii) reimbursement by SBC of expenses incurred by RI in seeking and maintaining patent protection for the invention in countries covered by the license (which reimbursement, as well as any such patent expenses incurred directly by SBC with RI's authorization, insofar as deriving from RI's interest in such invention, may be offset in full against up to _____ of accrued royalties in excess of any minimum royalties due RI); and, in the case of an exclusive license, (3) reasonable commercialization milestones and/or minimum royalties.

(2) Where Project Intellectual Property of RI is other than a potentially patentable invention, SBC will have an exclusive option for a license, for an option period extending until _____ months following completion of RI's performance of that phase of this STTR project in which such Project Intellectual Property of RI was developed by RI. SBC may exercise such option by giving written notice to RI, whereupon the parties will promptly and in good faith enter into negotiations for a license under RI's interest in the subject matter for SBC to make, use and/or sell products or services which embody, or the development, manufacture and/or use of which involve employment of, such Project Intellectual Property of RI. The terms of such license will include: (i) payment of reasonable royalties to RI on sales of products or services that embody, or the development, manufacture or use of which involves employment of, the Project Intellectual Property of RI and, in the case of an exclusive license, (ii) reasonable commercialization milestones and/or minimum royalties.

(3) Where more than one royalty might otherwise be due in respect of any unit of product or service under a license pursuant to this Agreement, the parties shall in good faith negotiate to ameliorate any effect thereof that would threaten the commercial viability of the affected products or services by providing in such license(s) for a reasonable discount or cap on total royalties due in respect of any such unit.

4. Follow-on Research or Development.

All follow-on work, including any licenses, contracts, subcontracts, sublicenses or arrangements of any type, shall contain appropriate provisions to implement the Project Intellectual Property rights provisions of this agreement and insure that the Parties and the Government obtain and retain such rights granted herein in all future resulting research, development, or commercialization work.

5. Confidentiality/Publication.

(a) Background Intellectual Property and Project Intellectual Property of a party, as well as other proprietary or confidential information of a party, disclosed by that party to the other in connection with this STTR project shall be received and held in confidence by the receiving party and, except with the consent of the disclosing party or as permitted under this Agreement, neither used by the receiving party nor disclosed by the receiving party to others, provided that the receiving party has notice that such information is regarded by the disclosing party as proprietary or confidential. However, these confidentiality obligations shall not apply to use or disclosure by the receiving party after such information is or becomes known to the public without breach of this provision or is or becomes known to the receiving party from a source reasonably believed to be independent of the disclosing party or is developed by or for the receiving party independently of its disclosure by the disclosing party.

(b) Subject to the terms of paragraph (a) above, either party may publish its results from this STTR project. However, the publishing party will give a right of refusal to the other party with respect to a proposed publication, as well as a _____ day period in which to review proposed publications and submit comments, which will be given full consideration before publication. Furthermore, upon request of the reviewing party, publication will be deferred for up to _____ additional days for preparation and filing of a patent application which the reviewing party has the right to file or to have filed at its request by the publishing party.

6. Liability.

(a) Each party disclaims all warranties running to the other or through the other to third parties, whether express or implied, including without limitation warranties of merchantability, fitness for a particular purpose, and freedom from infringement, as to any information, result, design, prototype, product or process deriving directly or indirectly and in whole or part from such party in connection with this STTR project.

(b) SBC will indemnify and hold harmless RI with regard to any claims arising in connection with commercialization of the results of this STTR project by or under the authority of SBC. The PARTIES will indemnify and hold harmless the Government with regard to any claims arising in connection with commercialization of the results of this STTR project.

7. Termination.

(a) This agreement may be terminated by either Party upon ___ days written notice to the other Party. This agreement may also be terminated by either Party in the event of the failure of the other Party to comply with the terms of this agreement.

(b) In the event of termination by either Party, each Party shall be responsible for its share of the costs incurred through the effective date of termination, as well as its share of the costs incurred after the effective date of termination, and which are related to the termination. The confidentiality, use, and/or nondisclosure obligations of this agreement shall survive any termination of this agreement.

AGREED TO AND ACCEPTED--

Small Business Concern

By: _____ Date: _____
Print Name: _____
Title: _____

Research Institution

By: _____ Date: _____
Print Name: _____
Title: _____

STTR Check List

For assistance in completing your Phase 1 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 25 8.5 x 11 inch pages, including Cooperative Agreement. (Sections 3.2.1, 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. The 1 page briefing chart does not include any proprietary data (Section 3.2.7)
6. Certifications in Form A are completed.
7. Proposed funding does not exceed \$100,000. (Sections 1.4.1, 5.1.1).
8. Proposed project duration should not exceed 12 months. (Sections 1.4.1, 5.1.1).
9. Cooperative Agreement has been electronically endorsed by both the SBC Official and RI. (Sections 3.2.5, 6.2).
10. Entire proposal including Forms A, B, C, and Cooperative Agreement submitted via the Internet.
11. Form A electronically endorsed by the SBC Official.
- 12. Proposals must be received no later than 5:00 p.m. EDT on Thursday, September 6, 2007** (Section 6.3).
13. Signed Allocation of Rights Agreement available for Contracting Officer at time of 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 NASA Mission Directorates (MDs):

Aeronautics Research
Exploration Systems
Science
Space Operations

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 that will lead to revolutionary concepts, technologies, and capabilities that 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 the Vision for Space Exploration.

ARMD conducts cutting-edge research that produces concepts, tools, and technologies that enable the design of vehicles that fly safely through any atmosphere at any speed. In addition, ARMD is directly addressing fundamental research challenges that must be overcome in order to implement the Next Generation Air Transportation System (NGATS). This research will yield revolutionary concepts, capabilities, and technologies that will enable significant increases in the capacity, efficiency and flexibility of the National Air Space. 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 NGATS vision.

NASA's Aeronautics Research Mission Directorate (ARMD) supports the Agency's goal (Goal 3) of developing a balanced overall program of science, exploration, and aeronautics, consistent with the redirection of the human spaceflight program to focus on exploration. 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.

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

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TOPIC: A1 Aviation Safety

The Aviation Safety Program focuses on the Nation's aviation safety challenges of the future. This vigilance for safety must continue in order to meet the projected increases in air traffic capacity and realize the new capabilities envisioned for the Next Generation Air Transportation System (NGATS). The Aviation Safety Program will conduct research to improve the intrinsic safety attributes of future aircraft and to eliminate safety-related technology barriers. The program is focusing on a foundational approach to advancing knowledge in core disciplines (e.g., fluid dynamics, computational methods, material science), which in turn is used to build integrated multidisciplinary system-level models, tools, and technologies.

This approach focuses on furthering our understanding of the underlying physics, chemistry, materials, etc., of aeronautics phenomena when broken down to these most basic elements. The results at the fundamental level will be integrated at the discipline and multi-discipline levels to ultimately yield system-level integrated capabilities, methods, and tools for analysis, optimization, prediction, and design that will enable improved safety for a range of missions, vehicle classes, and crew configurations.

Example areas of program interest include research directed at the detection, prediction and mitigation/management of aging-related hazards of future civilian and military aircraft; designs of revolutionary adaptive flight decks; in-flight prognosis of aircraft health, preventative and adaptive systems for in-flight operability; informed logistics and maintenance graceful recovery from in-flight failures; software safety assurance and formal verification methods for safety-critical systems; as well as system-level integrated resilient control technologies.

NASA seeks highly innovative proposals that will complement its work in science and technologies that build upon and advance the Agency's unique safety-related research capabilities vital to aviation safety.

A1.01 Mitigation of Aircraft Aging and Durability-related Hazards

Lead Center: GRC

Participating Center(s): ARC, LaRC

The mitigation and management of aging and durability-related hazards in future civilian and military aircraft will require advanced materials, concepts, and techniques. NASA is engaged in the research of materials (metals, ceramics, and composites) and characterization/validation test techniques for mitigation of aging and durability issues and to enable advanced material suitability and concepts. Proposals are sought for innovations in these mitigation technologies:

- Development of moisture-resistant resins and new surface treatments/primers. Novel chemistries are sought to improve the durability of aerospace adhesives with potential use on subsonic aircraft. This research opportunity is focused on the development of novel chemistries for coupling agents, surface treatments for adherends and their interfaces, leading to aerospace structural adhesives with improved durability. Work may involve chemical modification and testing of adhesives, coupling agents, surface treatments or combinations thereof and modeling to predict behavior and guide the synthetic approaches. Examples of adhesive characteristics to model and/or test may include, but are not limited to, hydrolytic stability of the interfacial chemistry, moisture permeability at the interface, and hydrophobicity of coupling agents and surface primers. Examples of adherends to model and/or test include carbon fiber/epoxy composites used in structural applications on subsonic aircraft, and aluminum, as well as their respective surface treatments.
- Concepts for autonomous self-healing of composite aerospace structures. NASA is interested only in passive approaches, i.e., approaches that do not require sensors or external energy to activate the healing process. Desired performance objectives include improved compression-after-impact performance and retarded/arrested damage growth. To be competitive with lightweight traditional (non-healing) aerospace structures, self-healing concepts must not introduce extensive passive weight, such as a reservoir tank of resin, etc.

- Test techniques to fully characterize aging history and strain rate effects on thermoset and/or thermoplastic resins as well as on advanced composites manufactured of such resins and reinforced with 3D fiber pre-forms such as the triaxial braid used in advanced composite fan containment structures.

Technology innovations may take the form of tools, models, algorithms, prototypes, and/or devices.

A1.02 Crew Systems Technologies for Improved Aviation Safety

Lead Center: LaRC

Participating Center(s): ARC

NASA seeks highly innovative and crew-centered technologies to improve aerospace system safety. Such advanced technologies may meet this goal by ensuring appropriate situation awareness: facilitating and extending human perception, information interpretation, and response planning and selection; counteracting human information processing limitations, biases, and error-tendencies; assisting in response planning and execution; and fostering successful, closely-coupled joint cognitive human/automation systems. NASA requires improved methods and tools for characterizing current and future users of aerospace systems, and tailoring designs to users. Such advanced technologies must be evaluated sensitively in operationally-valid contexts. Therefore, NASA also seeks tools and methods for ascertaining, measuring and evaluating aerospace system operator performance in advance aviation contexts, and how this performance is reflected in system performance.

Technologies may take the form of tools, models, operational procedures, instructional systems, prototypes, and/or devices for use in the flight deck, elsewhere by pilots, or by those who design systems for crew use. Specific topical areas of interest include the following:

- Intelligent systems monitoring and alerting technologies for improved failure mode identification, recovery, and threat mitigation;
- Designs for human-error prevention, detection, and mitigation;
- Support for crew response planning and selection;
- New sensors and/or new associated algorithms for determining operator states of attention, awareness, engagement, and intent;
- Approaches that appropriately modulate crew attention, engagement, workload, and situation awareness;
- Human-centered technologies to improve the performance of less-experienced operators and of pilots from special population groups;
- Human-error reliability approaches to analyzing flight deck displays, decision aids, procedures, and human/automation integration policies;
- Presentation and aiding concepts for the display and use of data with spatial or temporal uncertainty and of integrated streams of data with various levels of integrity;
- Naturalistic dialog approaches for interacting with aircraft systems and external agents in flight;
- Individual and team performance metrics, analysis methods, and tools to better evaluate and certify human and system performance for use in operational environments, simulation, and model-based analyses with focus on sequential behavior analysis.

A1.03 Aviation External Hazard Sensor Technologies

Lead Center: LaRC

Participating Center(s): ARC, GRC

NASA is concerned with new and innovative methods for airborne detection, identification, and evaluation of in-flight hazards to aviation. These hazards may include weather and other atmospheric phenomena, terrain, traffic, and runway contamination. Examples of hazards include: icing conditions, convective weather, wind shear, wind gusts, turbulence, volcanic ash, hail, low visibility, wake vortices, lightning, terrain, air traffic, runway incursions, man-made obstacles, and wet/icy runways. Proposals are invited that lead to innovative new technologies and approaches or significant improvements in existing technologies for in-flight hazard avoidance.

Technologies may take the form of tools, models, techniques, procedures, substantiated guidelines, prototypes, and devices. Although the emphasis is on airborne hazard detection, prediction, and avoidance, the following are also of interest: the sharing of information to support hazard avoidance by other aircraft; multi-sensor and multi-source hazard information utilization; collaborative decision-making; updates to terrain/obstacle databases; and provision of observations for input to weather models and forecast/now-cast products. Examples include:

- New and improved airborne forward-looking sensor systems;
- Data fusion technologies for integrating disparate sources of flight-related information with on-board and off-board sensor data to detect and evaluate aviation hazards;
- Innovative technologies and methods to detect, predict, and quantify hazards in order to provide accurate information and guidance to enable avoidance of hazards or to instigate strategies for mitigation; and
- Decision-support tools and methods to improve collaborative and distributive decision-making.

While this subtopic is focused on remote detection and avoidance of hazards, the same systems that provide for avoidance can be utilized for mitigation and escape. Proposals that explore these applications in addition to avoidance are welcome.

A1.04 Adaptive Flight Control

Lead Center: ARC

Participating Center(s): DRFC, GRC, LaRC

Small Business Innovative Research in adaptive flight control should address stability and performance, maneuverability, and safe landing of aircraft in adverse conditions (e.g., faults and failures, damage, and environmental upsets). This includes analysis and design methods for adaptive/intelligent reconfigurable control by developing practical and theoretic metrics. The approach must be able to address the following:

- Unmodeled dynamics (e.g., aeroelastic modes);
- Parametric uncertainty (e.g., stability and control derivative variations due to aerodynamic changes);
- Time-scale separation inherent in different actuators (e.g., slow engines as actuators);
- Nonlinear dynamic nature of the actuator response including time lag (e.g., engine variable spool-up time and actuator rate limiting);
- Stability of adaptive control methods in the presence of unmodeled dynamics and exogenous disturbances (e.g., wind shear and atmospheric turbulence).

Effective adaptive control methods need to be developed to mitigate multiple faults, failures, and damage conditions under uncertain (and potentially deteriorating) conditions. These methods include but are not limited to the following:

- Multi-objective adaptive optimal control;
- Aeroservoelastic mode filtering adaptive control;
- Direct adaptive control;
- Indirect adaptive control;
- Hybrid (direct and indirect) adaptive control.

These methods must be capable of achieving good performance (e.g., rise time, gain and phase margins, and command tracking) under adverse conditions while obeying system constraints (e.g., load limits and actuator rate saturation).

Innovative proposals are sought which can address the areas above and provide substantial improvements, in capability and range of applicability, over existing commercial technology.

A1.05 Data Mining for Integrated Vehicle Health Management

Lead Center: ARC

Participating Center(s): DFRC, GRC, LaRC

Innovative data mining technologies are being solicited to incorporate within systems and continuous risk management processes covering the life cycles of aircraft and their related ground support systems as well as spacecraft, in particular the Orion Crew Exploration Vehicle and the Aries launch vehicle and their related ground support systems. The life cycle includes design, development, integration, testing, operation (nominal and off-nominal), maintenance, enhancement (upgrades), and failure analysis.

Relevant technologies include those that:

- Detect anomalies and faults;
- Detect trends;
- Discover similarities;
- Infer models from data;
- Detect topics from text;
- Classify instances or events;
- Fuse data from multiple sources;
- Display data mining results in an intuitive manner.

To achieve the above capabilities, relevant technologies are expected to meet a subset of the following criteria:

- Perform automated learning, both supervised and unsupervised;
- Permit the user to define the search criteria and heuristics;
- Support a mixed-initiative approach combining automated learning and user search control;
- Perform real-time analyses on continuous streams of data;
- Perform off-line analyses on static databases;
- Process one or more data types including numeric sequences, character sequences, English free-form text, image sequences, and combinations of these forms;
- Perform real-time analyses on continuous streams of data;
- Perform on-demand, scheduled, or triggered analyses on periodic and/or aperiodic data streams;
- Perform off-line analyses on static databases.

NASA has a broad range of potential applications for these technologies. The following list provides a few examples:

- Enhance diagnostic and prognostic capabilities of an onboard integrated health management system;
- Perform clustering and topic identification on reports from a Problem Reporting and Corrective Action system;
- Detect faults from image sequences;
- Enhance acceptance tests to reduce false positive and false negative classifications;
- Enhance information-based security systems by detecting anomalies;
- Improve the design process by discovering similar applicable designs given requirements;
- Support analyses that assess risk of component or system failure.

Proposals are expected to identify commercial state-of-the-art technology that will be extended as well as the relevant research that will be implemented as the result of an award.

A1.06 Sensing and Diagnostic Capability**Lead Center: GRC****Participating Center(s): ARC, LaRC**

One element in NASA's contribution to solving the problem of aging and damage processes in future vehicles is research to identify aging-related hazards before they become critical. In order to provide early detection of these processes and hazards, new sensing and diagnostic capabilities to support nondestructive evaluation (NDE) systems are needed, as well as associated computational techniques and maintenance methods. Proposals are sought that provide innovations in sensing technologies and diagnostic solutions for these specific structural, material, and systems problems:

- 'Virtual' inspections on both monolithic homogeneous materials (i.e., metals) and composite materials using computational NDE tools. 'Virtual' inspections would include determining the size of flaws detectable with a particular technique, the parameters needed for inspections on a particular structure, or determining if a technique is applicable for a particular inspection. Techniques modeled could include (but are not limited to) terahertz imaging, thermography, ultrasonics, eddy current or radiographics.
- Chafing of wiring insulation is the primary reason for wire failure in both military and commercial aircraft. Computational methods are being solicited for analyzing data from nondestructive inspection techniques to detect and characterize chafing as early as possible, thus enabling useful life predictions.
- Hard shell composite fan containment components that include sandwich structures. Of interest are practical large-area rapid inspection and/or health monitoring methods that can monitor the bulk interior as well as the surface of the component over significant distances as the component goes through its service life. Techniques could include (but are not limited to) ultrasonic guided waves that interrogate the bulk while traveling laterally along the component surface, acoustic emission systems, and robust pressure-sensitive film systems that can visually record impacts and impact paths while surviving the service and impact conditions.
- Increased use of composite structure and components in aircraft will create new challenges for visual inspection which still constitutes 80-90% of all inspections. Because surface indicators of damage or delamination may be subtle or barely visible, NASA is interested in technologies and techniques that can enhance visual detectability in the operational environment. Such innovations could include (but are not limited to) treatments of the composite materials, enhancements to the work environment, or job aids for visual inspectors or maintenance technicians (outside the realm of NDE systems). Desirable features include ease of use and minimal change to the operational process.

Technology innovations may take the form of tools, models, algorithms, prototypes, and/or devices.

A1.07 Advanced Health Management for Aircraft Subsystems**Lead Center: GRC****Participating Center(s): ARC, DFRC, LaRC**

The purpose of this solicitation is to seek highly innovative and commercially viable technologies that will improve aircraft safety for current and future civilian and military aircraft, and to overcome aircraft safety technological barriers that would otherwise constrain the full realization of the Next Generation Air Transportation System (NGATS). Specifically, this subtopic seeks technologies in support of the Integrated Vehicle Health Management Project (IVHM) that will contribute to the reduction of aircraft system and component failures and malfunctions that cause and contribute to aircraft accidents and incidents.

The goal of IVHM is to develop technologies to determine system/component degradation and damage early enough to prevent or gracefully recover from in-flight failures in both the near-future and next-generation air transportation systems. These technologies will enable nearly continuous on-board situational awareness of the vehicle health state for use by the flight crew, ground crew, and maintenance depot. To achieve this, NASA will advance the state-of-the-art technology in on-board health state assessment to enable the continuous diagnosis and prognosis of the

integrated vehicle's health status. To help meet this goal, NASA seeks innovative technology development activities in the following areas:

- Airframe Health Management - including self-awareness and prognosis, anomaly detection and identification, and in-flight damage, degradation and failure mitigation;
- Propulsion Health Management - including self-awareness and prognosis of gas path, combustion, and overall engine state (containment systems and rotating and static components), and fault-tolerant system architectures;
- Aircraft Systems Health Management - including state-awareness and prognosis of landing gear, hydraulic and pneumatic systems, electrical and power systems, fuel and lubrication systems, avionics/communications, navigation, surveillance/flight critical and flight management systems, and robust, distributed, fault-tolerant, self-recoverable architectures for flight critical aircraft applications;
- Environmental Hazard Management - including the prevention, detection, and mitigation of hazards such as ice accretion, lightning strikes, EMI/EMC, and ionizing radiation, as well as the direct and indirect effects of these hazards;
- IVHM Architectures and Databases - including system design, analysis and optimization, information management, data flow and communication, control and reconfiguration, architecture development and validation, and database development and management;
- Validation and Predictive Capability Assessment - including analysis, simulation, ground testing, flight testing, environmental testing, and software assurance.

NASA's IVHM research will ultimately yield integrated, multi-disciplinary analysis and optimization capabilities that enable system-level designs providing graceful recovery from in-flight failures, computationally efficient tools for in-flight prognosis of aircraft health including integrated predictive and sensor capabilities, and preventative and adaptive systems for in-flight operability and informed logistics and maintenance. Innovative technology solutions are being sought for the following IVHM technical challenges:

- Large-scale distributed anomaly, fault, malfunction, degradation, and failure detection with data/decision/information fusion (multiple sensors, actuators, and processing nodes);
- Prevention, detection, isolation, and mitigation of multiple independent/correlated anticipated and unanticipated failures (modeling of correlated failures and system/vehicle effects, diagnosis and prognosis, real-time processing and decision-making for very large state spaces, and health state reasoning);
- Adaptive diagnostic and prognostic algorithms (adapts as systems and components age, are repaired, or replaced);
- Analytical methods to set local decision criteria so that global performance criteria are met (multi-dimensional optimization);
- Performance optimization in distributed systems (high probability of detection, low probability of false alarm);
- Vehicle-wide state and function monitoring of systems and structures (including digital avionics, auto-flight and control, propulsion, hydraulic, mechanical, pneumatic, electrical, and power generation and distribution systems);
- Large-scale distributed adaptive fault-tolerant processing architecture that is robust in adverse operating environments (EMI/EMC, ionizing radiation, low/high temperatures);
- Distributed hierarchical threat-tolerant self-healing embedded sensors and systems (embedded self-recovery mechanisms, adaptive, programmable and reconfigurable devices);
- Technology integration, verification, and validation (diagnostic and prognostic flight, airframe, and propulsion systems, environmental hazard management, advanced sensors and system architectures, Verification and Validation (V&V) with predictive capability).

Technology innovations may take the form of tools, models, algorithm, prototypes, and/or devices.

A1.08 Prediction of Aging Effects**Lead Center: LaRC****Participating Center(s): ARC, GRC**

In order to assess the long-term effects of potential hazards and aging-related degradation of new and emerging material systems/fabrication techniques, NASA is performing research to anticipate aging and to predict its effects on the designs of future aircraft. To support this predictive capability, structural integrity analytical tools, lifing methods, and material durability prediction tools are being developed. Physics-based and continuum-based models, computational methods, and validation techniques are needed to provide the basis for these higher level (e.g., design) tools. Proposals are sought that apply innovative methods, models and analytic tools to these specific applications:

- Improved structural analysis of complex metallic and composite airframe components through the use of novel multi-scale as well as global-local analytical codes. The methods used for these solutions need to detail the initiation and progression of damage to determine accurate estimates of residual life and or strength of complex airframe structures.
- Type II hot corrosion of turbine alloys is a product of molten salt exposure and is manifested by a localized pitting corrosion attack. Prolonged high temperature exposures of turbine disk alloys to sulfur-rich low temperature melting eutectic salts can lead to an onset of Type II hot corrosion attack causing serious degradation to the durability of the turbine components. Tools and models are needed to predict the onset and the rates of hot corrosion attack in these types of alloys.
- Simulation of the response to jet engine fan blade-out events of advanced composite fan case/containment structures in aged conditions, using relevant impact mechanics and structural system dynamics modeling techniques.

Technology innovations may take the form of tools, models, and algorithms.

A1.09 Integrated Avionics Systems for Small Scale Remotely Operated Vehicles**Lead Center: LaRC****Participating Center(s): ARC, DFRC**

Small scale remotely operated vehicles are becoming an increasingly attractive option for experimental research in flight dynamics, vehicle state assessment, and automatic flight control as well as a growing number of commercial applications. Small scale vehicles (nominally 20 lbs to 80 lbs total weight) place constraints on the amount of on-board avionics that can be accommodated and these systems can benefit from integration of components. For flight research activities key avionic systems are:

- Inertial navigation units which combine gyroscopic measurements with GPS position data;
- The capabilities to implement an autopilot fail-safe should RF uplink be lost;
- The ability to log instrumentation data from analog, pulse-width and serial stream inputs;
- The ability to read and generate serial-port data streams for RF communication systems;
- Telemetry systems to provide for both ground-based piloting and real-time data downlink.

When used as experimental research test beds the requirements for data quality (resolution, bandwidth, linearity, etc.) are often higher than would be derived just for automated flight operations on the vehicle itself. Although existing commercial technology can individually address each of these areas, an integrated high-fidelity system that is commensurate with the low-power, low-weight, and EMI sensitive environment of subscale remotely piloted vehicles is not available. For safety of flight a fail-safe autopilot should be able to recover vehicle stability from a range of entry conditions and also have GPS waypoint return-and-hold or full auto landing capability. Programmability of the avionics unit is important to allow the system to be extended to a wide range of platforms, application environments, and experimental requirements. Telemetry systems are flight critical for remotely piloted vehicles and

therefore must have high reliability in addition to meeting bandwidth requirements imposed by the data downlink from a fully instrumented vehicle.

Innovative system concepts are sought which can address some or all of the areas above and provide substantial improvements, in capability and range of applicability, over existing commercial technology.

A1.10 Adaptive Structural Mode Suppression

Lead Center: DFRC

Participating Center(s): ARC, LaRC

NASA has initiated an Integrated Resilient Aircraft Control (IRAC) effort under the Aviation Safety Program. The main focus of the effort is to advance the state-of-the-art technology in adaptive controls to provide a design option that allows for increased resiliency to failures, damage, and upset conditions. These adaptive flight control systems will automatically adjust the control feedback and command paths to regain stability, maneuverability, and eventually a safe landing. One potential consequence of changing the control feedback and command paths is that an undesired aeroservoelastic (ASE) interaction could occur. The resulting limit cycle oscillation could result in structural damage or potentially total loss of vehicle control.

Current airplanes with non-adaptive control laws usually include roll-off or notch filters to avoid ASE interactions. These structural mode suppression filters are designed to provide 8 dB of gain attenuation at the structural mode frequency. Ground Vibration Testing (GVT), Structural Mode Interaction (SMI) testing, and finally full scale flight testing are performed to verify that no adverse ASE interactions occur. Until a significant configuration or control system change occurs, the structural mode suppression filters provide adequate protection.

When an adaptive system changes to respond to off-nominal rigid body behavior, the changes in control can affect the structural mode attenuation levels. In the case of a damaged vehicle, the frequency and damping of the structural modes can change. The combination of changing structural behavior with changing control system gains results in a system with a probability of adverse interactions that is very difficult to predict a priori. An onboard, measurement based method is needed to ensure that the system adjusts to attenuate any adverse ASE interaction before a sustained limit cycle and vehicle damage are encountered. This system must work in concert with the adaptive control system to allow the overall goal of re-gaining rigid body performance as much as possible without exacerbating the situation with ASE interactions.

Adaptive, reconfigurable structural mode suppression methods that address the following are needed:

- Suppression of all ASE interactions with no a priori knowledge of structural modes;
- Minimal interference/interaction with rigid body controller;
- Implementable in a real-time flight control processor.

Research areas of interest include, but are not limited to, the following:

- Adaptive filtering techniques;
- Self-tuning notch filters;
- ASE modeling and predictive techniques;
- Online margin measurement techniques;
- Online identification of structural vibrations;
- Global stability proofs for adaptive systems.

A1.11 Universal Enabling IVHM Technologies in Architecture, System Integration, Databases, and Verification and Validation

Lead Center: LaRC

Participating Center(s): ARC, DFRC, GRC

A vehicle-wide Integrated Vehicle Health Management (IVHM) Project system must be information rich with embedded monitoring and diagnostic/prognostic functions that will penetrate deeper and with smaller granularity into physical components and structures. This will necessitate the development of safety-critical, real-time, distributed, embedded sensing and computing system design, development, integration, and assessment capability for applications with huge numbers of sensing and computing nodes which are networked and dynamically reconfigurable in response to changing physical conditions, modes of operation, failures, damage, and environmental disturbances. Furthermore, the development of advanced anomaly detection, prognostic, and diagnostic architectures will be required. The architecture will be designed to optimize multi-dimensional/objective criteria, enable optimal adaptive redundancy management, support large-scale data, decision, and information fusion, and meet safety, cost, and performance criteria for the IVHM system. However, the development of such a vehicle-wide system must be done by many teams of different disciplines at different locations. Therefore, a standard project database is needed that stores and manages test data, failure statistics, fault modes and effects, diagnostic and prognostic models, simulations, and related documentation for all the systems, subsystems, and components that are part of the complex system for which an IVHM system is being developed.

The IVHM database must also allow for seamless integration with a variety of IVHM algorithms, including data mining, machine learning, and exploratory data analysis tools, in order to enable algorithm development and knowledge discovery using the same database of historical data. The IVHM database will be owned and operated by NASA and will be provided as a service to the aircraft industry, U.S. government, and the R&D community. The database will provide industry standard access controls to protect proprietary data rights as well as to ensure compliance with ITAR and EAR restrictions. Additionally, design tools/decision support systems that enable the design of aircraft while accounting for the sensing, processing, and data mining/analysis needs of IVHM is vital. These tools/systems must enable the designers and the analysts/discipline specialists to work together, rather than as separate entities, and must allow IVHM system design, including study of IVHM system tradeoffs, at the early aircraft design stage.

In order to ensure the safe and reliable application of IVHM technologies to civil aviation, advances in verification and validation (V&V) processes and underlying methods and tools are needed to assure the safety of systems that will become increasingly complex and nondeterministic. Advances are needed in compositional verification that will enable the safe integration of complex adaptive systems with strong guarantees of integrity, fault-tolerance, partitioning, and real-time. New tools, methods, and processes are needed for the V&V of diagnostic algorithms with non-deterministic behavior. The goal of the V&V research is to enable compelling evidence that required system properties are guaranteed by the composition of constituent parts, and to develop tools, methods and processes that mitigate concerns about design validity, safety, and reliability for complex, nondeterministic software-intensive systems.

Proposals are sought that advance the state-of-the-art in architecture, system integration, databases, and V&V technologies that will facilitate the deployment of IVHM systems that satisfy safety and performance requirements. The potential impact of the proposed technologies should be linked to improvements in large-scale systems design, deployment, safety and reliability, quality and performance. Specific technology areas where contributions are sought include, but are not limited to the following:

- Design tools/decision support systems that account for the needs of IVHM, including sensing, processing, data collection, onboard data mining, and fault diagnostics and prognostics algorithms.
- A project database that stores and manages test data, failure statistics, fault modes and effects, diagnostic and prognostic models, simulations, and related documentation for all the systems, subsystems, and components. The IVHM database must also allow for seamless integration with a variety of IVHM algorithms,

including data mining, machine learning, and exploratory data analysis tools, in order to enable algorithm development and knowledge discovery using the same database of historical data.

- Advances in compositional verification supported by High Confidence Real-Time Operating Systems (RTOS), Middleware (MW), and/or Virtual Machines (VM) that may be independently designed and verified. Desired system properties include dynamic re-allocation of computational resources; correct and consistent disambiguation of fault syndromes, particularly with respect to segregating faults within the computational infrastructure from faults in other vehicle systems; and graceful evolution of system capabilities, with minimum adverse effects due to parts and software obsolescence.
- New tools, methods, and processes for verification and validation of diagnostic algorithms with non-deterministic behavior. A desired outcome from this research effort would be a demonstration of the relevance of the tools, methods, and processes towards flight software acceptance as applied to a specific non-deterministic algorithm (e.g., neural network, genetic algorithm, fuzzy rule-based inference, etc.).

A1.12 Technologies for Improvement Design and Analysis of Flight Deck Automation

Lead Center: ARC

Participating Center(s): LaRC

Information complexity in flight deck systems is increasing exponentially, and flight deck designers need tools to understand, manage, and estimate the performance and safety characteristics of these systems early in the design process. This is particularly true due to the multi-disciplinary nature of flight deck systems. NASA seeks innovative design methods and tools for representing the complex human-automation interactions that will be part of future adaptive flight deck systems. In addition, NASA seeks tools and methods for estimating, measuring, and/or evaluating the performance of these designs throughout the lifecycle from preliminary design to operational use. Specific areas of interest include the following:

- Computational approaches to support determining appropriate human-automation function allocations with respect to safety and performance;
- Design tools and methods that improve the application of human-centered design principles to the design and certification of mixed human-automated systems;
- Tools and methods for modeling the complex information management systems required for future flight deck systems;
- Methods of data uncertainty estimation during the flight deck system design phase particularly with respect to overall system integrity;
- Design and analysis methods or tools to better predict and assess human and system performance in relevant operational environments;
- Tools to extract information from analog information flows and transform to usable information content.

All proposals should include a means for verification and validation of proposed methods and tools in operationally valid, or end-user, contexts.

A1.13 On-Board Flight Envelope Estimation for Unimpaired and Impaired Aircraft

Lead Center: LaRC

Participating Center(s): ARC, DFRC, GRC

A primary goal of the NASA Aviation Safety Program is to develop technology for safe aircraft operation under different types of anomaly. Anomalies may occur in a variety of forms such as failed actuators, failed sensors, damaged surfaces or abrupt changes in aerodynamics or large changes in aerodynamics during upsets. As part of the Aviation Safety Program research, the Integrated Resilient Aircraft Control (IRAC) Project is investigating advanced control system concepts to provide greater aircraft resiliency to adverse events. The goal of the IRAC project is to arrive at a set of validated multidisciplinary aircraft control design tools and techniques for enabling safe flight in the presence of adverse conditions.

Research on advanced technical approaches (such as direct and indirect adaptive control) has focused on accomplishing stability and safe operability under anomaly. To be able to effectively develop and apply such methods, it is highly desirable, if not essential, to characterize the anomaly and assess the limits of operation of the impaired vehicle. Control application without regard to the vehicle impairment or adverse condition could have significant detrimental consequences. In particular, it would be desirable to characterize and isolate the anomalous condition, and then estimate the level of controllability, limits of maneuverability, and achievable flight envelope of the vehicle. This SBIR topic will develop analytical tools and prototype software to assess the ability of the vehicle to accomplish safe operation under specified anomalous conditions. Specific technology areas where contributions are sought include, but are not limited to, the following:

- Adaptive mathematical framework for control-centric onboard aircraft models that can accommodate real-time changes to subsystem dynamics;
- Real-time system identification capability for updating an onboard vehicle model with adaptive structure to satisfy sub-system constraints under adverse conditions;
- Real-time fault diagnostic and prognostics capability needed in adaptive flight, propulsion, structural control application;
- Real-time control power map identification with inclusion of aircraft sub-system constraints under adverse conditions;
- Real-time dynamic flight envelope identification and prediction capability;
- Metrics and assessment models for safety-of-flight diagnostics and prognostics.

TOPIC: A2 Fundamental Aeronautics

NASA is the Nation's leading government organization for civil aeronautical research. Within NASA's overall strategic plan, Aeronautics has the goal to "Advance knowledge in the fundamental disciplines of aeronautics and develop technologies for safer aircraft and higher capacity airspace systems." To address this goal, NASA's Aeronautics Research Mission Directorate (ARMD) is organized into three separate Programs: Fundamental Aeronautics, Aviation Safety, and Airspace Systems.

The Fundamental Aeronautics Program encompasses cutting-edge research in traditional aeronautical disciplines, as well as emerging fields with promising application to aeronautics. The overall program is long-term in scope as well as focused and integrated across disciplines. It is implemented through NASA's four research centers: the Ames Research Center, in Mountain View, California; the Dryden Flight Research Center in Edwards, California; the Glenn Research Center in Cleveland, Ohio; and the Langley Research Center in Hampton, Virginia.

To achieve these objectives NASA has defined a four-level approach to technology development: (1) conduct foundational research to further our fundamental understanding of the underlying physics and our ability model that physics, (2) leverage the foundational research to develop technologies and analytical tools focused on discipline-based solutions, (3) integrate methods and technologies to develop multi-disciplinary solutions, and (4) solve the aeronautics challenges for a broad range of air vehicles with system-level optimization, assessment and technology integration.

The Fundamental Aeronautics Program will provide for results yielding the following:

- Technology innovation and integrated, multidisciplinary analysis tools;
- Rapid evaluation of new concepts and technology;
- Accelerated application of new technology to a wide array of vehicles;
- Reduced environmental impact and increased public benefit of future aircraft through lower emissions, less noise, higher efficiency, and safer operation.

Structurally, the program is composed of four projects: hypersonic flight, supersonic flight, subsonic fixed-wing aircraft and subsonic rotary-wing aircraft. Each project, in turn, addresses specific discipline, multi-discipline, sub-system and system level technology issues relevant to that flight regime. However, a key aspect of the Fundamental Aeronautics Program is that many technical issues are common across multiple flight regimes and may be best resolved in an integrated coordinated manner. As such, the Fundamental Aeronautics subtopics are organized by discipline, not by flight regime, with a special subtopic for rotary-wing issues.

The full list of Fundamental Aeronautics subtopics are: (1) Materials and Structures for Future Aircraft, (2) Combustion for Aerospace Vehicles, (3) Aero-Acoustics, (4) Aeroelasticity, (5) Aerodynamics, (6) Aerothermodynamics, (7) Flight and Propulsion Control and Dynamics, (8) Experimental Capabilities and Flight Research, (9) Aircraft Systems Analysis, Design and Optimization, and (10) Rotorcraft. Each of the subsequent subtopic sections will describe the scope, key issues and technical content of the subtopic. It will also include the specific areas of interest spanning the four flight regimes. Individual proposals are not restricted to any one specific technical area or any single part of the full flight regime. They may address any or all areas included in a subtopic and may cover any or all parts of the entire flight regime.

A2.01 Materials and Structures for Future Aircraft

Lead Center: GRC

Participating Center(s): ARC, DFRC, LaRC

Advanced materials and structures technologies are needed in all four of the NASA Fundamental Aeronautics Programs research thrusts to enable the design and development of advanced future aircraft. In general, technologies of interest that cover the four research thrusts (Subsonic Fixed Wing, Subsonic Rotary Wing, Supersonic, Hypersonic) include:

- Fundamental materials development and characterization;
- Multifunctional materials and structures development;
- Life prediction and damage modeling;
- Validated structural analysis tools; and
- Computational materials development tools.

More specific information on materials and structures technologies of interest in this program is given below.

Subsonic Fixed Wing Aircraft

Proposals are sought that address specific design and development challenges associated with airframe and propulsion systems and directly support improvements to future subsonic fixed wing aircraft. The potential impact of the proposed technologies should be linked to improvements in aircraft performance indicators such as vehicle weight, noise, lift, drag, lifetime, and emissions. Specific technology areas where contributions are sought include, but are not limited to, the following:

- Advanced materials design concepts and processing development (e.g., multifunctional materials concepts, innovative approaches to damage tolerant lightweight structural materials, lightweight materials concepts to mitigate lightning strike damage, hybrid materials approaches to multifunctionality and/or improved durability and damage tolerance, and high-temperature materials for propulsion system applications);
- Design methods for material and structural concepts (in particular, multifunctional concepts) including variable fidelity methods, uncertainty based design and optimization methods, multi-scale computational methods, and multi-physics modeling and simulation tools;
- Adaptive materials and structures concepts (e.g., environmentally responsive materials and structures, intrinsically load/strain sensing materials and structures, active and/or highly flexible structures, shape memory and self-healing materials, innovative non-parasitic in situ methods to detect damage, impact and structural dynamics);

- Concepts and techniques for advanced multifunctional and/or adaptive material and structures characterization and evaluation (including combinations of thermal and mechanical loading environments);
- Identification, development and verification of degradation and failure mechanisms/criteria, residual strength (and other critical residual properties) and life prediction methods, and damage science design and analysis methods;
- Advanced materials fabrication and processing methods and joining and assembly methods, for ceramics, metals and polymers and/or hybrids of these materials;
- Tribological surface sciences, and mechanical components including oil-free bearings, seals technologies, and mechanical and electrical drive system to distribute engine power from a single engine core to drive multiple fans.

Supersonic Aircraft

Supersonic aircraft require durable and reliable materials and structures to provide continuous operation at speeds in excess of Mach 2. Specific technology areas where contributions are sought include:

- Oxidative fail-safe CMC, CMC structures for liners and airfoils;
- Advanced engine containment prediction tools;
- High temperature shape memory alloys;
- Accelerated life prediction tools;
- Rapid design methods for aircraft structures;
- Novel hot acoustic absorber technologies are also of interest to address the sound problems with supersonic flights.

Hypersonic Vehicle

The ultra-high temperatures and extreme environments experienced by a hypersonic or re-entry vehicle requires advanced materials and structures technologies to enable safe reliable vehicle operation. Specific technology areas where contributions are sought include:

- Physics-based life prediction methods for advanced high-temperature composites that support integrated structural design and analysis methods;
- SQL based software development tools for advanced material design database management;
- Advanced thermal protection systems using innovative structural and material concepts to improve vehicle safety and decrease weight including structurally integrated multifunctional systems;
- Advanced technology for enhanced thermal management, self sensing, and self healing of high-temperature materials;
- Design, development, analysis, and verification of advanced structural joining techniques for high-temperature composite airframe or propulsion structures;
- Computational materials development tools for durable high-temperature materials;
- Development of composite material systems and coatings for significantly improved hypersonic environmental durability for increased mission lifetimes;
- Development of durable structural sensor technology for extreme environments ($> 1800^\circ\text{F}$);
- Innovative structural concepts and materials leading to reliable high-mass planetary entry, decent, and landing systems.

A2.02 Combustion for Aerospace Vehicles

Lead Center: GRC

Participating Center(s): LaRC

Combustion research is critical for the development of future aerospace vehicles. Vehicles for subsonic and supersonic flight regimes will be required to emit extremely low amounts of gaseous and particulate emissions to satisfy increasingly stringent emissions regulations. Hypersonic vehicles require combustion systems capable of

sustaining stable and efficient combustion in very high speed flow fields where fuel/air mixing must be accomplished very rapidly and residence times for combustion are extremely limited. Fundamental combustion research coupled with associated physics based model development of combustion processes will provide the foundation for technology development critical for aerospace vehicles. Combustion for aerospace vehicles typically involves multi-phase, multi-component fuel, turbulent, unsteady, 3D, reacting flows where much of the physics of the processes are not completely understood. CFD codes used for combustion do not currently have the predictive capability that is typically found for non reacting flows. Practical aerospace combustion concepts typically require very rapid mixing of the fuel and air with a minimum pressure loss to achieve complete combustion in the smallest volume. Reducing emissions may require combustor operation where combustion instability can be an issue and active control may be required. Areas of interest where research is solicited, but is not restricted to, includes:

- Development of laser-based diagnostics and novel experimental techniques for measurements in reacting flows;
- Adaptive approaches for chemical kinetics in efficient combustion calculations;
- Two-phase flow simulation models and validation data under subcritical, superheated, and supercritical conditions;
- Development of ultra-sensitive instruments for determining the size-dependent mass of gas-turbine engine particle emissions;
- High frequency actuators (bandwidth ~ 1000 Hz) that can be used to modulate fuel flow at multiple fuel injection locations (with individual Flow Numbers of 3 to 5) with minimal fuel pressure drop for active combustion control;
- High frequency/temperature sensors for active combustion control;
- Combustion instability modeling and validation;
- Novel combustion simulation methodologies;
- Novel low emissions combustion concepts that enhance the state-of-the-art in subsonic combustors;
- Novel low emissions concepts suitable for low emissions operation at supersonic cruise conditions;
- Alternative fuels for aerospace applications;
- Reformer technology and catalyst development for the processing of aviation fuels;
- Combustor and/or combustion physics and mechanisms, enhanced mixing concepts, ignition and flame holding, turbulent flame propagation, vitiated-test media and facility-contamination effects, hydrogen/hydrocarbon-air kinetic mechanisms, multi-phase combustion processes, and engine/propulsion component characterizations;
- Novel combustor concepts that advance/enhance the state-of-the-art in hypersonic propulsion to improve system performance, operability, reliability and reduce cost. Both analytic and/or experimental efforts are encouraged, as well as collaborative efforts that leverage technology from on-going research activities;
- Computational and experimental technologies for the accurate prediction of combined cycle phenomena such as shock trains in isolators, inlet unstart, and thermal choke.

A2.03 Aero-Acoustics

Lead Center: LaRC

Participating Center(s): ARC, GRC

Innovative technologies and methods are necessary for the design and development of efficient, environmentally acceptable airplanes, and advanced aerospace vehicles. In support of the Fundamental Aeronautics Program, improvements in noise prediction, measurement methods and control are needed for subsonic and supersonic vehicles, including fan, jet, turbomachinery, and airframe noise sources. In addition, improvements in prediction and control of noise transmitted through aerospace vehicle structures are needed to reduce noise impact on passengers, crew and launch vehicle payloads. Innovations in the following specific areas are solicited:

- Fundamental and applied computational fluid-dynamics techniques for aero-acoustic analysis, which can be adapted for design codes;

- Prediction of aero-acoustic noise sources including engine and airframe noise sources and sources which arise from significant interactions between airframe and propulsion systems;
- Prediction of sound propagation (including sonic booms) from the aircraft through a complex atmosphere to the ground. This should include interaction between noise sources and the airframe and its flowfield;
- Computational and analytical structural acoustics techniques for aircraft and advanced aerospace vehicle interior noise prediction, particularly for use early in the airframe design process;
- Prediction and control of high-amplitude aero-acoustic loads on advanced aerospace structures and the resulting dynamic response and fatigue;
- Innovative source identification techniques for engine (e.g., fan, jet, combustor, or turbine noise) and airframe (e.g., landing gear, high lift systems) noise sources, including turbulence details related to flow-induced noise sources typical of jets, separated regions, vortices, shear layers, etc.;
- Concepts for active and passive control of aero-acoustic noise sources for conventional and advanced aircraft configurations, including adaptive flow control technologies, smart structures for nozzles and inlets, and noise control technology and methods that are enabled by advanced aircraft configurations, including advanced integrated airframe-propulsion control methodologies;
- Technologies and techniques for active and passive interior noise control for aircraft and advanced aerospace vehicle structures;
- Development of synthesis and auditory display technologies for subjective assessments of aircraft community and interior noise, including sonic boom;
- Development and application of flight procedures for reducing community noise impact while maintaining or enhancing safety, capacity, and fuel efficiency.

A2.04 Aeroelasticity

Lead Center: LaRC

Participating Center(s): ARC, DFRC, GRC

The NASA Fundamental Aeronautics Program has the goal to develop system-level capabilities that will enable the civilian and military designers to develop revolutionary systems, in particular by integrating methods and technologies to develop multi-disciplinary solutions. Aeroelastic behavior of flight vehicles is a particularly challenging facet of that goal.

The program's work on aeroelasticity includes conduct of broad-based research and technology development to obtain a fundamental understanding of aeroelastic and unsteady-aerodynamic phenomena experienced by aerospace vehicles, in subsonic, transonic, supersonic, and hypersonic speed regimes. The program content includes theoretical aeroelasticity, experimental aeroelasticity, and advanced aeroservoelastic concepts. Of interest are aeroelastic, aeroservoelastic, and unsteady aerodynamic analyses at the appropriate level of fidelity for the problem at hand; aeroelastic, aeroservoelastic, and unsteady aerodynamic experiments, to validate methodologies and to gain valuable insights available only through testing; development of computational-fluid-dynamic, computational-aeroelastic, and computational-aeroservoelastic analysis tools that advance the state-of-the-art in aeroelasticity through novel and creative application of aeroelastic knowledge.

The technical discipline of aeroelasticity is a critical ingredient necessary in the design process of a flight vehicle for assuring freedom from catastrophic aeroelastic and aeroservoelastic instabilities. This discipline requires a thorough understanding of the complex interactions between a flexible structure and the unsteady aerodynamic forces acting on the structure, and at times, active systems controlling the flight vehicle. Complex unsteady aerodynamic flow phenomena, particularly at transonic Mach numbers, are also very important because this is the speed regime most critical to encountering aeroelastic instabilities. In addition, aeroelasticity is presently being exploited as a means for improving the capabilities of high performance aircraft through the use of innovative active control systems using both aerodynamic and smart material concepts. Work to develop analytical and experimental methodologies for reliably predicting the effects of aeroelasticity and their impact on aircraft performance, flight dynamics, and safety of flight are valuable. Subjects to be considered include:

- Development of design methodologies that include CFD steady and unsteady aerodynamics, flexible structures, and active control systems.
- Development of methods to predict aeroelastic phenomena and complex steady and unsteady aerodynamic flow phenomena, especially in the transonic speed range. Aeroelastic phenomena of interest include flutter, buffet, buzz, limit cycle oscillations, and gust response. Flow phenomena of interest include viscous effects, vortex flows, separated flows, transonic nonlinearities, and unsteady shock motions.
- Development of efficient methods to generate mathematical models of wind-tunnel models and flight vehicles for performing vibration, aeroelastic, and aeroservoelastic studies.
- Development of unique control concepts that employ smart materials embedded in the structure and/or aerodynamic control surfaces for suppressing aeroelastic instabilities or for improving performance.
- Development of techniques that support simulations, ground testing, wind-tunnel tests, and flight experiments of aeroelastic phenomena.

Flight regimes of interest in the Fundamental Aeronautics Program include subsonic, supersonic, and hypersonic. The goal of the program is to develop validated physics-based multidisciplinary design, analysis, and optimization tools, integrated with technology development. Topics of interest include, but are not limited to, the following:

- Structure-induced noise, flutter and dynamic response prediction, stiffness and strength tailoring, propulsion-specific structures, quasi-static aeroelasticity. Fluid-structure interaction, validation methods, data processing and interpretation methods, probabilistic modeling, rapid modeling analysis development, nonlinear and time-varying methods development, unstructured grid methods, additional propulsion systems-specific methods, dampers, multistage effects, non-synchronous vibrations, coupling effects on blade vibration, probabilistic aerodynamics and aeroelastics. Stiffness and strength tailoring and actively controlled propulsion system core components (e.g., fan and turbine blades, vanes). High fidelity unsteady aeroelastic capability which utilize current and future computer capabilities effectively. Advanced turbomachinery active damping concept. Rapid, high-fidelity probabilistic aeroelastic modeling capability.
- Physics-based models for turbomachinery aeroelasticity related to highly separated flows, shedding, rotating stall, non-synchronous vibrations (NSV). Robust, fast-running, accelerated convergence, reduced-order CFD approaches to turbomachinery aeroelasticity for propulsion applications. Blade vibration measurement systems including closely spaced modes, blade-to-blade variations (mistuning) and system identification. Blade damping systems for metallic and composite blades, including passive and active damping methods.
- Aeroservoelasticity, including alternative control architectures, development and testing of control law concepts. Integrated tool set for fully coupled modeling and simulation of aeroservoelastocity/flight dynamic (ASTE/FD) and propulsion effects. Development of CFD-based methods (reduced-order models) aeroservoelasticity models that can be used to predict and alleviate gust loads, ride quality issues, and flutter issues. Fast and accurate aeroelastic analysis methods to predict fan/compressor flutter vibrations in the presence of the inlet and neighboring blade rows. Vortical effects and nonlinear unsteady aerodynamics influence on the aeroelastic/ASE response of supersonic configurations.
- Lightweight structures and flexible structures under aerodynamic loads, with emphasis on aeroelastic phenomena in hypersonic domain. High temperatures associated with high heating rates, resulting in additional complexities associated with varying thermal expansion and temperature dependent structural coefficients. Acquisition of data to verify analysis tools with these complexities.

A2.05 Aerodynamics

Lead Center: LaRC

Participating Center(s): ARC, DFRC, GRC

The challenge of flight has at its foundation the understanding, prediction, and control of fluid flow around complex geometries – aerodynamics. Aerodynamic prediction is critical throughout the flight envelope for subsonic, supersonic, and hypersonic vehicles – driving outer mold line definition, providing loads to other disciplines, and enabling environmental impact assessments in areas such as emissions, noise, and aircraft spacing.

In turn, high confidence prediction enables high confidence development and assessment of innovative aerodynamic concepts. This subtopic seeks innovative physics-based models and novel aerodynamic concepts, with an emphasis on flow control, applicable in part or over the entire speed regime from subsonic through hypersonic flight.

All vehicle classes will experience subsonic flight conditions. The most fundamental issue is the prediction of flow separation onset and progression on smooth, curved surfaces, and the control of separation. Supersonic and hypersonic vehicles will experience supersonic flight conditions. Fundamental to this flight regime is the sonic boom, which to date has been a barrier issue for a viable civil vehicle. Addressing boom alone is not a sufficient mission enabler however, as low drag is a prerequisite for an economically viable vehicle, whether only passing through the supersonic regime, or cruising there. Atmospheric entry vehicles and space access vehicles will experience hypersonic flight conditions. Reentry capsules such as the new Crew Exploration Vehicle deploy multiple parachutes during descent and landing. Predicting the physics of unsteady flows in supersonic and subsonic speeds is important for the design of these deceleration systems. The gas-dynamic performance of decelerators for vehicles entering the atmospheres of planets in the solar system is not well understood. Reusable hypersonic vehicles will be designed such that the lower body can be used as an integrated propulsion system in cruise condition. Their performance is likely to suffer in off-design conditions, particularly acutely at transonic speeds. Advanced flow control technologies are needed to alleviate the problem.

This solicitation seeks proposals to develop and validate:

- Turbulence models capturing the physics of separation onset at Reynolds numbers relevant to flight, where relevant to flight is dependent on a targeted vehicle class and mission profile;
- Boundary-layer transition models suitable for direct integration with state-of-the-art flow solvers;
- Active flow control concepts targeted at separation control and/or viscous drag reduction with an emphasis on the development of novel, practical, lightweight, low-energy actuators;
- Innovative aerodynamic concepts targeted at vehicle efficiency or control;
- Physics-based models for simultaneous low boom/low drag prediction and design;
- Aerodynamic concepts enabling simultaneous low boom and low drag objectives;
- Innovative methods to validate both flow models and aerodynamic concepts with an emphasis on aft-shock effects which are hindered by conventional wind tunnel model mounting approaches;
- Accurate aerodynamic analysis and multidisciplinary design tools for multi-body flexible structures in the atmospheres of planets and moons including the Earth, Mars, and Titan;
- Advanced flow control technologies to alleviate off-design performance penalties for reusable hypersonic vehicles.

A2.06 Aerothermodynamics

Lead Center: LaRC

Participating Center(s): ARC, DFRC, GRC

Development of accurate tools to predict aerothermal environments and their effects on space vehicles is critically important to achieving the goals of current NASA missions, and to enable the development of advanced spacecraft for future missions by reducing uncertainties during design and development.

Radiative heating was not critical for the Space Shuttle Orbiter, due to its relatively low re-entry velocity, or for entry probes such as Genesis and Stardust, due to their small size. However, the large size and high reentry velocity of the Crew Exploration Vehicle make it imperative to study shock layer radiation phenomena. The conditions encountered in proposed aerocapture missions to Titan, Neptune, and Venus also require study of radiative heat transfer and non-equilibrium thermodynamic and transport properties; these in turn require understanding of the internal structure and dynamics of the constituent gases.

Transition and turbulence effects are particularly complex in hypersonic flows, where special problems are posed by shocks, real gas effects, non-smooth body surfaces with complex and possibly time-dependent roughness distribu-

tion, nose bluntness, ablation, surface catalyticity, separation, and the unknown free-stream disturbance environment.

In particular, at the heating rates encountered during hypersonic re-entry, surface ablation products blowing into the boundary layer introduce new interactions, for example chemical reactions and radiation absorption, that strongly affect surface heating rates and integrated heat loads.

Aerothermal analyses and management are also relevant to the design of advanced propulsion systems. A better fundamental understanding coupled with the ability to accurately simulate the aerothermodynamics of highly loaded turbomachinery is needed, along with innovative ideas such as flow control for increasing fan and compressor work factors without sacrificing efficiency and operability. Improvements in turbine cooling effectiveness, secondary flow management, and component matching are also important for high-pressure ratio engines.

Proposals suggesting innovative approaches to any of these issues are of interest. Specific research areas of interest include:

- Computational analysis methods for radiation and radiation transport in the shock layer surrounding planetary entry vehicles;
- Advanced physics based thermal and chemical non-equilibrium models for thermodynamics, transport, and radiation;
- Studies of the interactions of gases in the shock layer with ablating materials from the vehicle thermal protection system;
- Experimental methods and diagnostics to measure the characteristics of hypersonic flow fields, either in flight or in ground-based facilities;
- Software tools coupling radiation, non-equilibrium chemistry, Reynolds-averaged Navier-Stokes, and large eddy simulation codes to enable the design, development, and validation of mission configurations for entry into planetary atmospheres;
- Computational modeling to improve the accuracy of flow simulations for highly loaded turbomachinery;
- Innovative flow control methods, such as aspiration and bleed, to reduce the losses associated with highly loaded turbomachinery;
- Development of active flow control devices such as Dielectric Barrier Discharge plasma actuators for application to turbomachinery flow control.

A2.07 Flight and Propulsion Control and Dynamics

Lead Center: GRC

Participating Center(s): ARC, DFRC, LaRC

Enabling advanced aircraft configurations for subsonic, supersonic and hypersonic flight, high performance "Intelligent Engines" will require advancement in the state-of-the art dynamic modeling and flight/propulsion control. Control methods need to be developed and validated for "optimal" and reliable performance of complex, unsteady, and nonlinear systems with significant modeling uncertainties while ensuring operational flexibility, enabling unique concepts of operations, lower emissions and noise, and safe operation over a wide operating envelope. New dynamic modeling and simulation techniques need to be developed to investigate dynamic performance issues and support development of control strategies for innovative aircraft configurations with enhanced control effectors and propulsion systems. Proposals for novel multidisciplinary nonlinear dynamic systems modeling, identification, and simulation for control objectives are encouraged. Control objectives include feasible and realistic boundary layer and laminar flow control, aeroelastic maneuver performance, and load control including smart actuation and active aerostructural concepts, active control of propulsion system components, and drag minimization for high efficiency and range performance. Technology needs specific to different flight regimes are summarized in the following:

Subsonic Fixed Wing Aircraft

Technologies of interest, with application to both flight and propulsion control, include: methods for development of dynamic models and simulations of the integrated component/control system being considered; defining actuation requirements for novel control approaches and developing prototype actuators; developing and applying innovative control methods and validating them through laboratory test and vehicle simulations as appropriate.

Supersonic Flight

Technologies of interest include: methods for developing integrated dynamic models and simulation including flexibility effects and suitable for control design; novel control design methods for integrated aero-servo-elastic-propulsive control leading to acceptable flying qualities over the operating flight envelope; novel, and feasible, takeoff and approach to landing procedures to accommodate the visibility challenges due to long forebodies; integrated inlet/engine control to ensure safe (no inlet unstart) and efficient operation.

Hypersonic Flight

Technologies of interest include: system dynamic models incorporating the essential coupled dynamic elements with varying fidelity for control design, analysis and evaluation; methods for characterizing uncertainty in the dynamic models to enable control robustness evaluation; hierarchical GNC (Guidance, Navigation and Control) architectures to enable trajectory shaping and control over a wide operating envelope with integrated flight/propulsion control; adaptive and robust control methods that can handle large modeling uncertainties; simulation test beds for evaluating hypersonic concept vehicle control under various types of uncertainty, system wide coupling and associated model misspecification.

A2.08 Experimental Capabilities and Flight Research

Lead Center: DFRC

Participating Center(s): ARC, LaRC

This subtopic is intended to solicit technologies for the following:

Modeling, identification, simulation, and control of aerospace vehicles in-flight research, flight sensors, sensor arrays and airborne instruments for flight research, and advanced aerospace flight concepts.

Safer and more efficient design of advanced aerospace vehicles requires advancement in current predictive design and analysis tools. The goal is to develop more efficient software tools for predicting and understanding the response of an airframe under the simultaneous influences of structural dynamics, thermal dynamics, steady and unsteady aerodynamics, and the control system. The benefit of this effort will ultimately be an increased understanding of the complex interactions between the vehicle dynamics subsystems with an emphasis on flight research validation methods for control-oriented applications. Proposals for novel multidisciplinary nonlinear dynamic systems modeling, identification, and simulation for control objectives are encouraged. Control objectives include feasible and realistic boundary layer and laminar flow control, aeroelastic maneuver performance and load control (including smart actuation and active aerostructural concepts), autonomous health monitoring for stability and performance, and drag minimization for high efficiency and range performance. Methodologies should pertain to any of a variety of types of vehicles ranging from low-speed, high-altitude, long-endurance to hypersonic and access-to-space aerospace vehicles.

Real-time measurement techniques are needed to acquire aerodynamic, structural, control, and propulsion system performance characteristics in-flight and to safely expand the flight envelope of aerospace vehicles. The scope of this subtopic is the development of sensors, sensor systems, sensor arrays, or instrumentation systems for improving the state-of-the-art in aircraft ground or flight research. This includes the development of sensors to enhance aircraft safety by determining atmospheric conditions. The goals are to improve the effectiveness of flight research by simplifying and minimizing sensor installation, measuring new parameters, improving the quality of measurements, minimizing the disturbance to the measured parameter from the sensor presence, deriving new information from conventional techniques, or combining sensor suites with embedded processing to add value to output information.

This topic solicits proposals for improving airborne sensors and sensor instrumentation systems in all flight regimes – particularly transonic and hypersonic. These sensors and systems are required to have fast response, low volume, minimal intrusion, and high accuracy and reliability.

This subtopic further solicits innovative flight test experiments that demonstrate breakthrough vehicle or system concepts, technologies, and operations in the real flight environment. The emphasis of this subtopic is the feasibility, development, and maturation of advanced flight research experiments that demonstrate advanced or revolutionary methodologies, technologies, and concepts, particularly related to separation characterization in subsonic flight, shockwave propagation in supersonic flight, and small scale technology development in hypersonic flight. It seeks advanced flight techniques, operations, and experiments that promise significant leaps in vehicle performance, operation, safety, cost, and capability; and that require a demonstration in an actual-flight environment to fully characterize or validate advances.

A2.09 Aircraft Systems Analysis, Design and Optimization

Lead Center: ARC

One of the approaches to achieve the NASA Fundamental Aeronautics Program goals is to solve the aeronautics challenges for a broad range of air vehicles with system-level optimization, assessment and technology integration. The needs to meet this approach can be defined by four general themes:

- (1) Design Environment Development;
- (2) Variable Fidelity, Physics-Based Design/Analysis Tools;
- (3) Technology Assessment and Integration; and
- (4) Evaluation of Advanced Concepts.

Current interdisciplinary design/analysis involves a multitude of tools not necessarily developed to work together, hindering their application to complete system design/analysis studies. Multi-fidelity, multi-disciplinary optimization frameworks, such as Numerical Propulsion System Simulation (NPSS), have been developed by NASA but have limited capabilities to simulate complete vehicle systems. Solicited topics are aligned with these four themes that will support this NASA research area.

(1) Design Environment Development

Technology development is needed to provide complex simulation and modeling capabilities where the computer science details are transparent to the engineer. A framework environment is needed to provide a seamless integration environment where the engineer need not be concerned with where or how particular codes within the system level simulation will be run. Interfaces and utilities to define, setup, verify, determine the appropriate resources, and launch the system simulation are also needed.

Research challenges include the engineering details needed to numerically zoom (i.e., numerical analysis at various levels of detail) between multi-fidelity components of the same discipline, as well as, multi-discipline components of the same fidelity. A major computer science challenge is developing boundary objects that will be reused in a wide variety of simulations.

Proposals will be considered that enable coupling differing disciplines, numerical zooming within a single discipline, deploying large simulations, and assembling and controlling secure or non-secure simulations.

(2) Variable Fidelity, Physics-Based Design/Analysis Tools

An integrated design process combines high-fidelity computational analyses from several disciplines with advanced numerical design procedures to simultaneously perform detailed Outer Mold Line (OML) shape optimization, structural sizing, active load alleviation control, multi-speed performance (e.g., low takeoff and landing speeds, but efficient transonic cruise), and/or other detailed-design tasks. Current practice still widely uses sequential, single-discipline optimization, at best coupling low-fidelity modeling of other relevant disciplines during the detailed

design phase. Substantial performance improvements will be realized by developing closely integrated design procedures coupled with highest-fidelity analyses for use during detailed-design. Design procedures must enable rapid determination of sensitivities (gradients) of a design objective with respect to all design variables and constraints, choose search directions through design space without violating constraints, and make appropriate changes to the vehicle shape (ideally both external OML shape and internal structural element size). Solicitations are for integrated design optimization tools that find combinations of design variables from more than one discipline and can vary synergistically to produce superior performance compared to the results of sequential, single-discipline optimization or repeated cut-and-try analysis.

(3) Technology Assessment and Integration

Improved analysis capability of integrated airframe and propulsion systems would allow more efficient designs to be created that would maximize efficiency and performance while minimizing both noise and emissions. Improved integrated system modeling should allow designers to consider trade offs between various design and operating parameters to determine the optimum design for various classes of subsonic fixed wing aircraft ranging from personal aircraft to large transports. The modeling would also be beneficial if it had enough fidelity to enable it to analyze both conventional and unconventional systems. Current analysis tools capable of analyzing integrated systems are based on simplified physical and semi-empirical models that are not fully capable of analyzing aircraft and propulsion system parameters that would be required for new or unconventional systems.

Analyses tools are solicited that are capable of analyzing new and unconventional aircraft and propulsion integrated systems. These include: (1) New combustor designs, alternate fuel operation, and the ability to estimate all emissions, and (2) Noise source models (e.g., fan, jet, turbine, core and airframe components). Analyses tools that are scalable, especially to small aircraft, are desired.

(4) Evaluation of Advanced Concepts

Conceptual design and analysis of unconventional vehicle concepts and technologies is needed for technology portfolio investment planning, development of advanced concepts to provide technology pull, and independent technical assessment of new concepts. This capability will enable "virtual expeditions through the design space" for multi-mission trade studies and optimization. This will require an integrated variable fidelity concept design system. The aerospace flight vehicle conceptual design phase is, in contrast to the succeeding preliminary and detail design phases, the most important step in the product development sequence, because of its predefining function. However, the conceptual design phase is the least well understood part of the entire flight vehicle design process, owing to its high level of abstraction and associated risk, its multidisciplinary design complexity, its permanent shortage of available design information, and its chronic time pressure to find solutions. Currently, the important primary aerospace vehicle design decisions at the conceptual design level (e.g., overall configuration selection) are still made using extremely simple analyses and heuristics. An integrated, variable fidelity system would have large benefits. Higher fidelity tools enabling unconventional configurations to be addressed in the conceptual design process are solicited.

A2.10 Rotorcraft

Lead Center: ARC

Participating Center(s): DFRC, GRC, LaRC

The challenge of the Subsonic Rotary Wing thrust of the NASA Fundamental Aeronautics Program is to develop validated physics-based multidisciplinary design-analysis-optimization tools for rotorcraft, integrated with technology development, enabling rotorcraft with advanced capabilities to fly as designed for any mission. Meeting this challenge will require innovative technologies and methods, with an emphasis on integrated, multidisciplinary, first-principle computational tools specifically applicable to the unique problems of rotary wing aircraft. Examples of technologies of interest are as follows:

Propulsion/Aeromechanics Integration: Encompassing dynamic and aerodynamic integration of rotorcraft including advanced configurations such as rotors operating at different speeds in hover and cruise (variable speed

transmission/engine), high speed rotorcraft, and heavy lift rotorcraft. Possibly including on-blade active rotor control, or flow control for hub, blades, or engine inlet.

Super-Integrated Vehicle Management System: Integrated, broadband rotorcraft control system incorporating flight control system, engine control, airframe/drive train/rotor load control, active rotor control of vibration and noise, vehicle health management, and guidance for low noise operation. Including control design methodology development.

Integrated Rotorcraft Design: Advanced light weight structural and propulsion concepts with integrated functionality to achieve reduced interior noise, vibration, and maintenance/inspection requirements. This includes gear vibration transmission through the gear/shaft/bearing/structural system and structural bonding techniques that increase fatigue life while allowing for post-buckling load capability for thin sheet sandwich construction.

Integrated Rotorcraft Design: Interactional aeroacoustics, encompassing dynamic, aerodynamic, aeroacoustic interactions of one or more main rotors, tail rotors, airframe, wings, empennage, engine, drive system. Possibly including active flow control for hub or fuselage drag reduction, or active rotor control.

Integrated Experimental Systems: Unified experimental techniques, integrating methods to enable efficient, multi-parameter, simultaneous measurements for characterizing rotorcraft behavior. Including unsteady pressure, blade deformation and position, flow field measurements, measurements that track wake vortex strength and position.

Examples of rotorcraft unique aspects of the aeronautics disciplines are as follows:

Materials and Structures: Advanced light-weight structural concepts exploiting material hybridization, selective reinforcement and material and geometric tailoring to achieve increased performance and durability while reducing weight, cabin noise and manufacturing cost, with emphasis on structural concepts for high oscillatory load environment of rotorcraft structures. Characterization of composite material properties under impact loading and models of impact damage. Characterization and simulation of fatigue damage in composite materials, crack/delamination growth models for spectrum loading, and high cycle fatigue thresholds, in particular for unique design and operational aspects of structures for rotor blades.

Propulsion: Research is solicited to improve rotorcraft propulsion and the ability to design and predict its performance in the following general areas:

Propulsion system (drives, engines, controls) technologies to enable variable speed rotor systems. Specific focus areas may include: enabling concepts and techniques for wide operability propulsion systems and variable speed drive systems/transmissions. Engine compressor stall control, engine flow control concepts for wide operability, cooling and secondary flow concepts for wide operability and integrated controls and modeling to support wide operability are sought. In addition, concepts for controlling and enabling variable speed drives, lightweight technologies and concepts and performance prediction capabilities for variable speed systems are sought.

Gearbox optimized propulsion systems in which both the engine and drive systems work together for improved performance. Specific concepts may include: dedicated gearbox lube systems coupled with oil-free engines; technologies to predict drive system windage losses and gear surface fatigue modeling; technologies to achieve lightweight propulsion such as composite propulsion structures and components; high power density electromechanical systems and efficient high power density propulsion concepts such as highly loaded components; engine flow control concepts; high temperature components; nano-composite components and other relevant propulsion system technologies. Propulsion system concepts must be focused on power range and operating environment required for rotorcraft.

Acoustics: Interior and exterior rotorcraft noise generation, propagation and control. Topics of interest include, but are not limited to, external noise prediction methods for manned and unmanned rotorcraft, improved acoustic

propagation models, psychoacoustics analysis of rotorcraft noise, interior noise prediction methods and active/passive noise control applications for rotorcraft including engine and transmission noise reduction, advanced acoustic measurement systems for flight and wind tunnel applications, acoustic data acquisition/reduction/analysis, rotor noise reduction techniques, noise abatement flight operations. Rotor noise, including broadband, harmonic, blade-vortex interaction, high-speed impulsive; alternate tail rotor and auxiliary power concepts, rotor/tail rotor, and rotor/rotor interactional noise. Frequency range includes not only audible range, but very low frequency rotational noise (blade-passage frequency below 20 Hz) as well. Optimized active/passive concepts and noise tailoring, including rotorcraft designs that are inherently designed for lower noise as a constraint.

Aeroelasticity and Dynamics: Advanced rotorcraft hub and blade concepts for improved stability and loads capability. High-fidelity, first-principles approaches to rotorcraft stability calculation, including finite state and reduced order aerodynamic modeling approaches. Vibration reduction methods and techniques, including utilization of on-blade active control, individual blade control, or nonrotating frame active and passive means.

Aerodynamics: Airloading of rotor blades, including unsteady, compressible, viscous flows and blade-vortex interaction; stall and dynamic stall; rotor wake formation, propagation, dissipation, and interactions; rotor wake geometry. Aerodynamics of rotorcraft airframes, including rotor hubs, airframe drag, rotor-airframe-wing interactions of tiltrotors and compound configurations. Performance, including force and power of isolated rotors and of rotorcraft systems with influence of interactions between components. Behavior of rotors and rotorcraft in maneuvers and high speed flight, and advanced configurations heavy lift and slowed-rotor rotorcraft. Advanced computational fluid dynamics methods, including turbulence behavior unique to rotary wings.

Flight Dynamics and Controls: Rotorcraft flight dynamics and handling qualities. Including hover and low-speed guidance and situational awareness augmentation; autorotation control and guidance; variable-speed rotor control; low-cost low-speed air data system; improved simulation of low-visibility conditions (e.g., brownout, whiteout); control concepts for redundant effectors; affordable tactile cueing for retrofit into civil rotorcraft; study of redundancy/reliability required to achieve low-cost single-pilot IFR certification; continuously-variable transmission (current technology is focused on discrete-speed, transmission, but continuously-variable is highly desirable; flight control mitigation of structure/power train/rotor frequency overlap with primary control frequencies; proprotor control to provide helicopter-like response in heave for tilt rotor helicopter-mode operations.

Experimental Capabilities: Instrumentation and techniques for assessing scale rotor blade boundary layer state (e.g., laminar, transition, turbulent) and/or profile in simulated hover and forward flight conditions, measurement systems for large-field rotor wake assessment, instrumentation and techniques to measure dynamic boundary layer transition on the fixed system (fuselage) during scale model wind tunnel testing, multi-parameter temporally-resolved flow diagnostic techniques for wind tunnel testing of model-scale rotors and engine acoustic testing, fast time response pressure sensitive paints, alternatives to conventional slip rings (e.g., optical slip rings, reliable telemetry methods), high temperature and pressure sensors for engine applications, high temperature proximity sensors for turbine blade clearance measurements, sensors and/or methods for high accuracy rotorcraft velocity measurement in very low speed forward flight (< 30 knots), instrumentation and methods to measure the rotor tip path plane angle of attack, lateral and longitude flapping, and shaft angle in flight. Low-speed (0-30 knots) velocity measurement for flight test vehicles that tracks, measures, and displays vehicle ground speed while the aircraft travels in any direction, including backwards and sideways flight. Non-contacting cockpit measurement of collective and cyclic control input.

TOPIC: A3 Airspace Systems

NASA's Airspace Systems (AS) Program is investing in the development of innovative concepts and technologies to support the development of the Next Generation Air Transportation System (NGATS). NASA is working to develop, validate and transfer advanced concepts, technologies, and procedures through partnership with the Federal Aviation Administration (FAA) and other government agencies represented in the Joint Planning and Development Office (JPDO), and in cooperation with the U.S. aeronautics industry and academia. As such, the AS Program will develop and demonstrate future concepts, capabilities, and technologies that will enable major increases in air traffic management effectiveness, flexibility, and efficiency, while maintaining safety, to meet capacity and mobility requirements of the NGATS. The AS Program integrates the two projects, NGATS ATM Airspace and NGATS ATM Airportal, to directly address the fundamental research needs of NGATS vision in partnership with the member agencies of the JPDO. The NGATS ATM Airspace Project develops and explores fundamental concepts and integrated solutions that address the optimal allocation of ground and air automation technologies necessary for NGATS. The Project will focus NASA's technical expertise and world-class facilities to address the question of where, when, how and the extent to which automation can be applied to moving aircraft safely and efficiently through the NAS. The NGATS ATM Airportal Project develops and validates algorithms, concepts, and technologies to increase throughput of the runway complex and achieve high efficiency in the use of airportal resources such as gates, taxiways, runways, and final approach airspace. NASA research in this project will lead to development of solutions that safely integrate surface and terminal area air traffic optimization tools and systems with 4-D trajectory operations. Ultimately, the roles and responsibilities of humans and automation influence in the ATM will be addressed by both projects. Key objectives of NASA's AS Program are to:

- Improve mobility, capacity, efficiency and access of the airspace system;
- Improve collaboration, predictability, and flexibility for the airspace users;
- Enable accurate modeling and simulation of air transportation systems;
- Accommodate operations of all classes of aircraft; and
- Maintain system safety and environmental protection.

A3.01 Next Generation Air Transportation System – Airspace

Lead Center: ARC

Participating Center(s): DFRC, LaRC

The primary goal of the NASA Next Generation Air Transportation System (NGATS) Airspace effort is to develop integrated solutions for a safe, efficient, and high-capacity airspace system. Of particular interest is the development of core capabilities, including: (1) Performance-based services, which will enable higher levels of performance in proportion with user equipage level; (2) Trajectory-based operations, which is the basis for changing the way traffic is managed in the system to achieve increases in capacity and efficiency; (3) Super-density operations, which maximizes the use of limited runways at the busiest airports; (4) Weather assimilated into decision making; (5) Equivalent visual operations, which will allow the system to maintain visual flight rule capacities in instrument flight rule conditions. These core capabilities are required to enable key NGATS-Airspace functions such as Dynamic Airspace Configuration, Traffic Flow Management, Separation Assurance, and the overarching Evaluator that integrates these air traffic management (ATM) functions over multiple planning intervals.

In order to meet these challenges, innovative and technically feasible approaches are sought to advance technologies in research areas relevant to NASA's NGATS-Airspace effort. The general areas of primary interest are Dynamic Airspace Configuration, Traffic Flow Management, and Separation Assurance. Specific research topics for NGATS-Airspace include:

- 4D trajectory based operations;
- Air/ground automation concepts and technologies;
- Airspace modeling and simulation techniques;

- Automated separation assurance;
- Collaborative decision making techniques involving multiple agents;
- Equivalent visual operations;
- "Evaluator" integrated solutions of ATM functions over multiple planning intervals;
- Human factors for ATM;
- Locus of control across humans and automation;
- Multi-aircraft flow and airspace optimization;
- Performance based services;
- Safety analysis methods;
- Spacing and sequencing management;
- Super density terminal area operations;
- Traffic complexity monitoring and prediction;
- Traffic flow management concepts/techniques;
- Trajectory design and conformance;
- Weather assimilated into ATM decision-making.

A3.02 Next Generation Air Transportation – Airportal

Lead Center: LaRC

Participating Center(s): ARC

The Airportal research of NASA's Airspace Systems (AS) Program focuses on key capabilities that will increase throughput of the airportal environment and achieve the highest possible efficiencies in the use of airportal resources such as runways, taxiways, terminal airspace, and gates. The primary capabilities addressed are: (1) Super-density operations, (2) Equivalent visual operations, and (3) Aircraft trajectory-based operations.

Super-density operations will include conflict detection and resolution for closely spaced approaches, reduced aircraft wake vortex separation standards, and less restrictive runway/taxiway operations. Additional mechanisms to increase the feasible density of operations will also be considered.

Equivalent visual operations will provide aircraft with the critical information needed to maintain safe distances from other aircraft during non-visual conditions, including a capability to operate at "visual performance" levels on the airport surface during low-visibility conditions. Advances in equivalent visual operations for the airportal air navigation service provider are also of interest.

Aircraft trajectory-based operations will utilize 4D trajectories (aircraft path from block-to-block, including path along the ground, and also including the time component) as the basis for planning and executing system operations.

NASA's AS Program has identified the following Next Generation Air Transportation System (NGATS) Airportal research activities: Optimization of surface traffic; Dynamic airport configuration management (including the optimal balancing of airportal resources for arrival, departure, and surface operations); Predictive models to enable avoidance of wake vortex hazards; New procedures for performing safe, closely spaced and converging approaches at closer distances than are currently allowed; and modeling, simulation, and experimental validation research focused on single and multiple regional airports; and other innovative opportunities for transformational improvements in airportal/metroplex throughput. Inherent within the AS Program approach is the integration of airborne solutions within the overall surface management optimization scheme.

In order to meet these challenges, innovative and technically feasible approaches are sought to advance technologies in research areas relevant to NASA's NGATS-Airportal effort. The general areas of interest are surface management optimization, converging and parallel runway operations, safety risk assessment methodologies, and wake vortex solutions. Specific research topics for NGATS-Airportal include:

- Airborne spacing algorithms and wake avoidance procedures for airports with closely spaced runways;
- Automated separation assurance and runway/taxiway incursion prevention algorithms;
- Automatic taxi clearance and aircraft control technologies;
- Characterization of wake vortex and atmospheric hazards to flight in terms of aircraft and flight crew responses;
- Collaborative decision making between airlines and air traffic control tower personnel for optimized surface operations, including push back scheduling and management of airport surface assets;
- Dynamic airport configuration management;
- High resolution CFD and real-time modeling of wake vortex strength and location;
- Human/automation interaction and performance standards;
- Integration of decision-support tools across different airspace domains;
- Methodologies and/or algorithms to estimate environmental impacts of increased traffic on the surface and in the terminal airspace, and to reduce the environmental impacts under increased levels of traffic;
- Methodologies to estimate and assess the risk of transformational airspace operations for which little historical risk data may exist and for which operations may be constrained by the potential for extremely rare events;
- Modeling and simulation of single airport operations for validating taxi planning concepts;
- Optimized 4D trajectory generation and conformance monitoring for surface and terminal airspace operations, including departure and arrival planning for individual flights;
- Scheduling algorithm for aircraft deicing and integration with a surface traffic decision-support tool;
- Surface and terminal airspace traffic modeling and simulation of multiple regional airports;
- Virtual towers;
- Other technologies and approaches to achieving 2-3X improvement in the throughput of airports/metroplexes.

TOPIC: A4 Aeronautics Test Technologies

NASA has implemented the Aeronautics Test Program (ATP) within its Aeronautics Research Mission Directorate (ARMD). The purpose of the ATP is to ensure the long term availability and health of NASA's major wind tunnels/ground test facilities and flight operations/test infrastructure that support NASA, DoD and U.S. industry research and development (R&D) and test and evaluation (T&E) needs. Furthermore, ATP provides rate stability to the aforementioned user community.

The ATP facilities are located at the NASA Research Centers, including at Ames Research Center, Dryden Flight Research Center, Glenn Research Center and Langley Research Center. Classes of facilities within the ATP include low speed wind tunnels, transonic wind tunnels, supersonic wind tunnels, hypersonic wind tunnels, hypersonic propulsion integration test facilities, air-breathing engine test facilities, the Western Aeronautical Test Range (WATR), support aircraft, test bed aircraft, and the simulation and loads laboratories.

A key component of ensuring a test facility's long term viability is to implement and continually improve on the efficiency and effectiveness of that facility's operations. To operate a facility in this manner requires the use of state-of-the-art test technologies and test techniques, creative facility performance capability enhancements, and novel means of acquiring test data.

NASA is soliciting proposals in the areas of instrumentation, test measurement technology, test techniques and facility development that apply to the ATP facilities to help in achieving the ATP goals of sustaining and improving our test capabilities. Proposals that describe products or processes that are transportable across multiple facility classes are of special interest. The proposals will also be assessed for their ability to develop products that can be implemented across government-owned, industry and academic institution test facilities.

A4.01 Test Measurement Technology**Lead Center: GRC****Participating Center(s): ARC, LaRC**

NASA is concerned with operating its ground test facilities with new and innovative methods for test measurement technology and with continually improving on the efficiency and effectiveness of operation of its ground test facilities. NASA's aeronautics and space research and development pushes the limits of technology, including the ground test facilities that are used to confirm theory and provide validation and verification of new technologies. By using state-of-the-art test measurement technologies, novel means of acquiring test data, test techniques and creative facility performance capability enhancements, NASA will be able to operate its facilities more efficiently and effectively and also be able to meet the challenges presented by NASA's cutting edge research and development programs. Therefore, NASA is seeking highly innovative and commercially viable test measurement technologies, test techniques, and facility performance technologies that would increase efficiency or overcome research and development technology barriers for ground test facilities.

The first emphasis for this subtopic is in the area of test measurement technology. Examples of the types of technology solutions sought, but not limited to, are: data acquisition system improvements; skin friction experimental measurement techniques; improved flow transition detection methodologies; new or novel, non-intrusive measurement technologies for pressure, temperature, and force measurements; and force measurement (balance) technology development. Solutions are also sought with regards to the instrumentation used to characterize ground test facility performance. This could be in the area of aerodynamics performance characterization (flow quality, turbulence intensity, etc.) or, for example, in the case of specialty facilities, the measurement of high ice water content conditions in an icing wind tunnel.

The second emphasis for this subtopic is in the area of test techniques and facility performance technologies. Examples of the types of technology solutions that are being sought, but not limited to, are expanded operating envelope, enhanced or rapid characterization of facility performance, improved dynamic (forced oscillation) test capability at transonic and supersonic speeds, and improved flow transition detection methodologies.

Proposals that lead to products or processes that are applicable specifically to the ATP facilities and across multiple facility classes are especially important. The proposals will also be assessed for their ability to develop products that can be used in government-owned, industry and academic institution aerospace ground test facilities.

A4.02 Test Techniques and Facility Development**Lead Center: GRC****Participating Center(s): ARC, DFRC, LaRC**

NASA is concerned with operating its flight test aircraft with new and innovative flight test measurement methods. By using state-of-the-art test measurement technologies and novel means of acquiring test data, NASA will be able to operate its flight test aircraft and test-beds more effectively and also meet the challenges presented by NASA's cutting edge research and development programs. NASA's missions and programs push the limits of technology which places greater demands on its flight test-beds. These flight test-beds are often used in conjunction with ground test facilities to confirm theory and provide verification and validation of new technologies. Therefore, NASA is seeking highly innovative and commercially viable test measurement technologies that would increase efficiency or overcome test limitations for flight research.

Flight test vehicles operate over a wide range of environmental conditions including among others: variable ambient pressure (the result of altitude changes), variable temperature (the result of altitude and airspeed changes), and vibration and acceleration (the result of engine vibration and dynamic flight maneuvers). In addition, weight, volume, and power requirements are at a premium because of limited space, power, and weight carrying capacity.

The first emphasis for this subtopic is in the area of flight test techniques. Factors in flight test techniques include, but are not limited to: methods for achieving accurate and repeatable flight test conditions (e.g., altitude, airspeed, flow quality, or turbulence intensity). Reconfigurable systems, alternative power sources, and novel methods for onboard data processing, storage, real-time access and RF data transmission are of interest. Technologies are also being requested to aid in multi-aircraft co-operative test techniques to enable chase aircraft to probe flow fields and visualize shock patterns around target aircraft.

The second emphasis for this subtopic is in the area of flight test measurement technology. Examples of the types of technology solutions sought are: data acquisition system improvements and miniaturization, skin friction experimental measurement techniques, and improved flow transition measurement techniques. Special emphasis is placed on new or novel, non-intrusive measurement technologies for pressure, temperature, and force measurements, and force measurement (balance) technology. Also, techniques that could facilitate shortening test measurement installation and setup times would be of interest such as methodologies that minimize the wiring infrastructure and other aircraft installation requirements would be applicable. Another area of interest is in test data conversions to different domains or data compression to reduce the volume of information that must be transmitted over existing telemetry links. It should be understood that all of these technologies must be capable of operating under extremes of temperature, pressure, and vibration typical in the flight environment.

Proposals that lead to products or processes that are applicable specifically to the ATP facilities and across multiple flight test-beds are especially important. Test-beds can be broadly categorized throughout a range of flight regimes encompassing hypersonic (e.g., orbital, sub-orbital, Phoenix missile), supersonic (e.g., F-15, F-16, F-18), and subsonic Fixed-Wing aircraft (e.g., ER2, G3, Predator-B). All platforms have a variety of different Mach/Altitude flight envelopes.

9.1.2 EXPLORATION SYSTEMS

The Exploration Systems Mission Directorate aims to develop a constellation of new capabilities, supporting technologies, and foundational research that enables sustained and affordable human and robotic exploration. In order to support this complex mission, program offices have been established at the NASA Centers to manage the development of the next generation of space vehicles. The Constellation Program, which will develop and build the Orion crew exploration vehicle and the Ares launch vehicles, is located at the Johnson Space Center (JSC). The Human Research Program (HRP), which will identify and perform initial supporting human research, is also located at JSC. Advanced technologies will be developed for Orion, Ares, and other space vehicles by the Exploration Technology Development Program (ETDP) at the Langley Research Center (LaRC). These three major ESMD Programs will maximize the use of Small Business Innovation Research (SBIR) Phase 1-3 technology research projects, in order to minimize technology development costs and expedite the activation of explorations systems as soon as possible.

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TOPIC: X1 Avionics and Software

The Exploration Development Technology Program leads the Agency in the development of advanced software and information technology capabilities and research for Exploration Systems. They perform mission-driven research and development to enable new system functionality, reduce risk, and enhance the capability for NASA's explorations missions. NASA's focus has clarified around Exploration, and the agencies expertise and capabilities are being called upon to support these missions. The Crew Exploration Vehicle (CEV) and teams of humans and robots working in space will all require advances in integrated systems health management, autonomous systems for the crew and mission operations, radiation hardened processing, and reliable, dependable software. Exploration requires the best of the nation's technical community to step up to providing the technologies, engineering, and systems to regain the frontiers of the Moon, to extend our reach to Mars, and to explore the beyond. These advanced Avionics and Software technologies will be implemented in the CEV, Crew Launch Vehicle (CLV), and robotic missions; embedded in operations; flown on spacecraft; and used by astronauts.

X1.01 Automation for Vehicle and Habitat Operations

Lead Center: ARC

Participating Center(s): JPL, JSC

Automation and autonomy are key elements in realizing the vision for space exploration. Constellation systems that would benefit from automation and autonomy include crewed vehicle systems, surface robots, habitats, and infrastructure (in situ resource utilization, power systems, etc.). Needed capabilities range from decision support systems in Mission Control to autonomous robotic operations for the Moon and Mars. These capabilities will be instrumental for decreasing workload, reducing dependence on Earth-based support staff, enhancing response time, and releasing crew and operators from routine tasks to focus on those requiring human judgment. In addition, significant reductions in Mission Risk can be achieved through the use of automated checking and enforcing of flight rules and constraints.

The NASA Exploration Technology Development Program (ETDP) has been developing a set of core autonomy capabilities that can adjust the level of human interaction from fully supervised to fully autonomous. To further the application of adjustable automation and autonomy, development is needed in three broad areas:

- Execution tools;
- Decision support systems;
- Trustable systems.

Execution Tools

Executives are a key autonomy capability. However, support tools are needed to facilitate the authoring and validation of execution scripts. Tools that are not tied specifically to one executive would provide NASA the most flexibility in applying such tools across projects. Examples of needed capabilities include:

- Graphical tool for monitoring and debugging plan execution;
- Graphical tool for creating and editing execution scripts;
- Tools for authoring and validating execution plans;
- User friendly abstraction of low-level execution languages by adding syntactic enhancements.

Decision Support Systems

Decision support systems amplify the efficiency of operators by providing the information they need when and where they need it. As the complexity of the constellation system increases, so must the capabilities of decision support systems. Decision support tools are needed that:

- Command and supervise complex tasks while projecting the outcome of actions and identify potential problems;
- Understand system state, including visualization and summarization;

- Allow the system to interact with a user when generating the plan and allow evaluation of alternate courses of action;
- Integration of a planning and scheduling system as part of an on-board, closed loop controller;
- Scale up existing techniques to larger problem applications.

Trustable Systems

Systems that support or interact with crew require a very high level of reliability. Tools are needed that improve the reliability and trustworthiness of autonomous systems. These include:

- Ability to predict what the system will do;
- Guarantees of behavioral properties;
- Other properties that increase the operator's trust;
- Verifiability (e.g., restricted executive languages that facilitate model-based verification).

To enable the application of intelligent automation and autonomy techniques, the technologies need to address two significant challenges: configuration management and software validation.

Reusable automation software must be adaptable to new applications without undue difficulty, and easily adjusted as the application operations change. The overhead of applying automation techniques to new applications is one of the two key obstacles to acceptance of such techniques in operations. A variation of the same issue is that of adjustment as requirements and application contexts change, which is inevitable in spacecraft operations.

The software and the adaptation to a given application must also be trusted before it can be accepted. Testing and other techniques are keys to establishing such trust and ensuring the correct function of automation systems. However, in both testing and validation, the complexity of intelligent software has proven to be a major obstacle. This has led to trust and correctness issues being another key obstacle to adoption of intelligent automation systems in both unmanned, and most importantly, in crewed vehicles.

Proposals in this area should address the definition of autonomy and automation software architectures that facilitate adaptation and ensure correctness.

X1.02 Reliable Software for Exploration Systems

Lead Center: ARC

Participating Center(s): JPL, JSC, LaRC

The objective of this subtopic is to bring to fruition software engineering technologies that enable engineers to cost-effectively develop and maintain NASA mission-critical software systems. Particular emphasis will be on software engineering technologies applicable to the high levels of reliability needed for human-rated space vehicles. A key requirement is that proposals address the usability of software engineering technologies by NASA (including NASA contractors) engineers, and not only specialists.

Many of the capabilities needed for successful human exploration of space will rely on software. In addition to traditional capabilities, such as GNC (guidance, navigation, and control) or C&DH (command and data handling), new capabilities are under development: integrated vehicle health management, autonomous vehicle-centered operations, automated mission operations, and further out – mixed human-robotic teams to accomplish mission objectives. It will be challenging, but critical to NASA's exploration objectives to ensure that these capabilities are reliable and can be developed and maintained affordably. Proposals should clearly indicate how the technology is expected to address the challenge of reliability and affordability. Mission phases that can be addressed include not only the software life-cycle (requirement engineering through verification and validation) but also upstream activities (e.g., mission planning that incorporates trade-space for software-based capabilities) and post-deployment (e.g., new approaches for computing fault tolerance; rapid reconfiguration, and certification of mission-critical software systems).

Software engineering tools and methods that address reliability for exploration missions are sought. Projects can address technology development and maturation that provide for the following and related capabilities:

- Automated software generation methods from engineering models that are highly reliable;
- Scalable verification technology for complex mission software, e.g., model-checking technology that addresses the 'state explosion' problem and static-analysis technology that addresses mission-critical properties at the system level;
- Automated testing that ensures coverage targeted both at the system level and software level, such as model-based testing where test-case generation and test monitoring are done automatically from system-level models;
- Technology for calibrating software-based simulators and test-beds against high-fidelity hardware-in-the-loop test-beds in order to achieve dependable test coverage;
- Technology for verifying and validating autonomy capabilities including intelligent execution systems, model-based diagnosis, and Integrated Systems Health Management (ISHM);
- Software-based radiation fault tolerance for computation;
- Methods and tools for development and validation of autonomic software systems (systems that are self protecting and self healing).

X1.03 Radiation Hardened/Tolerant and Low Temperature Electronics and Processors

Lead Center: LaRC

Participating Center(s): GSFC, MSFC

Electronic technologies that are to be used in near-term exploration activities must be capable of operating on the lunar and/or Martian surfaces. Systems will need to operate across a wide temperature range and must survive frequent (and often rapid) thermal-cycling. For example, the Moon's equatorial regions experience temperature swings from -180°C to +130°C during the lunar day/night cycle, and the sustained temperature at the shadowed regions of lunar poles can be as low as -230°C. Likewise, the diurnal temperature on Mars spans from about -120°C to +20°C. While many types of devices can operate down to very low temperatures (e.g., SiGE HBT's), there are significant circuit design challenges that need to be addressed.

Thermal cycling present in lunar and Martian environments introduces reliability concerns associated with mechanical stress and fatigue of components and integrated circuits. For example, thermal cycling may result in mechanical or packaging related fractures. The selection of appropriate materials is therefore critical to developing suitable electronic products.

In addition, electronic systems and/or components must be radiation tolerant, operating reliably after receiving a total ionizing dose (TID) greater than but not equal to 50 krad (Si) and providing single-event latchup immunity (SEL) greater than but not equal to 100 MeV cm²/mg.

Proposals are sought in the following specific areas:

- Wide temperature (-180°C to +130°C) and low-temperature (-230°C), radiation-tolerant, low-power circuits including analog-to-digital converters, digital-to-analog converters, low-noise pre-amplifiers, voltage and current references, multiplexers, power switches, microcontrollers, and integrated command, control, and drive electronics for sensors, actuators, and communications transponders.
- Packaging capable of surviving numerous thermal cycles and tolerant of the extreme temperatures on the Moon and Mars. This includes the use of appropriate materials including substrates, die-attach, encapsulants, thermal compounds, etc.
- Tightly-integrated electronic sensor and actuator modules that include power, command and control, and processing. Such modules should be capable of operating at the lunar and/or Martian temperature extremes.
- Radiation-tolerant, SEL immune, wide temperature (-180°C to +130°C), and low-temperature (-230°C) RF electronics for short-range and long-range communication systems.

- Computer Aided Design (CAD) tools for predicting the electrical performance, reliability, and life cycle for low-temperature and wide-temperature electronic systems and components.
- Physics-based device models valid at temperature ranging from -230°C to +130°C to enable design, verification and fabrication of custom mixed-signal and analog circuits.
- Circuit design and layout methodologies/techniques that facilitate improved low-temperature (-230°C) analog and mixed-signal circuit performance.
- Radiation-tolerant processors with significantly improved throughput and processing efficiencies. Chip-level (not board-level) technologies optimized for numerically intensive algorithms and applications with the following minimum performance metrics are sought:
 - Sustained throughput – 2 GMACS (16-bit operations);
 - Power efficiency – 1 GMACS/W (16-bit operations);
 - Total ionizing dose – 100 krad;
 - Single event upset rate – 10-10 errors / bit-day;
 - Single event latchup – greater than 75 MeV/cm²/mg;
 - Operational temperature range – -55°C to +125°C.

Proposals should demonstrate a working knowledge of temperature concerns, whether they be mechanical (material transition points, thermal stress, fatigue, fracture, etc.) or electrical (carrier freezeout, base-emitter injection efficiency, leakage, threshold voltage dependency, Johnson noise, charge trapping, kink effect, etc.).

Research should be conducted in two phases. During Phase 1, research should demonstrate the technical feasibility and show a path towards a hardware/software demonstration. During Phase 2, 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 space-worthy systems. When applicable, researchers should deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

X1.04 Integrated System Health Management

Lead Center: ARC

Participating Center(s): JPL, KSC, MSFC

Innovative health management technologies are needed throughout NASA's Constellation architecture in order to increase the safety and mission-effectiveness of future spacecraft and launch vehicles. In human space flight, a significant concern for NASA is the safety of ground and flight crews under off-nominal or failure conditions. The new Ares Crew Launch Vehicle will provide the means to abort the crew using a launch abort system. In case of a catastrophic failure during launch or ascent, the decision to abort the crew needs to be made within a very brief timeframe and with high certainty: either false positive or false negative crew abort indications carry a large safety and cost burden. Furthermore, the Constellation architecture allows for fully-automated crew abort under certain circumstances, increasing the accuracy and sensitivity requirements on the system health management function for the Ares launch vehicle and the Orion crew capsule.

There are other health and status requirements beyond launch and ascent. Traditional means of verifying space system health and status, such as caution and warning systems that are triggered by off-nominal sensor values are rather limited in their utility. In addition to issues such as sensor failures and false alarms, redline-triggered caution and warning events are difficult to interpret, often requiring involvement of large numbers of mission support staff to isolate a failure and initiate a recovery procedure. Health and status methods that depend on support from the ground are likely to become a safety liability as communication delays or bottlenecks increase (e.g., lunar trips). Under these circumstances, autonomous and automated solutions to systems health management provide the best means of increasing crew safety and mission success probability for future space exploration missions. For deployment on human missions, health management systems must be treated as Class A human-rated systems as defined by NASA procedural requirements (NPR 7150.2) and must undergo formal verification and validation.

Future ground operations will require quick and efficient turnaround and processing of spacecraft for launch. In addition, new operations concepts must be developed to provide a high level of safety and mission assurance while reducing ground processing and mission support staff. New methods driven by health management innovation may be used to curtail system lifecycle costs through more cost-effective inspection and certification of flight systems, as well as more cost-effective management of ground and mission operations.

Proposals should be responsive to the overall goals and objectives of NASA's Constellation and Lunar Precursors and Robotics Programs. Proposals may address specific vehicle health management capabilities required for exploration system elements (crewed spacecraft, launch systems, habitats, rovers, etc.). In addition, projects may focus on one or more relevant subsystems such as solid rocket motors, liquid propulsion systems, structures and mechanisms, thermal protection systems, power, avionics, life support, and communications. Proposals that involve the use of existing testbeds or facilities at one of the participating NASA centers (ARC, MSFC, KSC, or JPL) for technology validation and maturation are strongly encouraged.

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

- Methods and tools to enable early-stage design of health management functionality during the development of space systems. These methods and tools should provide a means to optimize health management system design at the functional level to decide on failure detection methods, sensor types and locations, and identify additional functionality to safeguard against failures before costly design decisions have been made.
- Innovative methods for sensor validation and robust state estimation in the presence of inherently unreliable sensors. Proposals should focus on data analysis and interpretation using legacy sensors rather than development of new sensors or sensor systems.
- Model-based methods for fault detection and isolation in rocket propulsion systems based on existing sensor suites during pre-launch propellant loading and during mission operations.
- Concepts for advanced built-in-tests for spacecraft avionics that reduce or eliminate the need for extensive functional verification and to predict remaining life of avionics systems based on usage history.
- Methods for robust control of critical components, subsystems, and systems and robust execution of critical sequences during launch operations or flight. Of special interest are robust recovery methods and innovative approaches to functional redundancy for the purpose of enhancing safety, availability, and maintainability.
- Prognostic techniques able to anticipate system degradation and enable further improvements in mission success probability, operational effectiveness, and automated recovery of function. Proposals in this area should focus on systems and components commonly found in spacecraft.
- Innovative human-system integration methods that can convey a wealth of health and status information to flight crews, ground and mission support staff quickly and effectively, especially under off-nominal and emergency conditions.
- Verification and validation techniques for advanced fault detection and prognostic capabilities leading to certification for use in human rated critical systems in a cost-effective manner.
- Innovative approaches to effective utilization of health information from NASA spacecraft and launch vehicles with seamless integration to ground based systems using commercial health information from programmable logic controller systems and commercial Reliability, Availability and Serviceability (RAS) systems.

TOPIC: X2 Sensors for Autonomous Systems

The Sensors for Autonomous Systems topic is defined to include sensors, sensor components or sensor systems that provide relative information between a spacecraft and another body, independent of Earth-based assets or personnel. The scope of this topic encompasses relative navigation for rendezvous, proximity operations and docking (RPOD) between a spacecraft and a target vehicle, such as the International Space Station or lunar module, and also precision landing and hazard detection for landing on a lunar or planetary surface. Technology development is needed to create robust sensor capabilities that work within the required environments and meet functional and performance requirements to accomplish the defined missions.

X2.01 Autonomous Rendezvous and Docking Sensors

Lead Center: JSC

Participating Center(s): ARC, GSFC, JPL, MSFC

The Exploration Systems Architecture defines missions that require rendezvous, proximity operations, and docking (RPOD) of two spacecraft both in Low Earth Orbit (LEO) and in Low Lunar Orbit (LLO). Uncrewed spacecraft must perform automated and/or autonomous rendezvous, proximity operations and docking operations (commonly known as Automated Rendezvous and Docking, AR&D). The crewed versions may also perform AR&D, possibly with a different level of automation and/or autonomy, and must also provide the crew with reliable, fault tolerant relative navigation information for manual piloting. The capabilities of the RPOD sensors are critical to the success of the Exploration Program. The relatively low technology readiness of existing relative navigation sensors for AR&D has been carried as one of the Crew Exploration Vehicle (CEV) Project's top risks.

This subtopic seeks innovative technologies that can provide relative navigation capabilities for rendezvous, proximity operations and docking of two spacecraft. Long-range rendezvous sensors should provide bearing from beyond 200 km to 5 km distance between spacecraft, but range and range-rate are also desirable. Proximity operations sensors should provide range, range-rate, and bearing from approximately 5 km to 100 m. Docking sensors should provide relative position and relative attitude from approximately 100 m to docking; relative attitude may only be needed from 30 m in to docking but longer ranges are desirable. Ideal solutions would combine multiple relative navigation sensing capabilities into a single system in order to reduce mass, volume, and power. Solutions should be designed to operate in Low Earth Orbit, Low Lunar Orbit, or both. Solutions can include a relative navigation sensor "suite" that consists of multiple sensor types but covers the full range; the sensor suite should allow RPOD under any lighting conditions. Solutions should also include a robust and fault tolerant capability that is suitable for a human-rated space vehicle. In addition, the relative navigation technologies should be designed so that existing infrastructure on the International Space Station (reflectors, communications systems, etc.) does not interfere with the relative navigation capability of the maneuvering vehicle.

Some specific technology focus areas of interest include: (1) use of relative navigation sensors that do not require special retro-reflectors or targets on the target spacecraft but can make use of natural features or existing infrastructure; this focus area may make use of Light-Imaging Detection and Ranging (LIDAR) components in order to get range and range-rate to the objects in the field of view, or may use video-based technology; (2) fault tolerant sensor systems; and (3) other technology areas for long-range rendezvous sensors that may include star trackers, infrared sensors, and radio frequency-based sensors; these types of sensors may have an extended range well beyond 200 km.

X2.02 Autonomous Precision Landing and Hazard Detection and Avoidance

Lead Center: JSC

Participating Center(s): JPL, LaRC

NASA seeks innovative sensor system technologies to support autonomous precision landing with hazard detection and avoidance for landing spacecraft on the lunar surface with extensibility to Mars. Sensor systems that can characterize and identify spacecraft landing surface hazards for purposes of avoidance and surface relative navigation with high precision and accuracy are of interest. The emphasis of this solicitation is for sensor systems or sensor

components that can be utilized in current sensor systems to go beyond current technology capability. These systems or components must be compatible with the environmental conditions of spaceflight and the rigors of landing on the planetary surface. Proposals for development of certain aspects of these technology systems including sensor components that include partnering with other vendors developing this kind of technology are encouraged.

Candidate items include but are not limited to the following:

- Innovative lidar sensor systems and component technologies that directly address autonomous precision landing and hazard avoidance needs
 - 3D imaging lidar systems capable of generating elevation maps covering terrain areas 10k to 100k square meters from 1-2 km altitude with a resolution of the order of 20 cm
 - High efficiency focal plane arrays with over 16k pixels capable of detecting laser pulses shorter than a few nanoseconds (wavelengths of interest are 1 to 1.5 microns)
 - Reliable Readout Integrated Circuit (ROIC) with high frame rate capability greater than 20 hertz and capable of resolving target depth to a few centimeters
 - Novel real-time lidar image reconstruction and processing technologies;
- Passive or active detector systems which operate in certain ranges between 100 km to 2 km for utilization in terrain relative navigation systems;
- Sensor systems which provide very high accuracy and precision for determining velocities and altitudes relative to the surface with 0.1% accuracy;
- Robust and reliable sensor system or sensor system components which significantly reduce the impact of incorporating such sensors or components on the spacecraft in terms of volume, mass, power, thermal dissipation, placement or cost;
- Semiconductor or solid-state-controlled mirror systems capable of rapidly moving a lidar FOV over a defined areas;
- Innovative systems that significantly improve current precision landing and hazard detection capability for lunar descent and landing.

Proposals should describe the expected improvements and advantages of proposed deliverables over existing technologies and should estimate the effects of these improvements on the state-of-the-art navigation and hazard detection capabilities. Attributes of interest include reliability, precision, lighting requirements, accuracy, thermal sensitivity, heat dissipation capability and performance degradation due to rocket plumes and lunar dust.

TOPIC: X3 Environmental Control and Life Support (ECLS)

Environmental Control and Life Support (ECLS) encompasses the process technologies and equipment necessary to provide and maintain a livable environment within a crewed spacecraft or surface habitat cabin. Functional areas of interest to this solicitation include atmospheric resource management; airborne particulate matter removal and disposal; water recovery systems; waste management; fire protection systems; and environmental monitoring. Technologies are needed for crewed space exploration missions supporting the Vision for Space Exploration with emphasis on missions to the lunar surface, including short duration lunar sortie and long duration lunar outpost missions. Vehicles of interest include the Lunar Lander and Lunar Outpost (LO). Requirements include operation in micro- and/or partial-gravity as well as ambient and reduced-pressure cabin environments. Special emphasis is placed on developing technologies that will fill existing gaps; have a significant impact on reduction of mass, power, volume and crew time; and increase safety and reliability.

X3.01 Spacecraft Cabin Atmospheric Resource Management and Particulate Matter Removal

Lead Center: JSC

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

Atmospheric resource management and particulate matter removal systems supporting critical needs for lunar mission architectures are requested. Vehicles and habitats are expected to be significantly restricted with respect to habitable volume and may operate at reduced atmospheric pressure with elevated oxygen concentrations. Improved non-regenerative and regenerative processes technologies for atmospheric quality control must be developed. The ability to economically supply atmospheric gases and refill storage tanks in flight will be needed. Isolating habitable volumes from surface dust and disposing of accumulated particulate matter will be challenges. Systems must be innovative and extremely efficient with respect to volume, mass, energy and thermal requirements.

Atmospheric Resource Management

Atmospheric resource management encompasses process technologies and equipment to supply, store, and condition atmospheric gases; provide gaseous oxygen at pressures at or above 3,000 psia; and achieve mass closure by recycling resources and using in situ resources. Typical process technologies employed for achieving these needs may include reduction of carbon dioxide to carbon, sub-critical gas storage, and electrolytic oxygen production with compression. Techniques for enhancing NASA's present capabilities and filling technology gaps are sought. The ability to provide early computer-based process technology predictive performance models for application scale-up and scale-down is desirable. Areas of emphasis include:

- Carbon Dioxide Removal and Reduction for Recovery of Oxygen: Process technologies for removing and sequestering carbon dioxide from cabin atmospheric gases (via means other than adsorption or chemisorption) and conditioning carbon dioxide for use in reduction processes to facilitate cabin mass balance closure are sought. Technologies to reduce carbon dioxide to a carbon product with high efficiency that yields a high percentage mass balance closure are also of interest.
- Gas Supply and Storage: Novel means for supplying and storing oxygen and nitrogen under sub-critical conditions that lead to enhancements in energy efficiency, reduced mass and volume, and mission flexibility are sought. Further, process technologies leading to a ready, in-flight renewable source of 3,000-psia gaseous oxygen are of interest.

Particulate Matter Removal and Disposal

Dust and particulate matter contamination are challenges that must be overcome for lunar surface exploration. Particulate contamination originating from the external surface environment or from internal sources are both of concern. Development of process technologies and equipment to minimize the impacts of surface dust on crew health and equipment inside the habitable volume are sought, including novel approaches to remove dust from spacecraft cabin atmosphere and isolate habitable volumes from surface dust. Candidate technology solutions should provide high efficiency and long-lived removal capacity. Technologies must be tolerant to the abrasive effects of dust particles. Performance should be demonstrated with appropriate lunar dust analogs or simulants. Areas of emphasis include:

- Removal of Fine Atmospheric Dust Particulates: Fine airborne lunar dust will be detrimental to crew health. Filtration technologies are sought that will provide significantly improved capture efficiency of both fines (10 nm to 2 microns) and ultra-fines (<100 nm) from the spacecraft atmosphere with minimal pressure drop. These may include but are not limited to mechanical filtration, inertial separation and impingement, and electrostatic separation filtration processes that are lightweight, low power and operate at reduced atmospheric pressures. Novel techniques and materials are of interest.
- Regenerative Processes and Filters: Regeneration techniques and regenerable filters are sought that effectively handle a broad particulate size range from larger-sized particles down to fine particle sizes. These techniques must be able to separate and dispose of lunar dust to the lunar surface, and/or dispose of and collect all other particulate matter to highly compacted units/states. Salient features for this application include capability for regeneration in place, long-lived and large bulk removal capacity, and high efficiency.

Operational modes of continuous regeneration or long interval regeneration cycles using either single or multi-stage regeneration processes will be considered. Methods for determining and annunciating the loading and unloading status of the regenerative unit and for automated regeneration are of interest.

- Isolation Technologies: Process technologies and design concepts to isolate habitable volumes from surface dust are sought. Such process technologies and design concepts may employ a variety of techniques to prevent surface dust from being transported through an airlock into the habitable part of the spacecraft or habitat cabin.

X3.02 Water Processing and Waste Management Systems

Lead Center: JSC

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

Water processing and waste management systems supporting critical needs for lunar mission architectures are requested. Improved technologies for recovery of water and other resources as well as safe long term stabilization and storage of residuals inside and outside the habitat are needed. Water processes collect, store, recycle, and disinfect water for reuse as both drinking water and hygiene water. Waste processes collect, process, recover resources, stabilize, and store residuals. Although this solicitation is directed at technologies for lunar missions, crosscutting technologies that are also applicable to human missions to Mars are of interest. Proposals should explicitly describe the weight, power, and volume advantages of the proposed technology.

Water Reclamation

Efficient treatment of wastewater from a variety of sources is critical to long-term exploration missions. Sources of water to be recovered may include urine, wash water, humidity condensate, and/or water derived from in situ planetary resources. Treatment processes should produce potable and hygiene water supplies. Treatment methods for long duration missions should seek high levels of mass closure. Systems targeted for planetary surface applications must be designed to function in hypogravity environments but need not be microgravity compatible. Areas of emphasis include:

- Disinfection and residual disinfectant technologies that are compatible with both biological and physico-chemical wastewater processing systems;
- Techniques to minimize or eliminate biofilms, microbial contamination and/or solids precipitation from potable water, wastewater and water treatment system components;
- Post-treatment methods to reduce total organic carbon from 100 mg/L to less than 1 mg/L in the presence of 50 mg/L bicarbonate ions, 25 mg/L ammonium ions and 25 ppm other inorganic ions.

Waste Management

Wastes (trash, food packaging, feces, paper, tape, filters, water brines, clothing, hygiene wipes, etc.) must be managed to protect crew health, safety, and quality of life, to avoid harmful contamination of planetary surfaces, and to recover useful resources. Areas of emphasis include:

- Solid waste stabilization including water removal and recovery of water from wet wastes (including human fecal wastes, food packaging, brines, etc.);
- Solid waste storage and odor control (e.g., catalytic and adsorptive systems);
- Energy efficient/internal heat recycling waste pyrolysis systems for mineralization of wastes.

Clothing Systems

Low mass reusable or long usage clothing options that meet flammability, out gassing, and crew comfort requirements. Cleaning and drying systems for re-use of clothing that have low-water usage, non-toxic cleaning agents compatible with physicochemical or biological water reclamation systems, or that do not require water.

X3.03 Spacecraft Cabin Environmental Monitoring and Control

Lead Center: JPL

Participating Center(s): ARC, GRC, KSC, JSC, MSFC

Monitoring technologies are employed to assure that the chemical and microbial content of the air and water environment of the astronaut crew habitat falls within acceptable limits, and that the chemical or biological life support system is functioning properly. The sensors may also provide data to automated control systems.

Technologies should be appropriate for a small crewed mission to the Moon, of duration no more than a few weeks. Emphasis is on major constituents in the air and lunar dust. Extendibility to trace monitoring for longer missions is a plus. Significant improvements are sought in miniaturization, accuracy, precision, and operational reliability, as well as long life, real-time multiple measurement functions, in-line operation, self-calibration, reduction of expendables, low energy consumption, and minimal operator time/maintenance for monitoring and controlling the life-support processes. Proposals should be for either new technologies or combine existing technologies in a new way to simultaneously monitor several major constituents and dust, and/or trace constituents.

Substances from an external environment such as lunar surface dust may be encountered during astronaut excursions and may be a mechanical or chemical threat both during the external encounter and if brought inside. Monitoring technologies are needed to assess and quantify these threats.

For longer missions, water monitoring will be required. Needs will include sensitive, fast response, online analytical sensors to monitor suspended liquid droplets, dispersed gas bubbles, and water quality, particularly total organic carbon. A desire is for an immersible water quality sensor that is reversible; i.e., it tracks analyte changes in water without having to replace any sensor chemistry element.

Monitoring of other species of interest include dissolved gases and ions, and polar organic compounds such as methanol, ethanol, isopropanol, butanol, and acetone in water reclamation processes; and particulate matter, major constituents (such as oxygen, carbon dioxide, and water vapor) and trace gas contaminants (such as ammonia, formaldehyde, ethylene) in air revitalization processes. Both invasive and noninvasive techniques will be considered.

Monitoring of microbial species, especially pathogens, primarily in water, will be important for longer missions. Enabling technologies may include proper sample preparation and handling, with minimal operator effort and minimal or no reagent usage.

Crew members will employ software tools to help them interpret sensor data. Methods are sought which will assist the crew in using sensor data to detect and predict failures.

Results of a Phase 1 contract should show feasibility of the technology and approach. A resulting Phase 2 contract should produce at least a prototype demonstration and test of the environmental monitor.

X3.04 Spacecraft Fire Protection

Lead Center: GRC

Participating Center(s): ARC, JPL, JSC, KSC, MSFC

The objective of fire protection strategies on exploration spacecraft is to quantitatively reduce the likelihood of a fire and reduce the impact to the mission should a fire occur. NASA's fire protection strategy includes: strict control of ignition sources and flammable material, early detection and annunciation of fire signatures, and effective fire suppression and response procedures. While proposals describing innovations in all of these areas are applicable, they are particularly sought in the following areas:

- Advanced fire detection strategies are desired that respond uniquely to one or more fire or pre-fire characteristics such as thermal radiation, smoke, or gaseous product. These sensors and detector systems should be appropriate for the unique fire behavior in low- and partial-gravity environments yet effectively discriminate between fire signatures and relevant spacecraft nuisance sources. Fire detection systems particularly attractive for long-duration exploration missions will have reduced mass, power, and volume requirements and exhibit high degrees of reliability, minimal maintenance, and self-calibration.
- Fire suppression technologies for exploration spacecraft and habitats must be applicable for use in a confined habitable volume having an atmosphere of up to 34% O₂ by volume and pressures as low as 7.6 psia. These systems would be effective in low- and partial-gravity environments and have minimal mass and volume requirements. Applicable technologies would be highly reliable with little or no maintenance, have multi-use capability and/or be replenishable during a mission, and be compatible with the spacecraft environmental control and life support system.

Results of a Phase 1 contract should show feasibility of the technology and approach. A plan for the demonstration of a prototype to be developed in Phase 2 should also be produced at the end of Phase 1. The Phase 2 contract should produce at least a prototype demonstration and test of the fire detection or suppression system.

TOPIC: X4 Extra Vehicular Activity (EVA)

Advanced extravehicular activity (EVA) systems are necessary for the successful support of future human space exploration missions. Advanced EVA systems include the space suit pressure garment, the portable life support system, tools and equipment, and mobility aids, such as rovers. Complex missions require innovative approaches for maximizing human productivity and for providing the capability to perform useful work tasks. Top level requirements include reduction of system hardware weight and volume; increased hardware reliability, durability, and operating lifetime (before resupply, recharge and maintenance, or replacement is necessary); reduced hardware and software costs; increased human comfort; and less-restrictive work performance capability in the space environment, in hazardous ground-level contaminated atmospheres, or in extreme ambient thermal environments. Environmental protection, such as space suit radiation protection and dust mitigation technologies, are of particular interest. Innovative and highly reliable EVA communications, avionics and informatics are also of interest. All proposed Phase 1 research must lead to specific Phase 2 experimental development that could be integrated into a functional EVA system.

X4.01 Space Suit Pressure Garment and Airlock Technologies

Lead Center: JSC

Participating Center(s): GRC

Innovative technologies are needed to meet the challenging requirements for the exploration space suit pressure garment and surface systems airlock. These technologies should be able to be developed further for application to the lunar missions.

Specifically, the space suit pressure garment requires radiation protection technologies that protect the suited crew member from radiation particles, puncture protection technologies that provide self-sealing capabilities when a puncture occurs and minimizes punctures and cuts from sharp objects, dust and abrasion protection materials to exclude dust and withstand abrasion and prevent dust adhesion, flexible thermal insulation suitable for use in vacuum and low ambient pressure, and space suit low profile bearings that maximize rotation which is necessary for partial gravity mobility requirements, and is also lightweight and low cost.

Due to the expected large number of space walks that will be performed on the lunar surface, innovative technologies and designs for surface airlocks will also be needed. Technology development is needed for minimum gas loss airlocks providing quick exit and entry that can accommodate an incapacitated crew member, suit port/suit lock systems for docking a space suit to a dust mitigating entry/hatch in order for the space suit to remain in the airlock

and prevent dust from entering the habitable environment, and active and passive space suit and equipment dust removal technologies inside and outside the airlock.

X4.02 Space Suit Life Support Systems

Lead Center: JSC

Participating Center(s): GRC

Exploration missions will require a robust, lightweight, and maintainable portable life support system. Technology development is needed for long-life and high-capacity chemical oxygen storage systems for an emergency supply of oxygen for breathing; low-venting or non-venting regenerable individual life support subsystem(s) concepts for crew member cooling, heat rejection, and removal of expired water vapor and CO₂; convection and freezable radiators that will be low cost and lightweight for thermal control; innovative garments that provide direct thermal control to crew member; high reliability pumps and fans that will provide flow for a space suit but can be stacked to give greater flow for a vehicle; CO₂ and humidity control devices that, while minimizing expendables, function in a CO₂ environment; and a non-toxic, non-flammable, super cooled below 32°F phase change material that can absorb metabolic heat for an 8 hour duration.

Also for removing metabolic heat from the astronaut, research is needed for a variable conductance flexible suit garment that can function as a radiator for high metabolic loads and as an insulator for low metabolic loads.

X4.03 Space Suit Displays, Cameras, Controls, and Integrated Systems

Lead Center: GRC

Participating Center(s): JSC

Future exploration space suits will require innovative technologies for displaying various types of information. Technology development is needed for space suit mounted displays for use both inside and outside the space suit; outside mounted displays must be compatible with the space radiation, thermal, and vacuum environment. Examples include internally or externally mounted helmet displays and lightweight wrist or arm mounted displays.

The spacesuit will also require research for lightweight CO₂, biomedical, and core temperature sensors with reduced size, increased reliability, and greater packaging flexibility; and camera systems that are lightweight, low power draw, and integrate with the spacesuit. The camera system should allow both motion and still imagery providing compressed digital data output suitable for transmission over IP networks. This camera must provide excellent situational awareness for crew members and quality imagery for remote viewing and public relations.

Research is also needed for lightweight, low power consuming general purpose computing platforms that are tolerant to the space radiation environment. Such platforms could be processor or FPGA based to allow the use of on-suit software applications such as biomedical advisory algorithms, procedure displays, navigation displays, and voice recognition. Technology development is needed for low computational overhead voice recognition processing systems capable of performing on lightweight radiation tolerant embedded computing platforms.

TOPIC: X5 Lunar In Situ Resource Utilization (ISRU)

The purpose of In Situ Resource Utilization (ISRU), or “living off the land”, is to harness and utilize space resources to create products and services which can enable and significantly reduce the mass, cost, and risk of near-term and long-term space exploration. By producing propellants, life support and fuel cell power consumables, and other items from in situ resources and eliminating the need to launch everything from the Earth, long-term launch and mission costs can be reduced, while potentially increasing science and exploration capabilities and mission safety. In Dec. 2006, NASA unveiled a draft lunar architecture that involves the deployment and buildup of an Outpost at a single location on the Moon that could take advantage of the sunlight and potential water resources at the lunar poles. The architecture also proposed the deployment of an ISRU system to make oxygen and water for life support

and Extra-Vehicular Activity (EVA) by 2023 and potentially for propulsion applications by 2027. Besides consumable production, the ability to excavate and manipulate lunar soil (or regolith) and modify surface features and terrain for crew radiation protection, landing plume mitigation and shielding, habitat and nuclear reactor deployment, and minimizing dust generation during surface activities were also considered as potentially important capabilities for Outpost deployment and operations. The purpose of the following subtopics is to demonstrate and/or develop critical technologies and capabilities to meet Outpost architecture and surface manipulation objectives for near and long term human exploration of the Moon.

X5.01 Oxygen Production from Lunar Regolith

Lead Center: JSC

Participating Center(s): GRC, KSC, MSFC

Oxygen production from lunar regolith processing consists of receiving regolith from the excavation subsystem into a hopper, transferring that regolith into a reactor where it is reduced using chemical or an electrochemical process, potentially intermediate reactions to reach oxygen, purification of the oxygen, and transfer of the oxygen to the liquefaction and storage subsystem. After oxygen has been extracted from the regolith, the spent regolith must be removed from the reactor and returned to the excavation subsystem for disposal. Depending on the process used, the reactor may contain reduced metals that can be extracted in their pure form for use as a manufacturing feedstock.

To maximize the benefits of In Situ Resource Utilization (ISRU) for the Lunar Exploration Architecture, oxygen production systems must minimize the mass and power consumption of ISRU systems. ISRU systems must be able to produce many times their own mass in oxygen and other products to provide a benefit to the architecture. ISRU systems must be able to autonomously operate in a harsh environment that has wide temperature swings, high radiation and abrasive dust. Depending on the outpost location, the systems must be able to sustain many startup and shutdown sequences when solar power is not available. Some of these shutdown periods may exceed several hundred hours.

The next phase of ISRU research and development will focus on the design and testing of a regolith reduction system that can produce roughly 1000 kilograms of oxygen in a year. The operation assumption is that the production plant will operate off of solar power which is estimated to be available about 70% of the time and will operate at a lunar pole with highlands soils. The current oxygen production approaches being developed into prototypes are: Hydrogen Reduction, Carbothermal and Molten Oxide Electrolysis. The basic description of these approaches can be found in the NASA funded report by Eagle Engineering, entitled “Conceptual Design of a Lunar Oxygen Pilot Plant (1988)”. The report can be found on the web at <http://www.isruinfo.com/index.php?page=research>.

NASA is seeking subsystem component technologies rather than full system proposals. We would like to encourage the development of subsystem components that could be inserted into our Exploration Technology Development Program funded oxygen production systems to improve the mass, power and efficiency of the system. Technology areas of particular interest are:

- Heat exchangers to recover energy from heated regolith;
- Low/No maintenance system filtration technologies for removing dust from gas lines;
- Water condensers that would use the cooling potential of the space environment to water condensation with minimal energy usage;
- Solar Concentrators that are lightweight and able to deliver concentrated solar thermal energy to reactors generating regolith temperatures from 900°C up to 1600°C;
- Gas Separators that provide low pressure drop separation of the system and product gas streams from impurities (e.g., H₂S, SO₂);
- Microchannel methanation reactors that convert a mixture of carbon monoxide, carbon dioxide, and hydrogen to methane and water vapor with carbon monoxide and carbon dioxide consumed to the maximum extent possible;

- O₂ Purification technologies that perform the removal (and reclamation) of all contaminants prior to liquefaction of the oxygen;
- Feed systems to introduce regolith to the reactors and remove the regolith, slag or molten products from the reactor post processing. The systems must minimize the possibility of dust contaminating the reactor seals;
- Reactor Seals: The sealing of reactors includes sealing gas interfaces from the reactor to the remainder of the system and also the regolith feed/exit to the reactor. Valves proposed for use for gas interfaces must be capable of 1000s of operations and able to operate when lunar dust is present in the gas stream. Reactor regolith feed/exit seals proposed for use must either be kept clean, can be automatically cleaned, or seal even with a coating of lunar dust. Interested companies should keep in mind that each reactor system operates at significantly different temperatures so the gas and regolith sealing methods could see a wide range of thermal conditions.

X5.02 Lunar Regolith Excavation and Material Handling

Lead Center: JSC

Participating Center(s): GRC, JPL, KSC

The lunar regolith excavation, handling, and material transportation subtopic is intended to include all aspects of lunar regolith handling for oxygen and other resource collection and site preparation and construction including tasks such as buildup of berms (approximately 3m above grade) and burying of reactors or habitats for radiation protection (approximately 3m below grade). Excavation capability may be limited to collection of unconsolidated surface regolith for oxygen production (approximately 0.2m) or extended to extraction of more consolidated material at greater depths (approximately 3m) if the power and mass requirements for transportation of surface regolith exceed those of deeper digging. Excavation, handling and transportation systems must be operable over broad temperature ranges (generally 110K to 400K) and in the presence of abrasive lunar regolith and partial-gravity environments. Excavation and material handling systems must process 100's to 1000's of times their own mass of extracted regolith in their useful lifetimes. Expectations for maintenance by human supervision, crew operation, and crew training for these systems must be minimal and affordable. Figures of merit for lunar regolith excavation, handling and material transportation technologies and systems include: excavation and material delivery rate (kg/hr), excavation and delivery energy efficiency (power required/excavation rate), and excavation depth and berm height. To insert hardware developed as part of the SBIR program, excavation for oxygen production should support a minimum of 20 kg/hr (worst case hydrogen reduction at poles for 1 MT oxygen per year) with maximum of 200kg/hr of the top 0.2m. Excavation requirements for surface construction, habitat emplacement, reactor burial, etc. are extremely preliminary at this time are 500 to 1000kg/hr with excavation down to 3m below the surface and berm building up to 3m above the surface. Specific areas of interest include:

- Excavation technology or systems for collecting unconsolidated surface regolith with low power consumption and hardware mass. Defining interfaces requirements with surface mobility platforms (mass, power, physical attachment, traction, storage and dump apparatus, etc.) is critical. Proposals can include some aspects and demonstration of surface mobility platform efforts but should not be a significant portion of the proposed work.
- Technologies and systems for collecting regolith and its delivery to oxygen production plants that address the engineering trade offs between total system mass, power and energy consumption that arise in co-varying excavation depth and transportation distance.
- Specific technologies for stabilizing a contoured lunar surface area, including but not limited to methods to induce regolith sintering, for the purpose of providing lunar outpost site preparation capabilities.
- Specific technologies for flow of regolith in the lunar environment related to excavation, handling and transportation.
- Modeling of granular material physics in partial gravity related to regolith excavation, handling and transportation.

X5.03 Lunar Volatile Resource Prospecting and Collection**Lead Center: JSC****Participating Center(s): GRC, JPL, KSC**

Lunar volatile extraction, separation, and collection consists of all aspects of locating and characterizing lunar volatile resources (especially polar hydrogen/water); excavating regolith in the permanently shadowed craters (-233°C and down to 2 meters); mechanical, thermal, chemical, and/or electrical processing of this regolith to release volatiles; identifying/quantifying all volatiles; and separating and collecting volatiles of interest. Metrics of interest include: excavation rate (kg/hr); excavation efficiency (power required/excavation rate); resource extraction efficiency (Watts per mass of volatiles produced per hour); collection efficiency (mass collected vs. total evolved); and collection purity (mass collected of desired product vs. total collected). Specific areas of interest include:

- Excavation techniques for soil-like to rock-like regolith (70MPa), depending on water content, and very cold (40K to 100K) regolith and local environment conditions;
- Excavation technology or systems for collecting regolith while preserving the loosely held volatile species that may be present;
- Regolith handling, processing, and heating techniques that minimize the amount of time and energy required to evolve volatiles (either solar wind implanted or in permanently shadowed craters);
- Gas separation and collection techniques for a product stream containing various concentrations of hydrogen, carbon dioxide, nitrogen, helium, water, ammonia, and methane;
- Demonstration of sealing technology for repetitive (less than 50 times) use at a wide range of temperatures (40K - 500K nominal and up to 1500K maximum) in abrasive, electrostatic, high vacuum environment; and
- Specific technologies or recipes for implanting volatile species in terrestrial samples of lunar regolith simulant to support volatile species collection and extraction technology development.

TOPIC: X6 Structures, Materials and Mechanisms

The SBIR topic area of Structures, Materials and Mechanisms centers on (1) developing lightweight structures and advance materials technologies to support Lunar Landers and Lunar Habitats and (2) low-temperature mechanisms to improve and or allow for reliable and efficient mechanism operation for long duration in the cold polar and crater regions of the lunar surface. Lightweight structures and advanced 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 mission phases. The structures and materials program utilizes and combines multi-center R&D teams into focused activities for developing lightweight structure technology for the primary load bearing structure of the pressurized elements of the Vision for Space Exploration (VSE) program. The major technology drivers of the lightweight structure technology development are to significantly enhance structural systems for man-rated pressurized structures by (1) lowering mass and/or improving efficient volume for reduced launch costs, (2) improving performance to reduce risk and extend life, and (3) improving manufacturing and processing to reduce costs. This topic area is responsible for mid-level technology research, development, and testing through experimental and/or analytical validation. Three subtopics represent the structures and materials area: (1) Lightweight Structures; (2) Low Temperature Mechanisms; and (3) Advanced Radiation Shielding Materials. In missions to the lunar surface, permanently shadowed regions of the Moon, e.g., the bottoms of craters in the Polar Regions, are high interest to science and exploration. These areas appear to remain at temperatures of 50 to 80K (-223°C to -193°C). Current surface exploration hardware has demonstrated capability to operate in the range of -115°C to 0°C on Mars. However, the technical challenges of developing and demonstrating hardware that can operate over 100°C colder than current capabilities are significant. The major technology drivers of the low temperature mechanism technology development are to significantly enhance operation of mechanized parts by (1) lowering the operating temperature for the life of the component and (2) improve mechanism performance (torque out put, actuation performance, lubrication state) at the lunar environment conditions of cold and vacuum. The targeted application of the technology is to provide for operation of motors and drive systems, lubricated mechanisms, and actuators of lunar rovers and mobility systems, ISRU machinery, robotic

systems mechanisms, and surface operations machinery (i.e., cranes, deployment systems, airlocks), for lunar surface operations. This topic area is responsible for mid-level technology research, development, and testing through experimental and/or analytical validation. There is one subtopic in this area, Low Temperature Mechanisms.

X6.01 Lightweight Structures

Lead Center: LaRC

Participating Center(s): ARC, GRC, JSC, MSFC

This subtopic solicits innovative structural concepts that support the development of lightweight structures technologies that could be applicable to lunar surface landers and habitats. The targeted innovative lightweight structures are for primary pressurized structures such as crewed vehicles (landers and habitats). Innovations in technology are needed to minimize launch mass and costs, and increase operational volume for minimal launch volumes while at the same time maintain required structural performance for loads and environments. Of particular interest are the following structural concepts:

- Lightweight multifunctional and/or integrated structural systems that include radiation shielding, impact shielding, thermal management, damage tolerance and durability, and/or integral diagnostics/health monitoring, and novel inspection/nondestructive evaluation capabilities are of interest if they can be developed to improve the efficiency (mass/performance) of the structural system over the parasitic systems used today.
- Inflatable structures are considered as viable technique to improve volume for crew in habitats and potentially other crewed vessels. However, areas of risk need to be mitigated to build confidence in the use of these structures. In particular, durability in the presence of micrometeoroid impact crew load induced damage, radiation-shielding protection, equipment placement and tie down concepts, and efficient packaging concepts are of interest.

Development of concepts can include structural components, improved low cost manufacturing processes, methods of validation, and/or predictive analysis capabilities. Technological improvements that focus on risk reduction/mitigation, and development of reliable yet robust designs are also being sought under this announcement. Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

X6.02 Low Temperature Mechanisms

Lead Center: GSFC

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

This subtopic focuses on the development of selected hardware and support technologies for motors, drive systems and related mechanisms that will operate in cryogenic temperature environments such as permanently shaded craters on the Moon, and/or on the lunar surface exposed to the day/night cycle. In the former situation such mechanisms may be exposed to, and will need to operate in, sink temperatures as low as approximately 25K. In the latter situation they will need to operate over a temperature sink range of approximately 83K to 380K (-190°C to +107°C). The component technologies developed in this effort will be utilized for rovers, operational equipment, instruments, drills, crushers, and other such facilities. The nearer term focus for this effort is for lunar missions, but these technologies should ideally be translatable to applications on Mars. These components must operate in a hard vacuum and/or planetary environment, with partial gravity, and full solar radiation exposure. Additional requirements include high reliability, ease of maintenance, low-system volume, low mass, and minimal power requirements. Low out-gassing is desirable, as are modular design characteristics, fail-safe operation, and reliability for handling fluids, slurries, biomass, particulates, and solids. While dust mitigation is not specifically included in this subtopic, proposed concepts should be cognizant of the need for such technologies.

Specific areas of interest include gear boxes, suspension systems, material components (i.e., wiring, harnesses, insulating materials, and jackets/covers) that are flexible in cryogenic environments; advanced lubricants and lubrication technology; and an accelerated means of life testing for cold temperatures.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

X6.03 Advanced Radiation Shielding Materials

Lead Center: LaRC

Participating Center(s): ARC, MSFC

Revolutionary advances in radiation shielding materials and structures technologies are needed to protect humans from the hazards of space radiation during NASA missions. All particulate radiation species are considered, including electrons, protons, neutrons, alpha particles, light ions, heavy ions, etc. All space radiation environments in which humans may travel in the near future are considered, including low-Earth orbit, geosynchronous orbit, Moon, etc. The primary area of interest for this 2007 solicitation is radiation shielding materials systems for long duration lunar surface protection for humans. Lightweight radiation shielding materials systems for short-term in-space operations for humans are also of interest. The materials emphasis is on multifunctional materials, where two of the functions are, but not exclusively, radiation shielding efficiency and structural integrity. Radiation shielding design software to optimize multifunctional materials usage in specific designs is also of interest. Radiation shielding augmentation materials are part of this solicitation, along with associated software tools to minimize augmentation requirements. Research should be conducted to demonstrate technical feasibility during Phase 1 and to show a path toward a Phase 2 technology demonstration. Specific areas in which SBIR-developed technologies can contribute to NASA's overall mission requirements for advanced radiation shielding materials and structures include, but are not limited to, the following:

- Innovative lightweight radiation shielding materials and structures to shield humans in crew exploration vehicles, large space structures such as space stations, orbiters, landers, rovers, rigid habitats, inflatable habitats, spacesuits, etc.;
- Radiation laboratory and spaceflight data to validate the shielding effectiveness of radiation shielding materials and structures;
- Physical, mechanical, structural, and other relevant characterization data to validate and qualify multifunctional radiation shielding materials and structures;
- Comprehensive radiation shielding databases to enable designers to incorporate and optimize radiation shielding structural materials into space systems during all phases of the design process;
- Radiation shielding software, compatible with Multi-Disciplinary Optimization (MDO) analysis, for optimization of specific vehicle designs;
- Innovative processing methods to produce quality-controlled advanced radiation shielding materials of all forms – resins, fibers, fabrics, foams, microcomposites and nanocomposites, fiber-reinforced composites, light alloys, and hybrid materials;
- Innovative fabrication techniques to fabricate advanced radiation shielding materials into useful products and structural components;
- Innovative manufacturing techniques to produce quality-controlled advanced radiation shielding products and structural components, including innovative scale-up methods for producing quality-controlled viable quantities of advanced radiation shielding materials and structures;
- Innovative commercialization strategies to introduce advanced radiation shielding materials and structures into the marketplace to enable availability of the technologies for use by NASA and the space exploration community;
- Innovative concepts to reuse, recycle, and reprocess materials and structures in space for use as radiation shielding materials and structures.

X6.04 Advanced Composite Materials

Lead Center: MSFC

Participating Center(s): GRC, LaRC

This subtopic solicits innovative research for advanced composite materials, processing and characterization concepts that support the development of lightweight structures technologies that should be applicable for space transportation vehicle systems, propulsion systems, and planetary access and operations. Reduction in structural mass translates directly to additional up-and-down mass capability that would facilitate logistics and increase science return for future missions. Advanced composites are targeted that could be implemented into vehicle and propulsion systems for launch vehicles, lunar landers, and habitats. Innovations in technology are needed to increase specific strength and stiffness, provide radiation shielding, enhance thermal management, reduce Micrometeoroid/Orbital Debris (MMOD) damage potential, and provide effective nondestructive verification and characterization, while maintaining safety, reliability, and reducing costs.

Advanced composite material systems and their corresponding manufacturing, processing and verification techniques are desired. Examples would include, but are not limited to, material systems and mature applications of nano-structured materials. Processing examples would include, but are not limited to, automated composite fiber/tape placement, non-autoclave curing, processing innovations for multifunctionality, ceramic processing, nano materials processing, freeform fabrication, and bonding of composites.

Development of concepts can include material system characterization, proof-of-concept demonstrations for integrated lightweight structures, innovative multifunctional concepts, enabling performance and affordability (including life cycle costs) enhancement, damage tolerance/control techniques, methods of validation, and/or predictive analysis methods that improve understanding of the technology to reduce risk and need for conservatism in design and demonstration of integrated system performance. Preferred processing and verification techniques would include non-contact, high-resolution nondestructive evaluation 2D and 3D imaging and characterization approaches using electromagnetic techniques such as Terahertz and millimeter waves with resolutions of 1-5 mm. Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 prototype demonstration.

TOPIC: X7 Lunar Operations

This call for technology development is in direct support of the Exploration Systems Mission Directorate (ESMD) Technology Development Program. The purpose of this research is to develop new technologies to support lunar exploration missions, providing systems that interact with humans, handle surface equipment and move people and their payloads at, and away from, a lunar outpost. The objective is to produce new technology that will reduce crew extra-vehicular activity (EVA) and intra-vehicular activity (IVA) workloads, lunar operations and reduce the total mass and volume of equipment and materials required to support missions. The proposals should focus on component technologies to improve the operations of exploration equipment, allowing for less expensive, more productive and less risky missions. This research will focus on technology development for the critical functions that fall into three phases of surface exploration. The first phase of surface exploration will be functions that are needed prior to crew arriving at a site. These precursors may be hours, days, weeks or years ahead of the crew landing on the surface. The second phase of surface exploration will be during a crew's stay at the site. This work will include supporting the crew in IVA and in EVA tasks. The third phase of surface exploration will include long-term maintenance of the facility, as well as supporting activities performed between crews.

X7.01 Supportability**Lead Center: JSC****Participating Center(s): GRC, KSC, LaRC, MSFC**

The objective of this subtopic is to develop technologies that can support the goal of significantly reducing the mass and volume of material required to support long-duration human spaceflight missions. Eventually, as the distance of mission destinations increases, resupply will become impossible. Therefore, unless support materials are prepositioned, it will be necessary for all required materials to be transported with the crew. The difficulty presented by this situation is compounded by the need for more material as mission duration increases. Capabilities to address these issues should be developed and demonstrated in conjunction with long duration lunar missions and, as they reach sufficient maturity, will be valuable enhancements to these missions.

This subtopic seeks proposals addressing maintenance and repair technologies that enable repair of failed hardware at all levels, technology that supports the production of replacement components during a mission, and technologies that reduce the quantity of material directly supporting the crew. Proposals are sought which address the following technology needs:

- Real-time, non-destructive evaluation during layer-additive processing for on-the-fly quality control. This will provide capabilities for in-process quality control and may serve as an input for closed-loop process control. Equipment should be portable, compact, and capable of integration with layer-additive manufacturing systems.
- Non-destructive material property determination. This will provide an in-process quality control capability to ensure that material deposited during layer-additive processing meets required material property criteria. Equipment should be portable, compact, and capable of integration with layer-additive manufacturing systems.
- Recycling/generation of feedstock materials for deposition processes. This will provide the capability to recycle failed parts and material removed from near-net-shape parts during machining operations to serve as feedstock material for subsequent layer-additive manufacturing. Initial focus should be placed on metallic materials. Additionally, emphasis should be placed on total system mass and volume.
- Compact, portable multi-axis machining systems. This will provide subtractive manufacturing capabilities to achieve final design dimensions and surface finishes following layer-additive processes that produce near-net-shape parts. Equipment to accomplish this should be of the minimum mass and volume possible while still providing required capabilities.
- Compact, portable, vacuum-compatible multi-axis manipulator. This will provide the capability for complex manipulation of the item itself, the processing equipment, or both during layer-additive manufacturing and machining. To be compatible with the widest variety of candidate processes, manipulation equipment should be vacuum compatible. Additionally, equipment to accomplish this should be of the minimum mass and volume possible while still providing required capabilities.

Rapid manufacturing processes have advanced rapidly in recent decades. The technology has gone from a means of quickly producing models to a means of quickly producing usable hardware. NASA seeks technology improvements which extend the efficiency of rapid manufacturing and improve the properties of resulting components. NASA also seeks to identify different applications that will highlight the capabilities of rapid manufacturing in support of the Vision of Space Exploration and potential commercial applications. NASA also seeks technology focused on integration of rapid manufacturing, computer numerical control, coordinate measuring machines, Robotics and Digital Manufacturing and Simulations technologies. This technology should be focused on an autonomous system where the parts fabricated in rapid manufacturing can be positioned for machining on critical surfaces, then positioned for measurements and inspections and ultimate delivery (independently and remotely). The results should be an autonomous system where these technologies are integrated as modules to produce the end result.

X7.02 Human Systems Interaction**Lead Center: JSC****Participating Center(s): ARC, GRC, GSFC, JPL, KSC, LaRC, MSFC**

The objective of this subtopic is to create an effective and efficient operational interface between a human and a robotic system that is supporting the human. This subtopic seeks to develop technology that reduces the risk of Extra-Vehicular Activity (EVA), improves the productivity of Intra-Vehicular Activity (IVA) and facilitates remote operations by both flight crew and ground control. Automation and robotics capabilities include the ability to use robots for site operations, both at an outpost and at remote lunar surface locations. Site operations support focuses on two types of activities: (1) tedious, highly repetitive, long-duration tasks that cannot be performed by EVA crew and (2) rapid response for addressing emergency, time-critical situations. Candidate tasks include: mobile camera platform control, systematic site survey (engineering and/or science), inspection, emergency response, site preparation (clearing, leveling, etc.), and instrument deployment. Proposals are sought which address the following technology needs:

- Telepresence and variable autonomy teleoperation systems that support human and robot teams operating: (1) in a shared space, (2) close but separated, (3) line-of-sight remote, and lunar. Particular interest is given to systems that flexibly support human-robot operations in the presence of time-delays of up to 10 seconds.
- Adaptive user interfaces including perception, speech recognition, context awareness, computational cognitive models, and collaborative 3D graphics, and EVA display devices (i.e., pressure-suit compatible devices and displays). Specific design objectives include enabling more natural interaction with autonomous systems, facilitating situational awareness, increasing overall productivity by reducing the amount of interaction effort the human has with the robot, and flexibly displaying multi-modal and mission-specific data.
- Geospatial tools for situational awareness including content generation tools for geospatial information, particularly for supporting planetary surface missions; software libraries for generating, parsing, and importing heterogeneous mission data (orbital imagery, navigation information, sensor and instrument readings, etc.); and terrain modeling (Digital Elevation Map).
- Vehicle control components and navigation sensors that support on-board driving, teleoperation, and autonomous operations. Control systems should support multiple control modes, include activity monitoring and operator intent prediction, and tolerate up to 10 seconds of time-delay. Navigation sensors that utilize passive computer vision (real-time dense stereo, optical flow, etc.) and/or active illumination (for recognizing/tracking non-textured objects and operation in permanently shadowed regions) are of particular interest.

X7.03 Surface Mobility and Transportation**Lead Center: JSC****Participating Center(s): ARC, GRC, GSFC, JPL, KSC, LaRC, MSFC**

The objective of this subtopic is to provide new capabilities for delivery, handling, transfer, construction and repackaging of Extra Vehicular Activity (EVA) equipment and preparation of site infrastructure for lunar operations. This includes access/handling and transportation equipment/carriers for delivery and deployment of materials, components, and infrastructure; surface mobility systems to provide the power train for site clearing, pad construction, and regolith manipulation (note that the power train attachments for this activity will be provided by the in situ resource utilization (ISRU) area); and commodities distribution systems (including umbilicals) for routing to equipment and infrastructure. These new capabilities are required to make planetary surface missions more reliable, safer, and affordable.

Several vehicle features will be critical to surface operations: expanded mobility, range and duration, life support recharge, crew following, automated path planning, automated driving, and obstacle avoidance. Vehicles with life support recharge capabilities will extend useful EVA time. The ability of a vehicle to follow a crewmember will enable science and exploration support equipment to be carried for the astronaut as well as extend the traverse

distances. While the utility of autonomy is easily recognized when the crew is not on the surface, these functions could also be advantageous to long traverses and rescue or emergency operations when crewmembers are present.

Proposals are sought which address the following technology needs:

- Lightweight, power-efficient manipulation devices (dexterous and non-dexterous) that can be deployed on small rovers and that are appropriate for multiple tasks. Much of this activity can be performed with teleoperated and semi-autonomous robots controlled from ground. Some of this activity, however, will also require human presence at the site. In both cases, the effectiveness of Human-Robot interaction (HRI) will have a major impact on the efficiency and productivity of mission operations.
- Low-mass, high-strength, long-life wheels capable of spreading supported load over an extended contact patch area and moving over surface terrain similar to loose beach sand. Range, Life, Mass, Mean-time-to-repair, and Mean-time-between-failure are key performance parameters being sought.
- Reliable navigation sensors to support surface mobility by a range of vehicles (ranging from MER-class to LRV-class). For example, a range finder with dynamically-operated foveal aperture could support wide field-of-view scanning and three-dimensional object tracking.
- Navigation and communication infrastructure technologies for use on the Lunar surface to support surface mobility and communication between lunar base, EVA astronaut and mobile rover/robotic assistant.

X7.04 Surface System Dust Mitigation

Lead Center: GRC

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

The general objective of the subtopic is to provide knowledge and technologies (to Technology Readiness Level (TRL) 6 development level) required to address adverse dust effects to exploration surface systems and equipment, which will reduce life cycle cost and risk, and will increase the probability of sustainable and successful lunar missions. The subtopic will help to develop a balance of near- and long-term knowledge and technology development, driven by Exploration Systems Mission Directorate needs and schedule requirements, aligned with existing technology investments where possible. The technical scope of the subtopic includes the evaluation of lunar dust effects and development of mitigation strategies and technologies related to Exploration Surface Systems, such as: Rovers and Robotic Systems, In Situ Resource Utilization (ISRU) Systems, Power Systems, Communication Systems, Airlock Systems and Seals, Habitats, and Science Experiments.

The subtopic specifically requests technologies addressing dynamic mechanical systems used for lunar surface missions with potential to mitigate effects of lunar dust. For lubricated mechanisms, such as drives and pointing mechanisms, the sealing element must be durable enough to maintain a hermetic seal to prevent lubricant out gassing and dust contamination for at least 5 years. Also, the bearings, gears, etc. of the mechanism must be robust enough to survive and provide nominal operation with lunar dust contamination and possible lubrication starvation.

The subtopic also requests proposals for advanced materials, coatings, and related technologies with the proper combination of physical, mechanical, and electrical properties, and lunar environmental durability, suitable for use in dust mitigation applications on the lunar surface.

TOPIC: X8 Energy Generation and Storage

This topic includes the development of power capabilities that are on the critical path to enabling the Exploration Vision including human and robotic exploration missions from Earth orbit to the Moon and ultimately, Mars. Areas of primary interest are: orbital and planetary surface energy storage and non-solar power generation. Flight elements of the Exploration Vision initially include the Orion and ARES crew and launch vehicles, respectively. For lunar capability, additional elements include the Lunar Lander or Lunar Surface Access Module (LSAM), robotic missions, and surface systems. Surface systems include human habitats, Extravehicular Activities (EVA), science measurements, and the utilization of in situ resources. These flight systems require energy storage capabilities up to and greater than 10 kW-hr. Effective solutions require high-capacity, high-energy density, and long-life energy storage systems. Rechargeable lithium-based batteries (e.g., ion, sulphur) that provide energy storage for Exploration missions are required to be human-rated. For the lunar environment, batteries must operate over a greater range of temperatures than current state-of-the-art systems. The Exploration architecture calls for advanced fuel cells to meet the LSAM and surface system power requirements. Fuel cell systems provide power largely independent of environment (solar incidence), which allows greater mission flexibility and provide more power than other energy storage systems. Regenerative fuel cell systems, which combine a fuel cell with a water electrolyzer, will be required to meet long duration surface power energy storage needs. Prior architecture studies have identified nuclear power technology to effectively satisfy high power requirements for extended duration lunar surface missions. Nuclear power generation is especially attractive for missions with significant solar eclipse periods, including non-polar locations and inside lunar craters. Likewise, nuclear power has been identified as a critical power technology for Mars exploration and a lunar deployment is proposed to reduce risk through demonstration and validation of capabilities.

X8.01 Fuel Cells for Surface Systems

Lead Center: GRC

Participating Center(s): JPL, JSC

Energy storage devices are required to enable future robotic and human exploration missions. Advanced regenerative fuel cell (RFC) energy storage systems are sought for use in a wide range of Exploration mission applications including portable power for landers and rovers, and stationary power for surface bases. Technology advances that will reduce the weight and volume, improve the efficiency, life, safety, system simplicity and reliability of RFC systems are desired. The specific advancements of interest are outlined below.

Regenerative Fuel Cell (RFC) Systems: Primary fuel cells and water electrolyzers are the two major constituent subsystems of RFC systems. Of these two subsystems, water electrolyzers are at a lower level of technology readiness than primary fuel cells.

Specifically, technological advances are sought in the area of highly efficient, high-pressure proton-exchange-membrane (PEM) water electrolyzers. Highly efficient operation reduces the total quantity of reactants required, thereby minimizing weight. The efficiency of electrolysis stacks increases by operating at lower current densities. High-pressure electrolysis eliminates or reduces the need for external gas compression prior to reactant storage. The draw-back of high-pressure operation, however, is the increased diffusion of reactants across the proton exchange membrane of the cell, which effectively decreases the efficiency. This efficiency loss is magnified at lower current densities. The challenge, therefore, is to minimize this diffusion at higher operating pressures and low current densities, making efficient electrolysis operation possible.

High-pressure electrolysis systems capable of oxygen and hydrogen gas production at pressures less than 2000 psi are of special interest.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

X8.02 Advanced Space Rated Batteries**Lead Center: GRC****Participating Center(s): JPL, JSC**

Advanced human-rated energy rechargeable batteries are required for future robotic and human exploration missions. Advanced Li-based battery systems are sought for use in a wide range of Exploration mission applications including portable power for landers, rovers, Extravehicular activities (EVA), and astronaut equipment; storage systems for crew exploration vehicles and spacecraft; and stationary energy storage applications such as base power or peaking power applications. Areas of emphasis include advanced component materials with the potential to achieve weight and volume performance improvements and safety advancements in human-rated systems.

Rechargeable lithium-based batteries with advanced non-toxic anode and cathode materials are of particular interest. Technology advancements that contribute to the following performance goals are sought: specific energy greater than 180 Wh/kg, energy density greater than 400 Wh/l, calendar life less than 5 years, cycle life at 100% Depth of Discharge (DOD) greater than 2000 cycles, and fast recharge capability (100% recharge in less than 15 minutes). Systems that combine all of the above characteristics and demonstrate a high degree of safety and reliability are desired.

Proposals are sought which address advanced cathodes with specific capacities in excess of 240 mAh/g at C/2 rate discharge and 25°C and/or advanced anodes with specific capacities in excess of 400 mAh/g at 25°C with minimal irreversible capacity loss.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

X8.03 Nuclear Surface Power**Lead Center: GRC****Participating Center(s): MSFC**

NASA is interested in the development of highly advanced systems, subsystems and components for use with fission and isotopic power systems for future lunar and Mars robotic and manned missions. Proposals are sought for critical technologies for fission and isotopic power systems to meet the following anticipated missions and applications.

The current Vision for Space Exploration identifies the first human lunar landing in 2017 with subsequent longer duration stays of approximately 6 months in 2021. Fission-based systems are anticipated to enable the long duration stay over the lunar night and for “global access” Mars missions. Initial planetary outpost power levels are anticipated to be between 30-50 kWe with anticipated growth to 100’s kWe, accommodating resource production and advanced life support habitation, which require additional power.

Planetary surface human base applications include: habitats, propellant production/liquefaction/maintenance, surface mobility for both robotic and piloted rovers, excavating and mining equipment and science applications such as: deep drilling, resource production demos, weather stations, etc. Isotopic technologies are needed for unique space environments that improve the utilization of a limited fuel supply and have extensibility to fission systems.

Specific technology topics of interest are:

- Advanced, high efficiency, high temperature power conversion less than 20%;
- Electrical power management, control and distribution (1000-5000 V);
- High temperature, low mass thermal management/heat rejection less than 6kg/m²;
- Deployment systems/mechanisms for large radiators, surface mobility systems for remote emplacement of power systems, innovative methodology for use of indigenous shielding materials;

- High temperature materials or coatings compatibility with local soil and atmospheric environments;
- Systems/technologies to mitigate planetary surface environments. Dust accumulation, wind, planetary atmospheres, (CO₂, corrosive soils, etc.);
- Power system design considerations for long life (greater than 10 years), autonomous control and operation, including sensor and control technologies;
- Radiation tolerant systems and materials enabling robust, long life operation;
- Innovative methodologies and approaches to accelerated life testing.

In addition to reducing overall system mass, volume and cost, increased safety and reliability are of extreme importance. It is envisioned that these technologies will be used on robotic and human missions and it is to NASA's advantage to develop those technologies that satisfy both robotic and human mission requirements.

TOPIC: X9 Propulsion and Cryogenic Systems

The Exploration Systems architecture presents some propulsion challenges that require new technologies to be developed. Some of these technologies are for long term cryogenic propellant storage, management, and acquisition; deep throttle cryogenic propellant space engines; pressure-fed liquid oxygen\liquid methane propellant reaction control engines; and pressure-fed liquid oxygen\liquid methane propellant space engines. Furthermore, specific technologies are required in valves, regulators, combustion devices, turbo pumps, ignition, instrumentation, modeling, controls, materials and structures, pressurization, mass gauging, and cryogenic fluid management. The anticipated technologies to be proposed are expected to increase reliability, increase system performance, and be capable of being made flight qualified and certified for the flight systems and dates to meet Exploration Systems mission requirements.

X9.01 Cryogenic Propellant Storage and Distribution for Space Exploration Applications

Lead Center: GRC

Participating Center(s): ARC, GSFC, KSC, JSC, MSFC

This subtopic includes technologies for long term cryogenic propellant storage and distribution applications in-space as well as on the lunar surface. These technologies will impact cryogenic systems for space transportation orbit transfer vehicles, space power systems, spaceports, spacesuits, lunar habitation systems, robotics, and in situ propellant systems. Each of these applications has unique performance requirements that need to be met. The sizes of these systems range from the small (less than 20m³ for supercritical air and payload cooling) to very large (greater than 3400m³ for LOX and LH₂ propellant storage). Advanced cryogenic technologies are being solicited for all these applications. Proposed technologies should offer enhanced safety, reliability, or economic efficiency over current state-of-the-art, or should feature enabling technologies to allow NASA to meet future space exploration goals.

Technology focus areas are divided as follows: passive and active thermal control, pressure control, and propellant feed line conditioning. Innovative concepts are requested for cryogenic insulation systems, fluid system components, and instrumentation. Cryogenic propellants such as hydrogen, methane, and oxygen are required for many current and future space missions. Operating efficiency and reliability of these cryogenic systems must be improved considering the launch environment, operations in a space environment, and system life, cost, and safety. This subtopic solicits unique and innovative concepts in the following technologies:

1) Thermal Control

Passive Thermal Control:

Successful passive thermal control is enabling for all aspects of Cryogenic Fuel Management. The propellant boil-off losses attributable to the passive thermal control subsystem are influenced by Multi-Layer Insulation (MLI) design, MLI to tank attachment techniques and materials, tank to vehicle support structure and attachments, tank size and configuration, tank and insulation penetrations, insulation venting provisions for launch and ascent, flight

and surface environments, vehicle orientation in those environments, and thermal control surface coatings and materials.

Applications/Technology Maturity: The Earth Departure Stage (EDS) and the Lunar Surface Access Module (LSAM) descent stage require LH_2 and LO_2 storage durations of 5 to 95 days in Low Earth Orbit (LEO).

The LSAM ascent stage requires LO_2 and LCH_4 storage durations of up to 95 days in LEO and up to an additional six months on the lunar surface.

Development Needs: Passive thermal control development needs include; integration of MLI with micro-meteoroid protection, tank support structure, and other insulation penetrations. Other development needs include; characterization of the potential advantages of subcooled propellants, investigation of options such as shading, advanced materials, mechanisms and other techniques for passive thermal control on the lunar surface.

Active Thermal Control:

Active thermal control combines the passive thermal control technology element with active refrigeration (cryocoolers) to allow storage periods from a few months to years with reduced boil-off losses.

Applications/Technology Maturity: Flight-type 20K (LH_2) cryocoolers of sufficient cooling capacity (20 watts) to eliminate LH_2 boil-off do not exist, and thus the development of 20K cryocoolers is a long-lead technology item. State-of-the-art cryocoolers in the 80K range (LO_2/LCH_4 temperatures) have been developed for cooling sensors and have flown on numerous satellites. However, the integration of these cryocoolers into an active thermal control system for propellant storage of LO_2 and LCH_4 and LH_2 is a technology issue.

Development Needs: Flight cryocooler to propellant tank integration techniques for large space-based storage systems, distributed cooling shields integrated with MLI and development and testing of active cooling techniques for tank penetrations and supports is required. Development of flight-type 20K, 20 watt capacity cryocoolers designed for integration into large space-based LH_2 storage systems is also required for application to Mars missions.

2) Pressure Control

Controlling cryogenic propellant tank pressure in low gravity with minimum boil-off losses without settling the propellants can be accomplished with a thermodynamic vent system (TVS). A TVS subsystem typically consists of a pump for circulation and mixing, a Joule Thompson expansion device/heat exchanger for heat removal, valves and a vent line.

Applications/Technology Maturity: A TVS will be required for the EDS, LSAM and the LO_2/LCH_4 version of the Orbital Maneuvering Systems (OMS) and Reaction Control Systems (RCS) for the CEV.

Development Needs: EDS, LSAM and CEV development needs include innovative TVS configurations and applications, system integration and control and modeling of low-gravity fluid dynamics and heat transfer for specific TVS designs. EDS, LSAM and CEV vehicle advanced development needs include integrated system testing with LH_2 , LO_2 and LCH_4 to determine the effect of internal tank hardware configuration on fluid mixing.

3) Propellant Feed Line Conditioning:

Maintaining vapor-free liquid propellant between the tank outlet and the OMS/RCS engine inlet is a significant technology challenge. For lunar in situ cryogenic applications, systems are needed to store and transfer to warm tanks in the dusty lunar surface environment.

Applications/Technology Maturity: Propellant feed line conditioning will be required for all vehicles with a cryogenic OMS/RCS. Specific feed line configuration, routing and heat loads for each vehicle must be addressed.

Development Needs: CEV, EDS and LSAM vehicle development needs includes integrated system testing with LH₂, LO₂ and LCH₄ to address vehicle specific feed line routing and heat loads, and couplings for lunar in situ propellant systems.

X9.02 Cryogenic Propellant Mass Gauging and Liquid Acquisition for Low Gravity Applications

Lead Center: GRC

Participating Center(s): MSFC

This subtopic includes technologies for applications related to cryogenic propellant management in low gravity. Liquid Acquisition Device (LAD) and Mass Gauging (MG) technologies will principally impact cryogenic systems for Orbital Maneuvering Systems (OMS) and Reaction Control Systems (RCS) for orbit transfer vehicles for in-space transportation applications, and are critical to successful liquid propellant delivery to Orbital Maneuvering Systems (OMS) and Reaction Control Systems (RCS) propulsion system and allowance of smaller propellant tank residuals to assure mission success. Advanced cryogenic technologies are being solicited for all these applications. Proposed technologies should offer enhanced safety, reliability, or economic efficiency over current state-of-the-art, or should feature enabling technologies to allow NASA to meet future space exploration goals.

Technology focus areas are divided as follows: liquid acquisition devices and mass gauging/advanced instrumentation. Innovative concepts are requested for devices that interface with the tank and provide vapor-free liquids for on-orbit propulsion systems, low-gravity mass gauging technologies to enable accurate and reliable measurements of cryogenic liquid mass in low-gravity storage tanks without propellant settling or undue constraints on mission, and cryogen leak detection technologies. Cryogenic propellants such as hydrogen, methane, and oxygen are required for many current and future space missions. Operating efficiency and reliability of these cryogenic systems must be improved considering the launch environment, operations in a space environment, and system life, cost, and safety. This subtopic solicits unique and innovative concepts in the following technologies:

1) Liquid Acquisition:

Providing vapor free cryogenic propellants to in-space propulsion systems at expulsion efficiencies less than 98% without settling the propellants is the objective of the liquid acquisition technology element. Capillary liquid acquisition devices (LADs) are state-of-the-art for toxic propellants, but have not yet been developed for cryogenics. Existing cryogenic upper stage main engine restarts use auxiliary thrusters to settle the propellants.

Applications/Technology Maturity: Cryogenic LADs will be required for the LO₂/LCH₄ version of the OMS/RCS for the CEV and LSAM and possibly the EDS. LH₂ LAD performance represents the primary challenge while LO₂ and LCH₄ performance risk is substantially less if the liquids are sub-cooled relative to the propellant tank ullage pressure.

Development Needs: Liquid acquisition technology needs include investigation of helium solubility and heat entrapment effects, propellant tank LAD integration, LAD materials selection, analytical performance model development, and techniques to minimize vaporization inside the LAD channel caused by incident heating through tank wall/lines and/or changes in tank pressure. CEV, LSAM and possibly the EDS vehicle advanced development needs include integrated system testing with LH₂, LO₂ and LCH₄ to determine the effect of internal tank hardware configuration on LAD performance.

2) Mass Gauging/Advanced Instrumentation:

The need for a reliable, accurate method for measuring cryogenic propellant mass without settling the propellants is the principal objective of the mass gauging technology element.

Applications/Technology Maturity: Applications for cryogenic mass gauging include the EDS, LSAM and the CEV OMS/RCS. A measurement uncertainty metric of less than 3% of full-tank mass has been established for the propellant mass measurements for these vehicles.

Development Needs: Methods of determining liquid quantity gauging in propellant tanks in low gravity, high accuracy differential pressure transducers which can operate submerged in liquid cryogen, and in-space cryogenic fluid leak detectors.

X9.03 Cryogenic and Non-Toxic Storable Propellant Space Engines

Lead Center: GRC

Participating Center(s): JSC, MSFC

This solicitation intends to examine a range of key technology options associated with cryogenic and non-toxic storable propellant space engines. Non-toxic engine technology is desired for use in lieu of the toxic but currently operational nitrogen tetroxide and monomethylhydrazine engine technology. Safety concerns with toxic propellants drive mission planners to the use of more costly propulsion modules that are fueled and sealed on the ground. There are also concerns with exhaust residue from toxic systems, which may be carried into habitats for lunar and Mars systems.

The primary mission will be to support lunar ascent/descent reaction control engines and lunar ascent engines. These engines can be compatible with the future use of in situ propellants such as oxygen, methane, and methanol. Key performance parameters:

- Reaction control thruster development is in the 100-500-lbf thrust class with a target vacuum specific impulse of 325-sec. These RCS engines would operate cryogenic liquid-liquid for applications requiring integration with main engine propellants; or would operate gas-gas or gas-storable liquid for small total impulse type applications.
- Ascent engine development is projected to be in the 3,500-6,000-lbf thrust class with a target vacuum specific impulse of 355-sec. The engine shall achieve 90% rated thrust within 0.5 second of the issuance of the Engine ON Command.

Specific technologies of interest to meet proposed engine requirements include:

- Low-mass propellant injectors that provide stable, 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;
- Combustion chamber thermal control technologies such as regenerative, transpiration, swirl or other cooling methods which offer improved performance and adequate chamber life;
- Highly-reliable, long-life, fast-acting cryogenic valves that tolerate high thermal loading due to heat soak-back in low-thrust, pulsing propulsion systems (Thermal Isolation less than 1 Btu/hr) with reduced volume and size is also desirable;
- Highly-reliable, long-life, fast-acting propellant valves for gaseous propellants with reduced power, volume and size.

A key risk related to the use of cryogenic and gaseous propellants such as oxygen and methane are the ability to reliably ignite the propellants in a timely manner. This is of particular importance on ascent engines during abort operations. Recently NASA has been conducting a number of investigations into the ignition characteristics for oxygen and methane, primarily for spark torch systems. NASA continues to be interested in new and innovative methods which may be used as primary or back-up systems. Proposals are also solicited for igniter exciter technologies. In particular, for reaction control systems involving multiple engines that are not all co-located, issues between distributed vs. centralized exciter architectures must be balanced when selecting an exciter design. A “distributed” system refers to an integral exciter at each spark plug, whereas a “centralized” arrangement has at least some exciter components (e.g., DC-DC converter, control electronics, etc.) remotely located (e.g., with other avionics) and shared by multiple engines/spark plugs. Specific technologies of interest include:

- Reliable ignition systems such as spark torch, catalytic, microwave, combustion wave, laser, etc.;
- Exciters to support either capacitive (CDI) or inductive (IDI) discharge ignition types;
- High cycle spark plugs for use with cryogenic and/or gaseous propellants;
- Cryogenic instrumentation such as pressure and temperature sensors that will operate for months/years instead of hours.

X9.04 Launch Vehicle Propulsion and Pyrotechnic Technologies

Lead Center: MSFC

Participating Center(s): GRC

The goal of this subtopic is the development of innovative components, manufacturing techniques, health management systems, and design and analysis tools for launch vehicle propulsion and pyrotechnic systems. Performance, reliability, and cost of operations improvements to existing and planned Constellation launch vehicle propulsion and pyrotechnic systems are needed. Technologies that would contribute to decreased sensitivity to manufacturing and handling effects, that will lead to reduction in development and qualification testing, and that will lead to reduction in touch labor during ground operations and vehicle turnaround are particularly welcomed. Also solicited are proposals that would reduce the time, cost, and complexity associated with designing and analyzing launch vehicle propulsion and pyrotechnic systems. While solid or hybrid rocket propulsion is specifically emphasized, compelling proposals related to liquid engine boost propulsion are also invited.

Specific areas of interest include:

- Concepts for solid or hybrid propulsion systems and related components that would lead to increased payload mass fraction over current solid rocket motors.
- Concepts for solid or hybrid auxiliary propulsion systems that can be throttled to provide enhanced vehicle maneuverability; technology that supports applicability of these systems for in-space primary propulsion is also of interest.
- Health management technologies, including embedded sensors and modeling methodologies, that would improve the ability to monitor the reliability of solid or hybrid rockets during manufacturing, handling, and flight.
- Manufacturing techniques improvements that allow for reductions in the cost and schedule required to fabricate and test solid or hybrid rockets.
- New propellant ingredients or formulations that would increase the propellant specific impulse while maintaining a Department of Transportation Class 1.3 hazard classification; proposals that would experimentally synthesize and characterize new ingredients, or formulate and demonstrate new propellants are encouraged.
- Retrofittable technologies to existing boost liquid engines that address the goals of performance enhancement and/or lower operations cost.
- Improvements in explosive bolt technology, both for traction as well as ejector bolts, to improve handling safety and increasing robustness of installation.
- Improvement to detonators to reduce the required initiation power, or to provide integrated safe-and-arm functions within detonator.
- Wireless or optical approaches for initiation of explosive bolts and frangible nuts for reduced system weight and improved safety.
- Improvements to explosive cutters, cutting chords, and specialty cutting charges to reduce installation labor, check-out labor, and sensitivity to environmental, handling, and ageing effects without reducing reliability.
- Analysis tools that support development and operation of launch vehicle propulsion systems (liquid, solid, or hybrid) by allowing for a more accurate definition of the environment internal to the propulsion system. Test data that provides for validation of existing design and analysis tools is also sought.
- Improvement to the design and analysis tools that support pyrotechnic devices development and integration into the launch vehicle system, especially those tools that define the induced environments created during

and immediately after the action time of the pyrotechnic device; Test data to validate and quantify uncertainty in launch vehicle pyrotechnic devices design and induced environments.

Proposals that address more than one of these items are highly encouraged.

TOPIC: X10 Protection Systems

The Thermal Protection System (TPS) protects a spacecraft from the severe heating encountered during hypersonic flight through a planetary atmosphere. In general, there are two classes of TPS: reusable and ablative. Typically, reusable TPS applications are limited to relatively mild entry environments like that of Space Shuttle. No change in the mass or properties of the TPS material results from entry with a significant amount of energy being re-radiated from the heated surface and the remainder conducted into the TPS material. Typically, a surface coating with high emissivity (to maximize the amount of energy re-radiated) and with low surface catalyticity (to minimize convective heating by suppressing surface recombination of dissociated boundary layer species) is employed. The primary insulation has low thermal conductivity to minimize the mass of material required to insulate the primary structure. Ablative TPS materials, in contrast, accommodate high heating rates and heat loads through phase change and mass loss. All NASA planetary entry probes to date have used ablative TPS. Most ablative TPS materials are reinforced composites employing organic resins as binders. When heated, the resin pyrolyzes producing gaseous products that are heated as they percolate toward the surface thus transferring some energy from the solid to the gas. Additionally, the injection of the pyrolysis gases into the boundary layer alters the boundary layer properties resulting in reduced convective heating. However, the gases may undergo chemical reactions with the boundary layer gases that could return heat to the surface. Furthermore, chemical reactions between the surface material and boundary layer species can result in consumption of the surface material leading to surface recession. Those reactions can be endothermic (vaporization, sublimation) or exothermic (oxidation) and will have an important impact on net energy to the surface. Clearly, in comparison to reusable TPS materials, the interaction of ablative TPS materials with the surrounding gas environment is much more complex as there are many more mechanisms to accommodate the entry heating. NASA has successfully tackled the complexity of thermal protection systems for numerous missions to inner and outer planets in our solar system in the past; the knowledge gained has been invaluable but incomplete. Future missions will be more demanding. For example, if existing materials were to be used for the proposed Mars Sample Return mission, the TPS mass fraction would be on the order of 40%. The potential savings that could be achieved with some investment in TPS technology development is sizeable.

X10.01 Detachable, Human-rated, Ablative Environmentally Compliant TPS

Lead Center: ARC

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

The Crew Exploration Vehicle (CEV) will first be used for transporting crew and cargo to the International Space Station and later for the human exploration of the Moon and Mars. The TPS for the CEV will have to protect the crew and cargo from entry heating at entry velocities of approximately 8 km/s for International Space Station missions, 11 km/s for lunar return missions, up to 8 km/s for Martian aerocapture and entry, and between 12-15 km/s for Martian return missions. Ablative TPS is an enabling technology for all CEV superorbital reentry missions.

Ablation Modeling

The heat shield for CEV will employ a thermal protection system (TPS) material that pyrolyzes and ablates at high temperature for mass-efficient rejection of the aerothermal heat load. Pyrolysis is an internal decomposition of the solid that releases gaseous species, whereas ablation is a combination of processes that consume heat shield surface material (including chemical reactions, melting, and vaporization). For the design and sizing of TPS materials, it is imperative to have reliable simulation tools that can compute surface recession rate, in-depth pyrolysis, and internal temperature histories under general heating conditions. In addition, lunar and Martian reentry environment heating will consist of significant radiation from the shock layer. The models need to include the effect of not only convective but radiative heating as well.

Therefore, advances are sought in modeling of radiation, gas surface interactions, ablation mechanisms, pyrolysis, and other processes such as coking and charring. Specifically for charring, advances are sought in the development of a low density charring ablator model to give insight into how conductivity changes as function of temperature and pressure for the virgin material and for the material as it pyrolyzes.

Shape Optimization/Entry System Architectures

The design of a reentry craft must encompass not only aerothermodynamic heating concerns but also the conflicting constraints of aerodynamic stability, mass, and cross-range performance. Therefore, the TPS cannot be designed in isolation but must be viewed as a part of a whole. Advances are sought in multidisciplinary design optimization (MDO) methods such as gradient methods and genetic algorithms.

Instrumentation

Thermal Protection System (TPS) sensors and experimental diagnostic tools are required to provide traceability of TPS sizing tools, design, and material performance. Traceability will lead to higher fidelity design tools, which in turn will lead to risk reduction and decreased heat shield mass on missions requiring atmospheric aerocapture or entry/reentry. Decreasing heat shield mass will enable certain missions that are not otherwise feasible and directly increase payload. Heat flux sensors and surface recession diagnostic tools are essential to advancing the state of TPS traceability for material modeling and aerothermal simulation.

Advances in the understanding of how heat flux sensor performance changes upon integration of the sensors into TPS materials in ablative environments through simulation or experimental investigation are sought. Specifically, the following list of sensor materials is of primary interest:

- Type K, C, R, and S thermocouples
- Sapphire windows
- Inconel superalloys
- Pure platinum
- Teflon

For surface recession, advances in optical methods (photometrics/tomography) are sought.

Non-destructive Testing Techniques and Novel Techniques for Material Characterization:

The CEV heat shield will be the largest ever built. During manufacturing and integration, it will be necessary to understand the variability in material properties, to determine voids and inclusions, to assess bond line integrity, and to ensure that the established flight heat shield requirements are met.

For this purpose, advances in NDE and proposals of novel techniques for material characterization applicable for ablative TPS are sought.

Ablation Materials Development

Early NASA missions [Gemini (1964-1966), Apollo (1966-1973), and Mars Viking (1976)] employed new ablative TPS materials that were tailored to each specific entry environment. However, after Mars Viking, NASA-sponsored ablative TPS development essentially ceased as the research focus shifted to reusable TPS in support of the Space Shuttle. For example, the Pioneer Venus (1978) and Galileo (1995) missions employed carbon phenolic TPS material that had previously been developed by the United States Air Force for ballistic missile applications. Over the past 40 years, NASA has adopted a risk averse philosophy relative to TPS, i.e., use what was used before since it has been flight-qualified. For Mars Direct Return, the entry velocities will be in the range of 12-15 km/s. Heritage carbon phenolic can satisfy Mars Return requirements however the TPS mass fraction would be less than optimal. Thus, advances toward new reliable and efficient TPS materials are desired. Similarly, development of adhesives, joints, penetrations, and seals are of equal importance and advances are sought. Advances are sought in material development to address survivability in the severe convective and radiative heating environment and to address mass

constraints and technological developments to address flow stability concerns and control authority in the face of atmospheric uncertainties and targeting errors. Advances and innovative concepts in integrated TPS design for multi-mission modes (aerocapture followed by entry requiring multi-use ablators vs. multi-layered ablators) are sought.

TOPIC: X11 Thermal Management

Future spacecraft will be in low Earth orbit, travel to the Moon, and travel to Mars, Jupiter, Venus, and their moons. Innovative thermal management technologies are needed to manage the waste heat from these spacecraft as efficiently as possible.

X11.01 Thermal Control for Surface Systems and Spacecraft

Lead Center: JSC

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

Advanced technologies are sought for thermal management of Earth-orbiting spacecraft, the human lunar habitat, landers, and rovers, for Martian transit spacecraft, as well as planetary expeditions to Jupiter, Venus, and their moons. Future spacecraft will require more sophisticated thermal control systems that can dissipate or reject greater heat loads at higher input heat fluxes while using fewer of the limited spacecraft mass, volume and power resources. The thermal control designs also must accommodate the harsh environments associated with these missions including dust and high sink temperatures. Modular, reconfigurable designs could limit the number of required spares.

Earth-orbiting spacecraft contain instruments, such as LIDAR lasers and electronics systems and/or components, which can generate high thermal dissipation loads at high heat flux rates. Spacecraft instruments can have tight temperature control requirements and/or thermal gradient requirements (micro-Kelvin requirements). Spacecraft instruments operate in temperature regimes ranging from cryogenic to above ambient (-180°C to +100°C). Radioisotope thermoelectric generators (RTGs) generate relatively large amounts of heat. Design plans for Earth-orbiting spacecraft seek smaller (down to MEMS level components or instruments) and reconfigurable designs.

The lunar environment presents several challenges to the design and operation of active thermal control systems. During the Apollo program, landings were located and timed to occur at lunar twilight, resulting in a benign thermal environment. The long duration polar lunar bases that are foreseen in 15 years will see extremely cold thermal environments, as will the radiators for Martian transit spacecraft. Long sojourns remote from low-Earth orbit will require lightweight, but robust and reliable systems.

Innovative thermal management components and systems are needed to accomplish the rejection of heat from lunar bases. Advances are sought in the general areas of radiators, thermal control loops and equipment. Radiators on the Moon's poles and on a Martian transit vehicle are required that will operate and survive in very cold environments. Variable emissivity coatings, clever working fluid selection, or robust design could be used to prevent radiator damage from freezing at times of low heat load. Also, the dusty environment of an active lunar base may require dust mitigation and removal techniques to maintain radiator performance over the long term.

The lunar base and Martian transit spacecraft active thermal control systems will include high efficiency, long life mechanical pumps. Part of the thermal control system in the lunar base is likely to be a condensing heat exchanger, which should be designed to preclude microbial growth. Small heat pumps could be used to provide cold fluid to the heat exchanger, increasing the average heat rejection temperature and reducing the size of the radiators.

Thermal management of the lunar habitat, landers, and rovers may require mechanically pumped two-phase fluid loops. Innovative design of the loops and components is needed.

A scaling methodology is needed to allow long term 1-g testing of two-phase systems (including pumped two-phase loops, heat pumps, and condensing heat exchangers) representative of the 1/6th Earth-normal gravity of the Moon.

TOPIC: X12 Exploration Crew Health Capabilities

Human exploration capabilities must keep the crew healthy so they can adequately perform their mission and return safely to Earth. These subtopics seek innovative technologies to prevent degradations in performance and health from the adverse physiological responses to the space flight environment and to provide medical support in both normal activities and medical emergencies. They assure that there will be no long-term adverse health consequences while supporting a healthy and productive sustained human presence.

X12.01 Health Preservation in the Space Environment

Lead Center: JSC

Participating Center(s): ARC, GRC

Living and functioning efficiently and safely in space and in the hypogravity of the Moon (1/6g) or Mars (3/8g), requires an understanding of the effects of micro- and hypogravity and other space-environment related factors on human physiology responses and adaptations to a unique set of imposed demands. As a result, a variety of countermeasures are needed to mitigate the deleterious changes that occur during space flight and upon subsequent exposure to reduced-gravitational environments. The ability to monitor the effectiveness of countermeasures and alterations in human physiology during space exploration missions, particularly when several countermeasures are used concurrently, is equally important. This subtopic seeks innovative technologies in several very specific key areas. As launch costs relate directly to mass and volume, instruments and sensors must be small and lightweight with an emphasis on multi-functional capabilities. Low power consumption is a major factor, as are design enhancements to improve the operation, design reliability, and maintainability of these instruments in the environment of space and on planetary surfaces. As the efficient use of time is extremely important, innovative instrumentation setup, ease of usage, improved astronaut (patient) comfort, noninvasive sensors, and easy-to-read information displays are also very important considerations. Extended shelf-life and ambient storage conditions of consumables are also key necessities. Ability to operate in 0g, 1/6g, and 3/8g become more important as we march towards human Moon and Mars missions.

Non-invasive Pharmacotherapy and Monitoring

Development of innovative technologies resulting in non-invasive methods for diagnosis, treatment, and therapeutic drug monitoring is needed to facilitate effective pharmacotherapy of humans in space. Many questions remain about the effectiveness of pharmaceuticals in micro- and hypogravity environments, which may interfere with their activity by sensitizing or desensitizing the crew member or interfering in other ways with the desired physiological effect. Micro-encapsulation of drugs and development of novel drug delivery systems under micro- and hypogravity conditions. Devices for continual monitoring of physiology during pharmacotherapy would also be advantageous to ensure that on-orbit expression of therapies relates to on-Earth histories.

Non-invasive Technology to Assess Bone Micro- and Macroarchitecture

A complete assessment of bone strength will better monitor life-time skeletal integrity and will generate data critical for developing probability fracture risk models in younger-aged crew. Novel technology for non-invasive assessments of “bone quality” indices such as microarchitecture, macroarchitecture and trabecular Bone mineral density (BMD).

Technologies to Detect Biomarkers

Develop technologies to detect products of bone demineralization in urine during Flight and the biomarkers of bone degradation include N-telopeptide (NTX), C-telopeptide (CTX), pyridinoline and deoxypyridinoline collagen cross-links [PYR and dPYR], and calcium ion. Develop technologies to monitor bone specific alkaline phosphatase and osteocalcin in serum samples.

Portable Motion Simulator

Develop a portable research platform to investigate the influence of spatial disorientation on manual control tasks during lunar-type landings. A 6-DOF motion simulator with full visual motion display will be developed to simulate landing tasks with and with visual motion (brownout) conditions. The simulator should be portable, and fit within standard (8 ft) room heights. The power requirements should be limited to 240VAC 30A. The subject restraint should accommodate both standing and seated positions. The control system should allow the user to import motion profiles, and provide the capability to evaluate various pilot-induced filter (PIO) options from a hand-held controller.

X12.02 Crew Exercise Systems

Lead Center: JSC

Participating Center(s): GRC

1) Identify compact, multi-function exercise devices to protect muscle and cardiovascular health during lunar sortie missions (missions with total duration less than 30 days). This device must be 10kg or less including all accessories, require no vehicle power to operate, include materials/components that can be flight certified and do not pose risk to the crew vehicle/habitat, and be stowed within 1 cubic foot of space aboard the Crew Exploration Vehicle/Orion and/or Lunar Surface Access Module. The device must be require no crew calibration or maintenance (for missions less than 30 days), require minimal deployment/setup time (easily portable between vehicles), and include instrumentation to document exercise session parameters using portable electronic media. The device must be capable of providing whole body and individual joint resistive loading that ideally simulates free weights. The load must be adjustable in increments no greater than 2.5 kgs and provide adequate loading to protect muscle strength to levels specified per the NASA Space Flight Human System Standards, Volume 1. The same device must be capable of providing whole-body aerobic exercise levels necessary to maintain aerobic fitness per the NASA Space Flight Human System Standards, Volume 1.

2) Identify compact, reliable multi-function exercise devices/systems to protect bone, muscle, and cardiovascular health during lunar outpost missions (missions with total duration less than 6 months). This device should be easily configured and stowed, require minimal power to operate, include instrumentation to document exercise session parameters including portable electronic media, and require minimum periodic calibration (no more than 2X/year). The device must be capable of providing whole body axial loading and individual joint resistive loading that ideally simulates free weights. If unable to match the inertial properties of free weights, then the device must provide near constant loading at any given load setting and achieve an eccentric to concentric load ratio greater than 90%. The load must be adjustable in increments no greater than 2.5 kgs and provide adequate loading to protect muscle strength and bone health to levels specified per the NASA Space Flight Human System Standards, Volume 1. The same device must be capable of providing whole-body aerobic exercise levels necessary to maintain aerobic fitness per the NASA Space Flight Human System Standards, Volume 1. Finally, the ideal device should also stimulate the sensory-motor system which controls balance and coordination.

3) Identify small, lightweight, sensor-based exercise monitoring systems that can be used to assess periodic fitness during lunar outpost missions and transit to Mars. Devices should be small, employ re-usable elements (versus requiring consumables), and be minimally invasive to measure heart rate and rhythm, oxygen consumption and lactic acid threshold. The ideal system would also include other medical monitoring capabilities such that it could be utilized to assess other crew health variables (e.g., imaging capabilities, respiration rate, blood parameters, etc.).

X12.03 Exploration Medical Capability

Lead Center: GRC

Participating Center(s): ARC, JSC

On-board clinical diagnostics to monitor crew member physiology must be available for both mid-term lunar and long-term Mars exploration missions. As in terrestrial medicine, devices with which to measure multiple constituents of small volume samples of bodily fluids are crucial components in assessing astronaut health. Nevertheless,

mass, space, and power requirements of such devices are an obvious concern in an environment with scarce resources. Miniaturized laboratory analysis sensors represent a potential solution, given that these devices and supporting hardware are designed to be small, lightweight, and require little power. However, current sensor cartridges are typically single-use with limited shelf life. In order to satisfy the needs of longer duration exploration missions, reusable laboratory analysis sensors with increased shelf life must be designed without compromising accuracy or sensitivity. NASA seeks proposals for developing such reusable laboratory analysis sensors for measuring complete blood count with differential. Both the actual chips and associated electronics should minimize the use of electrical power and be as small as possible. Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 breadboard demonstration.

TOPIC: X13 Space Human Factors and Food Systems

The new Vision for Space Exploration encompasses needs for innovative technologies in the areas of Space Human Factors and Food Systems. Operations in confined, isolated, and foreign environments can lead to impairments of human performance. This Topic seeks methods for monitoring, modeling, and predicting human performance in the spaceflight environment. These methods and tools are needed for accurate and valid human system integration into vehicle design and operations. Additionally, significant advancements in food technologies will be needed for long-duration Lunar and Mars missions. This Topic seeks innovative technologies for providing shelf-stable food with a shelf-life of 3 – 5 years, new food packaging technologies that eliminate or minimize waste, and new technologies for on-orbit meal preparation and dining.

X13.01 Space Human Factors Assessment Tools

Lead Center: JSC

Participating Center(s): ARC

The Human Research Program (HRP) and the Behavioral Health and Performance Research Program (BHP) are among NASA's major Space Human Factors research programs. In collaboration with these two programs, the SBIR program is looking for research proposals that address the following two research areas: (1) an Automated Human Factors Incident Reporting Tool (AHFIRT) and (2) a Cognitive Assessment Tool (CAT).

Automated Human Factors Incident Reporting Tool (AHFIRT)

The HRP provides human health and performance countermeasures, knowledge, technologies, and tools to enable safe, reliable, and productive long-duration human space exploration. Objectives of the HRP include developing capabilities and technologies to support and mitigate risks to crew health and performance, reducing human systems resource requirements (mass, volume, power, data, etc.), and ensuring effective human-system integration across exploration systems.

To support these objectives, the HRP determines that obtaining timely and context-specific Human Factors (HF) incidents data is a technology gap the program wants to address. Currently, space HF data come from crew debriefs. Such debriefs rely on retrospective recall, which could suffer delays of up to six months. Furthermore, opportunities to discuss HF issues in detail during these debriefs are limited. Consequently, the HRP sees the need to develop an Automated Human Factors Incident Reporting Tool (AHFIRT).

Objective: Development of an AHFIRT that assists the gathering and reporting HF incidents for long-duration space missions.

Requirements: In general, the AHFIRT will be used to help detect areas where HF can contribute to mission success, access the effects of operational and hardware changes, and complement existing HF data sources for operations including crew debriefs. Specifically, the AHFIRT shall meet the following requirements:

- The crew shall have easy access to the tool at any time to eliminate the need for the crew to recall information retrospectively.
- An easy-to-use data gathering protocol with the following functionalities:
 - Allow data to be entered either as text, audio, and/or video inputs
 - It is desirable for AHFIRT to detect system anomaly automatically and immediately record system status. At the minimum, however, the tools should provide an easily accessible event marker for the crew to mark the context and take a snapshot of the system and operator system status.
- Provide a user-friendly automated data search engine for extracting meaningful incident information from the raw data. Examples of desirable search schemes include natural language, spatial, temporal searches, etc.

Phase 1 Requirements: Technology Evaluation

The technical merit of the AHFIRT will be explored to evaluate feasibility. This process shall include:

- Evaluating/researching/developing automated data mining technologies
- Defining optimal data gathering protocol
- Determining optimal hardware/software design
- Developing hardware and software algorithms

Phase 2 Requirements: Prototype Development

The process shall include:

- Developing a working AHFIRT prototype
- Evaluate and test the functionality and usability of the prototype device

Cognitive Assessment Tool (CAT)

The NASA Behavioral Health and Performance Research Program (BHP) identifies and characterizes the behavioral health and performance risks associated with training, living and working in Space, and return to Earth. The BHP Research Element develops strategies, tools, and technologies to mitigate these risks. Currently, the BHP has the need for a Cognitive Assessment Tool (CAT).

Due to the high-intensity workload, disturbed sleep conditions, and other stressors of spaceflight, some astronauts have reported experiences of disturbed cognitive processes and fatigue.

Presently, a tool is utilized on the International Space Station (ISS) to detect neurocognitive deficits as a result of physical changes to the brain, which can occur from an injury to the head or exposure to a toxin. However, this assessment is designed as a programmed test that is not sensitive to crewmember fatigue. Consequently, there has been increased interest for a validated tool that that can:

- Detect cognitive decrements as a result of fatigue or other stressors of spaceflight
- Support the Astronauts with an entertaining assessment activity(s)
- Support crew autonomy by providing objective feedback directly to the crewmember regarding their behavioral health

Objective: Design, develop, and fabricate a handheld, CAT that is in the form of a video game.

Requirements: The CAT game may include a suite of games as opposed to one single game. Ideally, the game would determine whether the player's deficit is a result of fatigue, stress, or neurocognitive impairment. Specifically, the CAT shall be as follows:

- In a hand-held video game format
- Portable hand-held unit

- Enjoyable and entertaining
- Flexible enough for increasing levels of difficulty
- Able to detect and identify cognitive decrements catalysts such as fatigue, stress, and/or neurocognitive deficits
- Able to provide immediate feedback to crewmembers, especially flight surgeons, with recommended countermeasure(s) based on his/her cognitive performance to support crew autonomy

Potential means for the CAT to assess performance may include measures of:

- Reaction times
- Accuracies
- Memory recall
- Complex decision making
- Physiological measures, such as heart rate via thumbs
- Speech acoustic analysis
- Facial monitoring
- Eye analysis

Note that the aforementioned methods are provided as examples of current research developments and are not intended as an all-inclusive or restrictive mandate for the development of the CAT.

Phase 1 Requirements: CAT Start-Up

The technical merit of the CAT will be explored to evaluate feasibility. This process will include:

- Defining predictors of cognitive decrements
- Determining which aspects of cognition should be assessed
- Determining optimal hardware design
- Hardware and software algorithms development

Phase 2 Requirements: CAT Research and Development

Content development of the CAT games should be determined based upon results of a qualitative study conducted with sample population (similar to Astronauts) to ensure corroboration and interest prior to the following stages:

- Develop software for gaming, data analysis, feedback, and recommended countermeasures
- Develop prototype hardware
- Develop manual and trouble shooting guide
- Evaluate and test the functionality of the prototype device.

X13.02 Advanced Food Technologies

Lead Center: JSC

The purpose of the Advanced Food Technology Project is to develop, evaluate and deliver food technologies for human centered spacecraft that will support crews on missions to the Moon, Mars, and beyond. Safe, nutritious, acceptable, and varied shelf-stable foods with a shelf life of 3 – 5 years will be required to support the crew during future exploration missions to the Moon or Mars. Concurrently, the food system must efficiently balance appropriate vehicle resources such as mass, volume, water, air, waste, power, and crew time. One of the objectives during the lunar outpost missions is to test technologies that can be used during the Mars missions.

This subtopic will concentrate on two specific areas; food packaging and lunar outpost food preparation and food processing.

Non-Foil High Barrier Materials

Development of shelf-stable food items that use high-quality ingredients is important to maintaining a healthy diet and the psychosocial well being of the crew. Shelf-life extension may be attained through new food preservation methods and/or packaging. New food packaging technologies are needed that have adequate oxygen and water barrier properties to maintain the foods' quality over a 3 - 5 year shelf life. The packaging must also minimize waste by using high barrier packaging with less mass and volume.

The current flexible pouch packaging used for the thermostabilized and irradiated food items contains a layer of foil. Although the foil provides excellent oxygen and water barrier properties, it also contributes to added waste. Food packaging will be a major contributor to the trash on the lunar or Mars surface. One of the proposed methods to dispose of trash on the lunar or Mars surface is incineration. However, the foil layer will not incinerate completely and there will be ash formed.

Two emerging food preservation technologies, high pressure processing and microwave processing, are being considered for future NASA missions. However the current high barrier packaging material cannot be used for these processes. The material delaminates during high pressure processing and cannot be used in microwave processing. Hence, any food packaging material developed in response to this subtopic should be compatible with one or more of the following food preservation technologies – retort processing, microwave processing, and/or high pressure processing. In addition, the material should have an oxygen transmission rate that shall not exceed 0.06 cc/m²/24 hrs/atm and a water vapor transmission rate that shall not exceed 0.01 gm/m²/24 hrs as stated in the MIL-PRF 33073F specification.

Effect of Partial Gravity and Reduced Atmospheric Pressure

It will require approximately 10,000 kg of packaged food for a 6-crew, 1000 day mission to Mars. For that reason, it has been proposed to use a food system which incorporates processing of raw ingredients into edible ingredients and uses these edible ingredients in recipes in the galley to produce meals. This type of food system will require food processing and food preparation equipment. The equipment should be miniaturized, multipurpose and efficiently use vehicle resources such as mass, volume, water, and power. Food preparation may include gourmet kitchen appliances such as food processors or bread makers in addition to the standard stove and oven. Proposed food processing equipment may include a mill to produce wheat and soy flour, a soy milk/tofu processor, and a concentrator.

The Moon's gravity is 1/6 of Earth's gravity. In addition, it is being proposed that the habitat will have a reduced atmospheric pressure of 8 psia which is equivalent to a 16,000 foot mountain top. These two factors will affect the heat and mass transfer during food processing and food preparation of the food. Heat transfer is required for proper microbial kill and to produce the desired texture and appearance of the food prior to consumption. At this pressure, the boiling temperature of water will be 181°F which has significant implications for preventing microbial contamination and to acceptable food quality.

Prior to any design of food processing or preparation equipment, the effects of partial gravity and partial atmospheric pressure as it relates to fluid management, heat and mass transfer and chemical reactions must be determined. Once the effects are determined, countermeasures must be developed. All of this needs to happen prior to any fabrication of actual food processing or food preparation equipment that can be used in the Lunar Habitat.

The response to this subtopic should (1) develop food packaging technologies that respond the above requirements, (2) develop a technology which will aid in determining the effects of reduced cabin pressure and reduced gravity and/or (3) develop a technology that will enable safe and timely food processing and food preparation in reduced cabin pressure and reduced gravity.

TOPIC: X14 Space Radiation

The goal of the NASA Space Radiation Research Program is to assure that we can safely live and work in the space radiation environment, anywhere, any time. Space radiation is different from forms of radiation encountered on Earth. Radiation in space consists of high-energy protons, heavy ions and secondary products created when the protons and heavy ions pass through spacecraft shielding and human tissue. The Space Radiation Program Element uses the NASA Research Announcement as a primary means of soliciting research to understand the health risks and reduce the uncertainties in risk projections. Reliable radiation monitoring for manned and unmanned spaceflight is a specific area where the SBIR technologies can potentially contribute to NASA's overall goal. Three particular areas of interest are: Small Personal Dosimetry; Charged Particle Spectroscopy; Neutron Spectroscopy.

X14.01 Small Personal Dosimetry

Lead Center: JSC

Participating Center(s): ARC, GSFC

Background:

As astronauts return to the Moon, and this time, work for extended periods, there will be a critical need for crew personnel radiation monitoring as they perform a myriad of extravehicular activities (EVAs). Increased ISS crew size and mission duration are also driving the need for during-mission evaluation of crew specific radiation exposures.

The components of the radiation field, both primary and secondary particles, can vary significantly in charge, energy, and intensity between galactic cosmic rays and solar particle events (SPEs). This dynamic and complex radiation environment requires the development of suitable detection systems that can meet the requirements of each component of the field.

Of particular concern is the need for active monitoring capabilities that provide relevant radiation personal dosimetry information for long term galactic cosmic ray exposure (including neutron secondary radiation) and for short term high dose rate SPEs. In addition to a complex Lunar radiation environment, which must be detected while electronics are protected by radiation hardening, there are restrictions on size, weight, power availability, and data transmission, as well as challenges presented by the Lunar surface environment, such as dust, temperature, and UV radiation. If mounted on or in the EVA suit, suit constraints must be addressed and crew safety ensured. For daily mission use, the requirements on size, data storage, and battery life/operation are particularly challenging.

Requirements/Needs:

Advanced spaceflight detector systems to provide reliable environment data for a specific spectrum of energies, including: real time dosimetry providing dose and particle types and energies and cumulative dosimeters for characterizing space environments for use onboard spacecraft and planetary surfaces as well as alarm systems for Solar Particle Events. Dosimeters should provide time resolved linear energy transfer (LET) data and have embedded LET-based quality factor algorithms for determining dose equivalent. New software needs to be fault tolerant and compatible with current operating systems, new hardware and software must be fully documented (schematics, etc.).

The expected radiation environment includes protons from 10 MeV to 1 GeV, electrons from .5 MeV to 7 MeV, primary and secondary HZEs (He to Fe) from 10 MeV/amu to 1 GeV/amu and secondary neutrons from 1 MeV to 200 MeV. NASA acknowledges the difficulty in measuring secondary neutrons from interactions of protons and heavy ions with spacecraft structures and has particular interest in this area.

For EVA and Mission Needs

- The dosimeter should be an omnidirectional detector system that can continuously measure and record the absorbed dose from charged particles with linear energy transfer 0.2 to 300 keV/micrometer, as a function of time, at two shielding depths: 0.5 g/cm² and 3 g/cm².

- The dosimeter should measure cumulative absorbed dose and dose equivalent once per minute and report data with latency less than five minutes.
- The dosimeter should produce and alarm whenever the absorbed dose rate exceeds a programmable threshold in the range 0.05 mGy/min to 10 mGy/min for 3 consecutive 1 minute readings.
- The dosimeter dimensions should be no larger than 8.5 cm x 4.5 cm x 2 cm.
- The dosimeter should weigh no more than 150 g.

Additional Mission Only Needs

- The dosimeter should be able to be battery (re-chargeable) powered and operate for 14 days without re-charge.
- The dosimeter shall be able to measure dose rates in the range 0.005 mGy/hour (0.0075 mSv/hour) to 1 cGy/hour (1.5 cSv/hour)
- The dosimeter should be able to measure neutron exposure (personal dose equivalent) in the energy range 0.5 MeV to 10 MeV, with dose equivalent sensitivity of 0.2 mSv to 0.1 Sv in a 1 hour measurement, delivered at 0.02 mSv/hour to 1 mSv/hour.

Additional EVA Only Needs

- For suit based versions, the dosimeter would interface to the EVA suit with TBR power available. No battery is allowed for suit versions.
- The dosimeter shall be able to measure dose rates in the range 0.005 mGy/hour (0.0075 mGy-Eq/hour for proton fields in the energy 10 MeV to 300 MeV) to 70 cGy/hour (105 cGy-Eq/hour for proton fields in the energy range 10 MeV to 300 MeV).
- Software and algorithms must interface with the suit data system, but do not necessarily need to be integrated into suit control algorithms.

X14.02 Charged Particle Spectroscopy

Lead Center: ARC

Participating Center(s): GSFC, JSC

Charged particles (protons and heavy ions) contribute most of the dose-equivalent received by astronauts. Current instruments at NASA, and those under development, can provide the total (combined) dose and dose-equivalent for protons, heavy ions, gamma rays, and neutrons. At present NASA has active detectors for ISS that measure energy fluence of charged particles; however, more compact detection systems that measure energy fluence and spectrum for Exploration class missions are needed. Advanced technologies (up to technology readiness level (TRL) level 4) are requested.

Subtopic Requirements/Needs:

Of particular interest are compact real-time detection systems that can measure energy fluence and spectrum of protons and other ions ($Z = 2$ to 26) and be sensitive to charged particles with LET of 0.2 to 1000 keV/ μm . For Z less than 3, the spectrometer should detect energies in the range 20 MeV/n to 400 MeV/n. For $Z = 3$ to 26, the spectrometer should detect energies in the range 50 MeV/n to 1 GeV/n.

The monitor should be able to measure charged particles at both ambient conditions in space (0.005 mGy/hr) and during a large solar particle event (1000 mGy/hr).

The time resolution should be less than or equal to 1 minute.

The dosimeter shall be able to perform data reduction internally and provide processed data out to ISS, CEV, and future lunar outpost data systems. New software needs to be fault tolerant and updated to current operating systems, new hardware and software must be fully documented (schematics, etc.).

X14.03 Neutron Spectroscopy

Lead Center: ARC

Participating Center(s): GSFC, JSC

Neutrons can contribute a significant fraction to the total dose-equivalent received by astronauts. Current instruments at NASA, and those under development, can provide the total (combined) dose and dose-equivalent for protons, heavy ions, gamma rays, and neutrons. At present, neutrons are included as integral measurements of NASA space flights; however compact active detection systems that can measure neutrons only are needed. Advanced technologies (up to technology readiness level (TRL) level 4) are requested.

Subtopic Requirements/Needs:

Systems are needed specifically to measure the neutron component of the dose and provide the neutron dose-equivalent in real time. Of interest also would be compact active monitoring devices that could measure neutron energy spectra.

The principal energies of interest are neutrons from 0.5 MeV to 150 MeV.

The monitor should be able to measure neutrons at ambient conditions such that proton/ion veto capability should be approaching 100% at solar minimum GCR rates.

During solar particle events, neutrons will be present at increased levels and should also be measured.

The device should be able to measure ambient dose equivalent of 0.02 mSv in a 1 hour measurement period, using ICRP 74 (1997) conversion factors.

The instrument shall be able to perform data reduction internally and provide processed data out to ISS, CEV, and or future lunar outpost data systems. New software needs to be fault tolerant and updated to current operating systems, new hardware and software must be fully documented (schematics, etc.).

9.1.3 SCIENCE

To pioneer the future in space exploration, scientific discovery, and aeronautics research.

NASA has pursued these three areas throughout its history. Fresh impetus is provided by the President's Vision for Space Exploration announced in January 2004, which includes robotic exploration of planetary bodies in the solar system, advanced telescope searches for Earth-like planets around other stars, and studying the origin, structure, evolution, and destiny of the universe in addition to extending human presence to the Moon, Mars and beyond. Other Presidential initiatives guide NASA's study of Earth from space and build on NASA's rich heritage of aeronautics and space science research.

Goal 3 in the 2006 NASA Strategic Plan is to "develop a balanced overall program of science, exploration, and aeronautics consistent with the redirection of the human spaceflight program to focus on exploration." In the arena of science, NASA's focus is in disciplines where access to space enables new scientific endeavors or enhances existing ones. Responsibility for defining, planning and overseeing NASA's science programs is assigned by the NASA Administrator to the Science Mission Directorate (SMD). SMD organizes its work into four broad scientific pursuits, each managed by a Division within the Directorate, implementing the four science sub-goals in the NASA Strategic Plan:

Earth Science: Study planet Earth from space to advance scientific understanding and meet societal needs;

Planetary Science: Advance scientific knowledge of the origin and history of the solar system, the potential for life elsewhere, and the hazards and resources present as humans explore space;

Heliophysics: Understand the Sun and its effects on Earth and the solar system;

Astrophysics: Discover the origin, structure, evolution, and destiny of the universe, and search for Earth-like planets.

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) encompasses research in the areas of Astrophysics, Earth Science, Heliophysics, and Planetary Science. 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, large format 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, 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 which can be deployed on surface landers, rovers, and airborne platforms. Consequently, the 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. The following subtopics are concomitant with this objective and are organized by technology.

S1.01 Lidar System Components

Lead Center: LaRC

Participating Center(s): GSFC

Accurate measurements of atmospheric parameters with high spatial resolution from ground, airborne, and space-based platforms require advances in the state-of-the-art lidar technology with emphasis on compactness, efficiency, reliability, lifetime, and high performance. Innovative lidar component technologies that directly address the measurements of the atmosphere and surface topography of the Earth, Mars, the Moon, and other planetary bodies will be considered under this subtopic. Innovative technologies that can expand current measurement capabilities to spaceborne or Unmanned Aerial Vehicle (UAV) platforms are particularly desirable. Development of components that can be used in planned missions such as Laser Interferometer Space Antenna (LISA) or Earth and planetary composition is highly encouraged. Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 prototype demonstration. For the PY07 SBIR, we are soliciting only the specific component technologies described below.

- Flight qualified, radiation hardened fiber optic components for high power fiber amplifier packages at 1064 nm. Pulse energies in the hundreds of microJoules, and even milliJoule-level, are needed.
- Fiber optic components specifically for use with Yb-doped photonic crystal fibers (PCF), to permit removal of any bulk optics or air gaps in fiber amplifier systems that use a PCF amplifier stage. The following specific components are needed: standard multimode or singlemode fiber to PCF connections, pump couplers for 915 nm or 980 nm, high power isolators at 1064 nm, 1064 nm filters, fiber combiners, and fiber splitters.
- Development of polarization maintaining Er and/or Yb doped optical fibers that are optimized for suppression of stimulated Brillouin scattering (SBS). Resulting fiber must be capable of single frequency (< 1 MHz linewidth), peak power of one kW or higher, and M2 beam quality < 1.3 .
- Gravitational wave detection in space uses laser interferometric techniques to measure picometer distance changes over megameter baselines. The application requires a space-qualifiable high reliability frequency-stabilized CW laser source with 1 W output power and a 5 year mission lifetime. A Master Oscillator Power Amplifier (MOPA) configuration is desirable because the source must be phase-modulated.
- Efficient and compact single frequency solid state or fiber lasers operating at 1.5 and 2.0 micron wavelength regimes suitable for coherent lidar applications. These lasers must meet the following general requirements: pulse energy 0.2 mJ to 100 mJ, repetition rate 10 Hz to 1 kHz, and pulse duration of approximately 200 nsec.

- Single frequency semiconductor or fiber laser generating 10s of mW of CW power in 1.5 or 2.0 micron wavelength regions with less than 100 kHz linewidth. Frequency modulation with about 5 GHz bandwidth and wavelength tuning over several nanometers are desirable.
- Interferometer technology to separately derive aerosol and molecular backscatter via High Spectral Resolution Lidar (HSRL) technique at 532 and 355 nm. Resolving power of the order of 1 GHz over an acceptance angle up to several milliradians is required. High quantum efficiency detectors, such as electron multiplying CCDs, suitable for spaceborne HSRL instruments are also needed. Detectors should be capable of rapid sampling rates greater than 1.5 MHz at 532 and 355 nm operating wavelengths.

S1.02 Active Microwave Technologies

Lead Center: JPL

Participating Center(s): GSFC

NASA employs active sensors (Radars) for a wide range of remote sensing applications. These sensors include low frequency (less than 10 MHz) sounders to W-band radars for measuring precipitation and clouds. We are seeking proposals for the development of innovative technologies to support future radar missions. Technology innovations should either enhance measurement capabilities (e.g., improve spatial, temporal, or spectral resolution) or ease implementation in spaceborne missions (e.g., reduce size, weight, power, improve reliability, or lower cost). The areas of interest for this call are listed below.

For L- and P-band radar components for surface deformation, topography and soil moisture measurements:

- Lightweight deployable L-band antenna structures and deployment mechanisms suitable for large aperture (reflectors or phased array of 50m² and larger) systems.
- Compact (probably sub-optimal), P-band antennas (possibly folded-dipole arrays, etc.) for airborne and spaceborne systems.
- Rad-hard, high-efficiency, low-cost, lightweight L- and P-band Transmit/Receive (TR) modules (~250 W peak RF output power at ~100 us pulsewidth and 20% duty cycle) with respective energy storage unit to provide pulsed DC power to the power amplifier while minimizing ripple on the primary DC power source.
- 12-bit, 1 GSps, 500MHz analog bandwidth ADCs and digital filtering with an emphasis on rad-tolerance and space-qualification.
- Implementation of radar transmitters/receivers using digital signal synthesis.

For Ku- and Ka-band radars for snow cover measurement (Ku) and wetland, river, ocean surface monitoring (Ka) and precipitation radars (X to W-band):

- Lightweight deployable reflectors (Ku-band and Ka-band) and active feed electronics.
- High efficiency Ka-band (34-36GHz) TR modules with output power of 5-10W. The LNAs should have a NF less than 3dB and gain better than 30dB. Included in the TR module is a low loss phase shifter.
- Power amplifier and associated LNA for a Ka-band (34-36GHz) radar system with a peak output power of 2KW to 10KW (duty cycle of 10%) and system bandwidth of up to 1 GHz and LNA NF of less than 1.5dB. The LNA needs to have enough isolation and power handling capability to operate in this high power transmission environment.
- Wide-bandwidth (~500 MHz BW), high-efficiency, rad-tolerant linear FM (chirp) signal generators (sweep rates ~500 MHz in 10 us).
- High performance, low power, compact, rad-hard, real-time radar processors, FPGA based digital receivers, SAR data processing algorithms and data reduction techniques.

S1.03 Passive Microwave Technologies

Lead Center: GSFC

Participating Center(s): JPL, MSFC

NASA employs passive microwave and millimeter-wave instruments for a wide range of remote sensing applications from measurements of the Earth's surface and atmosphere to cosmic background emission. Proposals are sought for the development of innovative technology to support future science and exploration missions employing 450 MHz to 5 THz sensors. Technology innovations should either enhance measurement capabilities (e.g., improve spatial, temporal, or spectral resolution or improve calibration accuracy) or ease implementation in spaceborne missions (e.g., reduce size, weight, or power, improve reliability, or lower cost). While other concepts will be entertained, specific technology innovations of interest are listed below for missions to measure soil moisture, temperature sounding, cloud particles, and cosmic microwave background.

- Low power >200 Mb/s 1-bit A/D converters and cross-correlators for microwave interferometers;
- Automated assembly of 180 GHz direct conversion I-Q receiver modules;
- Low power, tunable, local oscillators from 400 to 600 GHz with 4-5 mW output power;
- Low noise (<2000 K DSB), compactly designed (< 8 cm³), heterodyne mixers requiring low local oscillator drive power (<2 mW) with RF input frequency between 100 GHz to 1 THz;
- Low DC power spectrometers covering 500 MHz with 125 kHz resolution;
- Highly stable variable correlated noise sources for calibrating correlation-type receivers;
- MMIC Low Noise Amplifiers (LNA). Room temperature LNAs for 165 to 193 GHz with low 1/f noise, and a noise figure of 6.0 dB or better; and cryogenic LNAs for 180 to 270 GHz with noise temperatures of less than 150K;
- High emissivity (near-black-body, >40 dB return loss) surfaces/structures for use as onboard calibration targets that will reduce the weight of aluminum core targets, while reliably improving the uniformity and knowledge of the calibration target temperature;
- New approaches, concepts, and techniques for microwave radiometer system calibration over or within the 1-700 GHz frequency band which provide end-to-end calibration to better than 0.1K, including corrections for temperature changes, standing waves, linearity, and other potential sources of instrumental measurement drift and error;
- RF (GHz to THz) MEMS switches with low insertion loss (< 0.5 dB), high isolation (>18 dB), capable of switching with speeds of >100 Hz at cryogenic temperatures (below 10 K) for 108 or more cycles;
- Lightweight deployable L-band antenna structures and deployment mechanisms suitable for large aperture (reflectors or phased array of 50m² and larger) systems;
- Dual-polarization multi-frequency micropatch array antenna designs for combinations of frequencies in the C-, X-, or K-bands.

S1.04 Sensor and Detector Technology for Visible, IR, Far IR and Submillimeter

Lead Center: JPL

Participating Center(s): GSFC, LaRC

Advances in detectors, readout electronics, and other technologies enabling polarimetry and large format imaging arrays for the visible, near IR, IR and far IR/submm and spectroscopy with unprecedented sensitivity are sought. These advances may enable future mission concepts such as the Single Aperture Far Infrared (SAFIR) Observatory (<http://safir.jpl.nasa.gov/technologies.shtml>), Space Infrared Telescope for Cosmology and Astrophysics (SPICA) (<http://www.ir.isas.ac.jp/SPICA/>), Cosmic Microwave Background Polarization (CMBPol), and Supernova/Acceleration Probe (SNAP) (<http://snap.lbl.gov>).

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 prototype demonstration. Innovations are sought in detector capability for the following wavelength ranges:

- 0.1-1 μm : Increased sensitivity and larger array size. Improved silicon response in the UV and NIR, smart pixel arrays, solar blind response detector arrays, energy resolving calorimeter arrays.
- 1-4 μm : Increased sensitivity and larger array size. Large format cryogenic readout multiplexers, large format ($>1000 \times 1000$) array hybridization techniques.
- 4-40 μm : Increased sensitivity and larger array size (megapixels). Low power cryogenic multiplexers, new sensor materials (e.g., novel dopants for extrinsic Si detectors).
- 40-200 μm : Increased sensitivity and larger array size (megapixels). Monolithic focal plane arrays (BIB technologies, new sensor materials).
- 200 μm - 1 mm: Noise equivalent power (NEP) of $10^{-20} \text{ W Hz}^{-1/2}$ in a 1,000 pixel spectroscopic array with low-power readout electronics, and NEP $10^{-18} \text{ W Hz}^{-1/2}$ in a 10,000 pixel photometric imaging array. Capabilities for photon counting, polarimetry, and energy resolving detection. Heterodyne receiver arrays operating near the quantum limit.

In addition to technologies specific to the astrophysics mission concepts above, NASA is seeking technologies and improvements to technologies leading to successful measurement of carbon monoxide, methane, nitrous oxide and other related trace species from geostationary and low-Earth orbital platforms. Of particular interest are new techniques in gas filter correlation spectroscopy, Fabry-Perot spectroscopy, or better component technologies for these. The following technologies are also of interest for the Scanning Microwave Limb Sounder Earth science instrument concept (<http://mls.jpl.nasa.gov/index-cameo.php>):

- Efficient, flight qualifiable, spur free, local oscillators for SIS mixers operating in low Earth orbit. Two bands: (1) tunable from 200 to 250 GHz, and (2) tunable from 610 to 650 GHz. Phase-locked to or derived from ultra-stable 5 MHz reference.
- Technologies for calibrating millimeter wave spectrometers for spaceborne missions, including:
 - Low power, flight qualifiable comb generators for gain, linearity, and sideband calibration of microwave spectrometers covering the bands from 180 to 270 GHz and from 600 to 660 GHz;
 - Flight qualifiable low noise diodes for the bands from 180 to 270 and 600 to 660 GHz;
 - Very low return loss (70 dB or better) calibration targets;
 - Techniques for quantifying and calibrating out the impact of standing waves in broadband heterodyne submillimeter spectrometers.
- Low power, stable, linear, spectrometers covering the band from 6-18 GHz with 100 MHz resolution.

S1.05 Detector Technologies for UV, X-Ray, Gamma-Ray and Cosmic-Ray Instruments

Lead Center: GSFC

Participating Center(s): MSFC

This subtopic covers detector requirements for a broad range of wavelengths from UV through to gamma ray. As would be expected requirements across the board are for greater numbers of readout pixels, lower power, faster readout rates, greater quantum efficiency, and enhanced energy resolution. Typical semiconductor devices in this energy range are based on silicon or germanium. However, proposals for other detector materials are welcomed if a compelling case is made.

Proposals are specifically solicited for improvements in microchannel plate technology for UV focal plane use; for CCD and active pixel sensor development, both for UV and x-ray use; for technologies leading to very-large-area x-ray detectors for survey instruments; and for electronic systems capable of meeting the needs of Mega-to-Giga-channel detectors. The latter can include not just device development but also, for example, novel interconnect schemes enabling efficient packaging to aid in thermal control and to reduce system noise.

The proposed efforts must be directly linked to a requirement for a NASA mission. These include Explorers, Discovery, Origins, Beyond Einstein and Vision Missions. Details of these can be found at the following URL: <http://science.hq.nasa.gov/missions/index.html>.

Specific technologies are listed below. Highly desirable are developments that satisfy multiple requested parameters:

- Large-format focal plane detectors for use in UV and X-ray imaging and spectrometry:
 - Microchannel-plate UV detectors: up to 109 readout channels; quantum efficiency up to 50%;
 - UV-sensitive CCD and active pixel sensors with large formats: to 6k x 6k abutable; extended UV response below 0.2 nm;
 - X-ray-sensitive CCD and active pixel sensors: up to 4k x 4k formats, 4-side abutable; power levels of 0.1 W / Megapixel; resolutions less than 120 eV; readout rates of at least 30 Hz; extended x-ray response above 6 keV.
- Very-large-area X-ray detectors for survey instruments: square-meter area capability; response from 3-30 keV; ultra-low power (10 microW/channel).
- Significant improvements in wide band gap materials, individual detectors, and detector arrays for UV and EUV applications. Specific examples include AlGaIn and SiC based detector arrays and associated readout systems.
- Mega-to-Giga-Channel analogue electronic systems for very-large-area X- and gamma-ray detectors as follows: up to 108 channel capability; less than 10 microW/channel power requirement; less than 100 electron rms noise level with interconnects.

S1.06 Particles and Field Sensors and Instrument Enabling Technologies

Lead Center: GSFC

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 Solar Sentinels, GEC, MAGCON, ITSP 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: +/-100,000 nT, accuracy with self-calibration: 1 nT, sensitivity: 5 pT / sqrtHz, 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 10⁵.
- Strong, lightweight, thin, compactly-stowed electric field booms possibly using composite materials that deploy sensors to distances of 10m or more.
- Cooled (-60°C) solid state ion detector capable of operating at a floating potential of -15 kV relative to ground.
- Low noise magnetic materials for advanced magnetometer sensors with performance equal to or better than those in the 6-81.3 Mo-Permalloy family.
- Radiation hardened ASIC spectrum analyzer module that determines mass spectra using fast algorithm deconvolution to produce ion counts for specific ion species.
- Low cost, low power, high voltage power supplies 5-15 kV.
- Low power charge sensitive preamplifiers on a chip.
- High efficiency (5% or greater) conversion surfaces for low energy neutral atom conversion to ions possibly based on nanotechnology.

- Long wire boom (≥ 50 m) deployment systems for the deployment of very lightweight tethers or antennae on spinning spacecraft.
- Systems to determine the orthogonality of a deployed electric field boom system in flight (for use with three-axis rigid 10-m booms) accurate to 0.1 degrees dynamic.

S1.07 Cryogenic Systems for Sensors and Detectors

Lead Center: GSFC

Participating Center(s): ARC, JPL, MSFC

Cryogenic cooling systems are often enabling technologies for cutting edge science from infrared imaging and spectroscopy to x-ray calorimetry. Improvements in cryogenic technologies enable further scientific advancement at lower cost, lower risk, reduced volume, and/or reduced mass. Lifetime, reliability, and power requirements of the cryogenic systems are critical performance concerns. Of interest are cryogenic technologies for cooling detectors for scientific instruments and sensors on advanced telescopes and observatories as well as on instruments for lunar and planetary exploration. Active coolers should have long life, low vibration, low mass, low cost, and high efficiency. Specific areas of interest include:

- Essentially vibration-free cooling systems such as reverse Brayton cycle cooler technologies with cooling capability of 20 mW at 4K.
- Highly efficient magnetic and dilution cooling technologies under 1 Kelvin.
- Components for advanced magnetic coolers (adiabatic demagnetization refrigerators) including:
 - Small (few cm bore), lightweight, low current (under 10A, goal under 5A) superconducting magnets capable of producing at least 3 Tesla central field while operating at least 10 Kelvin. Higher temperature superconductor (HTS) magnets operating at significantly higher temperatures are of particular interest.
 - Lightweight (relative to standard ferromagnetic flux guides) active and/or passive magnetic shielding for 3 to 4 Tesla magnets that reduces the stray field to tens of microTesla at a distance of several cm from the outside of the shield.
 - Large (several cm) single crystals of magnetocaloric materials.
 - Superconducting current leads operating between 90 Kelvin down to 10 Kelvin, capable of carrying up to 10 amperes while allowing only approximately 1 mW of heat to be conducted.
 - Compact, accurate, easy to use thermometers that operate down to 10 milliKelvin.

S1.08 In Situ Airborne, Surface, and Submersible Instruments for Earth Science

Lead Center: GSFC

Participating Center(s): ARC, JPL, MSFC

There are new platform systems that have the potential to benefit Earth science research activities. To capitalize on these emerging capabilities, proposals are sought for the development of in situ instruments for use on radiosondes, dropsondes, tethered balloons, kites, Unmanned Aerial Vehicles (UAVs), Unmanned Surface Vehicles (USVs), or Unmanned Underwater Vehicles (UUVs). Both miniaturization of current techniques, as well as innovative new methods that lead to compact and lightweight systems are important. Details of complete instrument systems are desired, including data acquisition, power, and platform integration. Instrument performance goals such as resolution, accuracy, and response time should be discussed. A plan for commercial production and marketing should be included as well. Technology innovation areas of interest include:

- Atmospheric measurements including temperature, humidity, solar radiation, clouds, liquid water, ice, precipitation, chemical composition (carbon dioxide, methane, reactive gases and radicals, dynamical tracer species), and aerosol properties;
- Three-dimensional wind measurements near the Earth's surface, and within the troposphere and lower stratosphere;

- Oceanic measurements including inherent and apparent optical properties, temperature, salinity, chemical composition, nutrient distribution, and currents.

The calibration/validation of the Orbiting Carbon Observatory (OCO - 2008) is a target application. Science campaigns to be conducted within the Sub-Orbital Science Program are also a high priority – the Tropical Composition, Cloud and Climate Coupling (TC4) is such an example: <http://www.espo.nasa.gov/tc4/>, as is the Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS): <http://www.espo.nasa.gov/arctas/>. Systems to enable field studies aimed to research fundamental processes are also of interest.

S1.09 In Situ Sensors and Sensor Systems for Planetary Science

Lead Center: JPL

Participating Center(s): ARC, GSFC

The adaptation of current standard laboratory techniques for deployment on planetary missions is a focus. Proposers are strongly encouraged to relate their proposed technology development to future planetary exploration goals. These goals include geochemical, geophysical and astrobiological objectives.

Instruments for in situ investigations are required for NASA's planned and potential solar system exploration missions. Instruments are required for the characterization of the atmosphere, surface and subsurface regions of planets, satellites, and small bodies. These instruments may be deployed for in situ measurements on surface landers and rovers, and airborne platforms. These instruments must be capable of withstanding operation in space and planetary environmental extremes, which include temperature, pressure, radiation, and impact stresses.

This subtopic seeks advances in instruments and critical components in the following areas:

- X-Ray Diffraction and X-Ray Fluorescence (XRD/XRF) instruments, with capabilities beyond those currently planned for the CHEMIN instrument on the Mars Science Laboratory (MSL - 2009), with a focus on elemental and mineralogical analysis in the Venus surface environment (90 bars CO₂, 450°C).
- Scanning electron microscopy with chemical analysis capability.
- Mass spectrometry/Gas chromatography with improved capabilities over the SAM instrument on MSL or applicability to in situ atmospheric measurements on Venus or Titan.
- Geochronology, with a focus on isotopic dating of planetary surfaces in the 100 Ma to 4.5 Ga timeframe with better than 10% accuracy.
- Gamma-Ray Spectroscopy, with a focus in short duration (<1 hr) measurements that could be made from a rover or Venus surface lander.
- X-Ray Photoelectron Spectroscopy (XPS) and Auger Electron Spectroscopy (AES)

Astrobiology includes the study of the origin, evolution, and distribution of life in the universe. New technologies are required to enable the search for extant or extinct life elsewhere in the solar system, to obtain an organic history of planetary bodies, to discover and explore water sources elsewhere in the solar system, and to detect microorganisms and biologically important molecular structures within complex chemical mixtures.

Astrobiology solicits new measurement concepts, advances in existing instrument concepts, and advances in critical components in the following areas:

- Instrumentation focused on assessments of the identification and characterization of biomarkers of extinct or extant life, such as prebiotic molecules, complex organic molecules, biomolecules, or biominerals. At this time we are not soliciting DNA and RNA analysis techniques.
- High sensitivity (femtomole or better) characterization of molecular structure, chirality, and isotopic composition of biogenic elements (H, C, N, O, S) embodied within individual compounds and structures.

In addition, enabling instrument component and support technologies for the above, such as miniaturized pumps, sample inlet systems, valves, integrated bulk sample handling and processing systems, and fluidic technologies for sample preparation, are also solicited. These must be presented in the context of a complete instrument system.

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 nano-technology, and wavefront sensing and control are needed to build telescope for Earth science that have the potential to cost between \$50 to \$150M.

S2.01 Precision Spacecraft Formations for Telescope Systems

Lead Center: JPL

Participating Center(s): GSFC

This subtopic seeks hardware and software technologies necessary to establish, maintain, and operate precision spacecraft formations to a level that enables cost effective large aperture and separated spacecraft optical telescopes and interferometers. Also sought are technologies (analysis, algorithms, and testbeds) to enable detailed analysis, synthesis, modeling, and visualization of such distributed systems.

Formation flight can synthesize large effective telescope apertures through, multiple, collaborative, smaller telescopes in a precision formation. Large effective apertures can also be achieved by tiling curved segments to form an aperture larger than can be achieved in a single launch, for deep-space high resolution imaging of faint astrophysical sources. These formations require the capability for autonomous precision alignment and synchronized maneuvers, reconfigurations, and collision avoidance. The spacecraft also require onboard capability for optimal path planning and time optimal maneuver design and execution.

Innovations are solicited for: (a) development of nanometer to sub-nanometer metrology for measuring inter-spacecraft range and/or bearing for space telescopes and interferometers (b) development of combined cm-to-nanometer-level precision formation flying control of numerous spacecraft and their optics to enable large baseline, sparse aperture UV/optical and X-ray telescopes and interferometers for ultra-high angular resolution imagery. Proposals addressing staged-control experiments which combine coarse formation control with fine-level wavefront sensing based control are encouraged.

Innovations are also solicited for distributed spacecraft systems in the following areas:

- Distributed, multi-timing, high fidelity simulations;
- Formation modeling techniques;
- Precision guidance and control architectures and design methodologies;
- Centralized and decentralized formation estimation;
- Distributed sensor fusion;
- RF and optical precision metrology systems;
- Formation sensors;

- Precision microthrusters/actuators;
- Autonomous reconfigurable formation techniques;
- Optimal, synchronized, maneuver design methodologies;
- Collision avoidance mechanisms;
- Formation management and station keeping.

S2.02 Proximity Glare Suppression for Astronomical Coronagraphy

Lead Center: JPL

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 and innovative advanced wavefront sensing and control for cost-effective space telescopes. 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 infrared wavelengths. The ultimate application of these instruments is to operate in space as part of a future observatory mission. Much of the scientific instrumentation used in future NASA observatories for the astrophysical sciences will require control of unwanted radiation (thermal and scattered) across a modest field of view. The performance and observing efficiency of astrophysics instruments, however, must be greatly enhanced. The instrument components are expected to offer much higher optical throughput, larger fields of view, and better detector performance. The wavelengths of primary interest extend from the visible to the thermal infrared. 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

- Advanced starlight canceling coronagraphic instrument concepts;
- Advanced aperture apodization and aperture shaping techniques;
- Pupil plane masks for interferometry;
- Advanced apodization mask or occulting spot fabrication technology controlling smooth density gradients to 10^{-4} with spatial resolutions $\sim 1 \mu\text{m}$, low dispersion, and low dependence of phase on optical density;
- Metrology for detailed evaluation of compact, deep density apodizing masks, Lyot stops, and other types of graded and binary mask elements. Development of a system to measure spatial optical density, phase in homogeneity, scattering, spectral dispersion, thermal variations, and to otherwise estimate the accuracy of masks and stops is needed;
- Interferometric starlight cancellation instruments and techniques to include aperture synthesis and single input beam combination strategies;
- Single mode fiber filtering from visible to $20 \mu\text{m}$ wavelength;
- Methods of polarization control and polarization apodization; and
- Components and methods to insure amplitude uniformity in both coronagraphs and interferometers, specifically materials, processes, and metrology to insure coating uniformity.

Wavefront Control Technologies

- Development of small stroke, high precision, deformable mirrors (DM) and associated driving electronics scalable to 10^4 or more actuators (both to further the state-of-the-art towards flight-like hardware and to explore novel concepts). Multiple DM 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;

- Development of instruments to perform broad-band sensing of wavefronts and distinguish amplitude and phase in the wavefront;
- Adaptive optics actuators, integrated mirror/actuator programmable deformable mirror;
- Reliability and qualification of actuators and structures in deformable mirrors to eliminate or mitigate single actuator failures;
- Multiplexer development for electrical connection to deformable mirrors that has ultra-low power dissipation;
- High precision wavefront error sensing and control techniques to improve and advance coronagraphic imaging performance; and
- Highly reflecting broadband coatings.

S2.03 Precision Deployable Optical Structures and Metrology

Lead Center: JPL

Participating Center(s): GSFC

Planned future NASA Missions in astrophysics, such as the Single Aperture Far-IR (SAFIR) telescope, Life Finder, and Submillimeter Probe of the Evolution of Cosmic Structure (SPECS), and the UV Optical Imager (UVOIR) require 10 - 30 m class cost effective telescopes that are diffraction limited at wavelengths from the visible to the far IR, and operate at temperatures from 4 - 300 K. The desired areal density is 1 - 10 kg/m². Static and dynamic wavefront error tolerances may be achieved through passive means (e.g., via a high stiffness system) or through active control. 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 L2.

This topic solicits proposals to develop enabling, cost effective component and subsystem technology for these telescopes. Research areas of particular interest include precision deployable structures and metrology (i.e., innovative active or passive deployable primary or secondary support structures); innovative concepts for packaging fully integrated (i.e., including power distribution, sensing, and control components); distributed and localized actuation systems; deployment packaging and mechanisms; active control distributed on or within the structure (downstream corrective and adaptive optics are not included in this topic area); actuator systems for alignment of reflector panels (order of cm stroke actuators, lightweight, submicron dynamic range, nanometer stability); mechanical, inflatable, or other deployable technologies; new thermally-stable materials (CTE < 1ppm) for deployables; innovative ground testing and verification methodologies; and new approaches for achieving packagable depth in primary mirror support structures.

Also of interest are innovative metrology systems for direct measurement of the optical elements or their supporting structure; requirements for micron level absolute and subnanometer relative metrology for tens of points on the primary mirror; measurement of the metering truss; and innovative systems which minimize complexity, mass, power and cost.

The goal for this effort is to mature technologies that can be used to fabricate 20 m class, lightweight, ambient or cryogenic flight-qualified telescope primary mirror systems. Proposals to fabricate demonstration components and subsystems with direct scalability to flight systems (concept described in the proposal) will be given preference. The target launch volume and expected disturbances, along with the estimate of system performance, should be included in the discussion. A successful proposal shows a path toward a Phase 2 delivery of demonstration hardware on the scale of 3 m for characterization.

S2.04 Optical Devices for Starlight Detection and Wavefront Analysis

Lead Center: MSFC

Participating Center(s): JPL, GSFC

This subtopic solicits technology for collecting and controlling star light with advanced optical telescopes and telescope arrays. This topic includes innovative optical subsystems, devices and components that directly collect and process optical signals and images for all regions of the electromagnetic spectrum from X-ray to UV to Visible to Far-IR/Sub-MM. Pre-detection technologies of interest include capabilities to preprocess or analyze an optical wave front or signal to extract time-dependent, spectral, polarization and spatial information from scenes or signals prior to detection. Specific technology area of interest include high reflectance UV coatings and uniform polarization coatings for all wavelengths; high angular resolution imaging enabled via large-baseline segmented-aperture telescopes and sparse aperture telescopes/interferometers; component-level technology needed to enable the characterization and combination of wavefronts from multiple apertures. Innovative technology to integrate, assemble, align and control test large aperture segmented mirrors for x-ray, ambient and cryogenic applications.

Proposed effort must address technical need of a recognized future NASA space science mission, science measurement objective or science sensor for a Discovery, Explorer, Beyond Einstein, Origins, GOESS, New Millennium, Landmark-Discovery, or Vision mission. Specific missions of interest include the following: Constellation-X (<http://constellation.gsfc.nasa.gov/>); Terrestrial Planet Finder (http://planetquest.jpl.nasa.gov/TPF/tpf_index.cfm); Single Aperture Far-Infrared (<http://safir.jpl.nasa.gov/technologies.shtml>).

Proposed effort should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 breadboard or prototype demonstration.

Proposals in the following areas are specifically solicited:

- Optical coatings: broad-band polarization preserving and polarizing for UV to Far-IR/Sub-MM; high-reflectivity EUV; large area, high acceptance angle narrow-band optical filters; broad-band wide-acceptance angle UV anti-reflection on PMMA substrates; environmentally stable protected silver.
- High throughput, radiation hard, large area, X-ray imaging devices such as Fresnel Zone plates and masks.
- Innovative mounting/support and metrology/control technologies to integrate, assemble, align and control large aperture lightweight low-cost segmented mirrors for x-ray, ambient and cryogenic normal incidence applications - also, systems with extreme alignment tolerances such as PIAA.
- Techniques to mitigate optical surface errors includes phase retrieval and wavefront sensing and control techniques and instrumentation, optical systems with high-precision controls, active and/or adaptive mirrors, shape control of deformable telescope mirrors, and image stabilization systems; techniques to sense/control segmented primary mirrors.
- Techniques to combine beams for wavelength-resolved fringe measurements from a large number of independent apertures with flat response over a broad wavelength range.

S2.05 Optics Manufacturing and Metrology for Telescope Optical Surfaces

Lead Center: GSFC

Participating Center(s): JPL, MSFC

This year's subtopic focuses primarily on manufacturing and metrology of optical surfaces, especially for very small or very large and/or thin optics. Missions of interest include, but are not limited to, Constellation-X (<http://constellation.gsfc.nasa.gov/>), TPF (http://planetquest.jpl.nasa.gov/TPF/tpf_index.cfm), and SAFIR (<http://safir.jpl.nasa.gov/technologies.shtml>). Optical systems currently being researched for these missions are large area aspheres, requiring accurate figuring and polishing across six orders of magnitude in period (i.e., 1st and 2nd order errors through micro-roughness). Technologies are sought that will enhance the figure quality of optics in any range as long as the process does not introduce artifacts in other ranges (i.e., mm-period polishing should not introduce waviness errors at the 20 mm or 0.05 mm periods in the power spectral density). Also, novel metrological

solutions that can measure figure errors over a large fraction of the PSD range are sought, especially techniques and instrumentation that can perform measurements while the optic is mounted to the figuring/polishing machine.

By the end of a Phase 2 program, technologies must be developed to the point where the technique or instrument can dovetail into an existing optics manufacturing facility producing optics at the R&D stage. Metrology instruments must have 10 nm or better surface height resolution and span at least 3 orders of magnitude in lateral spatial frequency.

Examples of technologies and instruments of interest include:

- Interferometric nulling optics for very shallow conical optics used in x-ray telescopes (segmented systems commonly span 60 degrees in azimuth and 200 mm axial length and cone angles vary from 0.1 to 1 degree);
- Low stress metrology mounts that can hold very thin optics without introducing mounting distortion;
- Low normal force figuring/polishing systems operating in the 1 mm to 50 mm period range with minimal impact at significantly smaller and larger period ranges;
- In situ metrology systems that can measure optics and provide feedback to figuring/polishing instruments without removing the part from the spindle;
- Innovative mirror substrate materials or manufacturing methods that produce thin mirror substrates that are stiffer and/or lighter than existing materials or methods;
- Extreme aspheric and/or anamorphic optics for pupil intensity amplitude apodization (PIAA).

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 beyond; chart the best route of discovery; and reap the benefits of Earth and space exploration for society. A major objective of the NASA science spacecraft systems development programs is to implement science measurement capabilities using small, affordable spacecraft enabling a single spacecraft to meet multiple mission requirements thus making the best use of our limited resources. To accomplish this objective, NASA is fostering innovations in propulsion, power, and guidance and navigation systems that significantly reduce the mass and cost while maximizing the scientific return for future NASA missions. Innovations are sought in the areas of power generation, energy storage, guidance, navigation, command/control, on-board propulsion (electric propulsion, advanced chemical and propellantless propulsion), on-board power management and distribution (power electronics and packaging), and thermal control technologies for spacecraft, piloted and unpiloted aircraft, balloons, drop sondes, and sounding rockets used for NASA Science Missions.

S3.01 Avionics and Electronics

Lead Center: GSFC

Participating Center(s): GRC, JPL, JSC

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 guidance, navigation, command and data handling are sought to support NASA's goals and several missions and projects under development, including the New World Observer, GEO Quick Ride and Radiation Hardened Electronics for Space Environments (RHESE).

The subtopic goals are to: (1) develop high-performance processors and memory architectures and reliable electronic systems and (2) develop precision line-of-sight sensing for large telescopes and spacecraft formations. The subtopic objective is to elicit novel architectural concepts and component technologies that are realistic and operate effectively and credibly in environments consistent with the future vision of the Science Mission Directorate (SMD).

Successful proposal concepts will significantly exceed the present state-of-the-art. Proposals will clearly (1) state what the product is; (2) describe how it targets the technical priorities listed below; and (3) outline the feasibility of the technical and programmatic approach. If a Phase 2 proposal is awarded, the combined Phase 1 and Phase 2 developments shall produce a prototype that is testable by NASA. The technology priorities sought are listed below.

Command and Data Handling

- Processors - General purpose (processor chips and radiation-hardened by design synthesizable IP cores) and special purpose single-chip components (DSPs and FPGAs) with sustainable processing performance (>500 MIPS), power efficiency (>100 MIPS/W) and radiation tolerance, including the tools to support the software flow.
- Radiation hardened: low power memories and Ethernet physical layer components.
- Models for analysis of interplanetary radiation and radiation belts, and technologies enabling in-flight total dose and single event radiation measurements.

Guidance Navigation and Control

- Navigation systems (including multiple sensors and algorithms/estimators, possibly based on existing component technologies) that work collectively on multiple vehicles to enable inertial alignment of the formation of vehicles (i.e., pointing of the line-of-sight defined by fixed points on the vehicles) on the level of milli-arcseconds relative to the background star field.
- Light-weight sensors (gyroscopic or other approach) to enable milli-arcsecond class pointing measurement for individual large telescopes.
- Isolated pointing and tracking platforms (pointing 0.5 arcseconds, jitter to 5 milli-arcsecond), targeted to placing a scientific instrument on GEO communication satellites that can track the sun for > 3 hours/day.

S3.02 Thermal Control Systems

Lead Center: GSFC

Participating Center(s): GRC, JPL, MSFC

Future Spacecraft and instruments for NASA's Science Mission Directorate will require increasingly sophisticated thermal control technology. Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract. Innovative proposals for thermal control technologies are sought in the following areas:

- Optical systems, lasers, and detectors require tight temperature control, often to better than $\pm 1^\circ\text{C}$. Some new missions such as CON-X and LISA require thermal gradients held to micro-degree levels. Methods of precise temperature measurement and control to this level are needed.
- Heat flux levels from lasers and other high power devices are increasing, with some projected to go as high as 100 W/cm^2 , especially for proposed wind/Lidar missions. They will require thermal technologies such as spray and jet impingement cooling. Also, high conductivity, vacuum-compatible interface materials will be needed to minimize losses across make/break interfaces.
- Future missions such as TPF will use large structures, like mirrors and detector arrays, at both ambient and cryogenic temperatures. Some anticipated technology needs include: advanced thermoelectric coolers capable of providing cooling at ambient and cryogenic temperatures, high conductivity materials to minimize temperature gradients and provide high efficiency light-weight radiators, and advanced thermal control coatings such as variable emittance surfaces and coatings with a high emissivity at ambient and cryogenic temperatures.
- Future advanced spacecraft present engineering challenges requiring systems which are more self-sufficient.

Some of the technology needs are:

- Single and two-phase mechanically pumped fluid loop systems which accommodate multiple heat sources and sinks, and long life, lightweight pumps for these systems;
- Efficient, lightweight vapor compression systems for cooling up to 2 KW;
- Advanced thermal modeling techniques that can be easily integrated into existing codes, emphasizing inclusion of two-phase system and mechanically pumped system models;
- Integration of standardized formats into existing codes for the representation and exchange of Thermal Network Models and Thermal Geometric Models and results.

S3.03 Power Generation and Storage

Lead Center: GRC

Participating Center(s): GSFC, 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 conversion, energy storage, and power electronics to enable or enhance the capabilities of future science missions. The requirements for the power systems for these missions are varied and include long life capability, high reliability, significantly lower mass and volume, higher mass specific power, and improved efficiency over the state of practice (SOP) components/systems. Other desired capabilities are high radiation tolerance, and ability to operate in extreme environments (high and low temperatures and over wide temperature ranges).

Advanced Photovoltaic Energy Conversion

- Photovoltaic cell and array technologies with significant improvements in efficiency (>30%), mass specific power (>600W/kg), stowed volume, cost, radiation resistance, and wide operating conditions are solicited;
- Photovoltaic cell technologies for low intensity, low-temperature operation (LILT) are solicited;
- Array technologies of interest are concentrators, deployable arrays, ultra-lightweight arrays for flexible, thin-film cells, and electrostatically-clean solar arrays.

Stirling Power Conversion

Novel methods or approaches for radiation-tolerant, sensorless, autonomous control of the Stirling converters with very low vibration and having low mass, size, and electromagnetic interference (EMI). Technologies of interest include:

- High-temperature, high-performance regenerators;
- High-temperature, lightweight, high-efficiency, low EMI, linear alternators;
- High-temperature heater heads (> 850°C) and joining techniques.

Energy Storage

Energy storage requirements for Science mission are:>10,000 charge/discharge cycles for LEO spacecraft, as low as 40K low-temperature storage/operation for planetary missions, and high mass specific power for small spacecraft. Energy storage technologies that enable one or more of the above requirements are of interest. Technologies of interest include:

- Fuel cells;
- Batteries including structural batteries;
- Integrated power systems (generation/storage/control integrated into one module).

Power Management and Distribution

Advanced electrical power technologies are required for the electrical components and systems on future platforms to address the size, mass, efficiency, capacity, durability, and reliability requirements. In addition to the above requirements, proposals must address the expected improvements in energy density, speed, efficiency, or wide-temperature operation (-125°C to 200°C) with a high number of thermal cycles. Advancements are sought in power electronic devices, components, and packaging. Technologies of interest include:

- Power electronic components and subsystems;
- Power distribution;
- Fault protection;
- Advanced electronic packaging for thermal control and electromagnetic shielding.

S3.04 Propulsion Systems

Lead Center: GRC

Participating Center(s): JPL, JSC, MSFC

The Science Mission Directorate (SMD) needs spacecraft with ever-increasing propulsive performance and flexibility for ambitious missions requiring high duty cycles and years of operation. Planetary spacecraft need the ability to rendezvous with, orbit, and conduct in situ exploration of planets, satellites and other solar system bodies. Platforms, satellites, and satellite constellations have high-precision propulsion requirements, usually in volume- and power-limited envelopes. This subtopic seeks innovations to meet SMD propulsion requirements, reflecting the goals of NASA's In-Space Propulsion Technology program to reduce the travel time, mass, and cost of SMD spacecraft. Propulsion areas include chemical and electric propulsion systems, propulsion technologies related to sample return missions to asteroids, comets, and other small bodies, propellantless options (such as aerocapture and solar sails), and less developed but emerging propulsion concepts such as advanced plasma thrusters and momentum exchange/electrodynamic reboost (MXER) tethers.

Specifically, innovations are sought in the following areas:

- Characterization of high strength fibers and compatible resins for composite overwrapped pressure vessels (COPVs) for use in higher-pressure, in-space propulsion systems. Of particular interest are fiber/resin systems exhibiting high uniformity of mechanical properties and high resistance to debonding.
- Improved capability and reduced cost of low- to medium-power electric propulsion systems, including power processing, long-life, high-efficiency cathodes and neutralizers, low-erosion materials for ion optics and Hall discharge chambers, plume mitigation, and next generation thrusters.
- Thin film materials, elastomeric materials, and/or high temperature fabrics for inflatable decelerator concepts used in aerocapture applications at planetary destinations. The decelerator will be stowed for many years (up to 10 years) in an uncontrolled space environment (-130°C). The inflatable decelerator will experience temperatures up to 500°C during the aerocapture maneuver. Materials of particular interest include polyimide thin films, polybenzobisoxazole (PBO) thin films, and ceramic fabrics.

S3.05 Terrestrial Balloon Technology

Lead Center: GSFC

Participating Center(s): JPL

The Balloon Program Office (BPO) is soliciting innovations in two specific areas:

(1) Currently, the Balloon Program Office is developing an Ultra Long Duration Balloon (ULDB) vehicle targeting 100 day duration missions in mid-latitude. This added capability will greatly enable new science investigations. The design of the current pumpkin shape vehicle utilizes light weight polyethylene film and high strength tendons made of twisted Zylon® yarn. The in-flight performance and health of the vehicle relies on accurate information on a number of environmental and design parameters. Therefore, NASA is seeking innovations in the following specific areas:

Tendons are the load carrying member in the pumpkin design. During a typical mission, loading on individual tendons should not exceed a critical design limit to insure structural integrity and survival. A key technology challenge is the development of devices or methods to accurately and continuously measure individual axial loading on an array of up to 200 separate tendons during a ULDB mission. Tendons are typically captured at the fitting via individual pins. Loading levels on the tendons can range from ~20 N to ~8,000 N and temperature can vary from

room temperature to the troposphere temperatures of -90°C or colder. The devices of interest shall be easily integrated with the tendons or fittings during balloon fabrication and shall have minimal impact on the overall mass of the balloon system.

Ambient air, helium gas, and balloon film temperature measurements are needed to accurately model the balloon performance during a typical flight at altitudes of approximately 120,000 feet. The measurement must compensate for the effects of direct solar radiation through shielding or calculation. Minimal mass and volume are highly desired. For film measurement, a non-invasive and non-contact approach is highly desired for the thin polyethylene film, with film thickness ranging from 0.8 to 1.5 mils, used as the balloon envelope.

(2) The Balloon Program Office is also seeking innovations to reduce the effects of parachute opening shock on gondolas and balloon subsystems. This shock is produced by the rapid opening of a flight system's parachute after the payload is released from the balloon at mission termination.

Innovations may address the problem either by reducing the termination shock via modifications to the recovery system or by attenuating the shock produced by current recovery systems. Proposed technologies will be evaluated for their mass efficiency, ease of integration, effectiveness at reducing shock levels, compatibility with balloon flight environments, and cost effectiveness, among other factors.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware/software demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

TOPIC: S4 Low-Cost Small Spacecraft and Technologies

The Low-Cost Small Spacecraft and Technologies Topic focuses on the technologies, subsystems, methodologies, and mission concepts for space missions which lower the over-all cost for scientific exploration. The "Small" of spacecraft and missions refer to small spacecraft that have "wet" masses below 500 Kg. (micro satellites 10-100kg, nano satellite 1-10kg, pico satellite <1kg), are substantially less expensive, and will require different approaches to solve traditional problems in development, operations and capability. The goal of these low-cost missions is not to replace the major missions, but rather to reduce the risks to, as well as the costs of, future major missions. Low-Cost Small Spacecraft and Technologies Missions will be used as test beds for new technologies, provide flight "heritage" for new instruments and components. Increasing the number of flight opportunities per year enables missions to be designed and flown during typical graduate and post-doctoral tenures, provide training for a new generation of scientists and engineers. These small spacecraft missions can also accomplish specific scientific investigations that would be too narrow for a major mission but still scientifically important. This topic is divided into two categories of subtopics: Small Spacecraft Technologies and Enablers and Small Spacecraft Build. Small Spacecraft Technologies and Enablers subtopics will lower the barrier to entry for small spacecraft missions by encouraging launch opportunities and creating open design and spacecraft management tools. These subtopics include nanosat launch vehicles and technologies, secondary and tertiary launch technologies, low-cost, rapid spacecraft design and multi-subsystem functionality, and project management, systems engineering and mission assurance tools. The Small Spacecraft Build subtopics, when used together, could create a small spacecraft mission. These subtopics include smart, autonomous command and data handling system, algorithms and data management, advanced avionics, mini-micro thrusters, LOX/hydrocarbon propulsion, and attitude control systems, low-cost assembly, integration, and testing, autonomous multi-mission virtual ground and spacecraft operations. The spacecraft is a modular spacecraft that operate using standard protocols (high speed: Ethernet, Spacewire™; low speed: RS-422, I2C) and operate at 28V +/- 6V. With this modularity a requirement for the Low-Cost Small Spacecraft and Technologies, components can be interchanged from a basic spacecraft design to tailor for specific missions. NASA intends to determine a mission concept that will be announced at a Mission Concept Review (MCR) provisionally in December 2007. NASA intends to award SBIR Phase 1 contracts in October 2007. After the December 2007 MCR, the awardees will be invited to a Preliminary Design Review (PDR) in June 2008. NASA understands that this is a best effort, by the

SBIR awardees and NASA alike. The Phase 2 awards will be formally announced in October 2008, and the Phase 2 recipients will be invited to attend a Systems Review in November 2008 and a Critical Design Review (CDR) in March 2009. By January 2010, the Phase 2 SBIR teams are encouraged to deliver to NASA the hardware to be integrated and ready for launch in July 2010. The Low-Cost Small Spacecraft and Technologies topic is envisioned to launch one satellite per year starting in 2010, kicking off a new team each year. NASA cannot direct SBIR awardees to conform to the provisional schedule outlined above, however when brought together this could create the opportunity for a spacecraft build. This topic will give significant priority to offerors that take full advantage of standard interfaces, protocols, methodologies, open source software and Commercial Of the Shelf (COTS)-derivative hardware.

S4.01 NanoSat Launch Vehicle Technologies

Lead Center: ARC

The space transportation industry is in need of low-cost, reliable, on-demand, routine space access. Both government and private entities are pursuing various launch systems and architectures aimed at addressing this market need. Significant technical risk and cost exists in new system development and operations – reducing incentive for private capital investment in this still-nascent industry. Public and private sector goals are aligned in reducing these risks and enabling the development of launch systems capable of reliably delivering payloads to low Earth orbit. The NanoSat Launch Vehicle Technology subtopic will particularly focus on higher risk entrepreneurial projects for dedicated nano and small spacecraft launch vehicles.

This subtopic is seeking proposals in the following, but not limited, areas:

- Conceptual designs of system/architectures capable of reducing the mission costs associated with small payload delivery to LEO.
- Maturation of low-cost propulsions systems using low-cost materials, and/or low-cost manufacturing processes.
- Maturation of low-cost propulsion systems using storable and environmentally friendly non-toxic propellants.
- Innovative propulsions system solutions, including robust integrated micro-propulsion systems for both primary propulsion, as well as on-board satellite propulsion.
- Maturation of hypersonic and small launch vehicle design and analysis tools or tool-sets aimed at increasing the state-of-the-art while reducing the required design cycle time and human interaction.
- Maturation of key technologies/processes for hypersonic and small launch vehicles including, but not limited to:
 - Thermal Protection Systems;
 - Airframe and subsystem structures that increase system performance and propellant mass fraction;
 - Vehicle Sensor Networks.
- Novel, low-cost modular adapters and release mechanisms.
- Lightweight interstage designs.

Applications of wireless networking technologies for small launch vehicles are also specifically of interest to this subtopic. This technology could be used for vehicle to ground communications (spread-spectrum and non-licensed technologies), as well as within the vehicle itself. We desire new architectures for intelligent on-board communications as well as satellite-to-satellite communication using machine-to-machine (M2M) solutions. The traditional wire harness architecture could be replaced by the wireless technology for command and control, which would reduce vehicle mass and improve reliability. Also stage-to-stage interfaces and vehicle-payload interfaces are of interest. These wireless technologies can include but are not limited to WIMAXTM and ZIGBEETM.

Non-propulsive approaches and architectures for new launch vehicles can also achieve increases in launch vehicle payload mass delivered to orbit for small spacecraft missions. Offerors should consider development, test, and operational factors to show improvements in development and operational costs, payload mass fraction, and mission

assurance. Special attention should be given to improved integration between the launch vehicle and payloads to further reduce operational costs. Furthermore, non-propulsive launch vehicle technologies have a dramatic impact on launch vehicle performance and constitute a large percentage of development and operational costs. They include, but are not limited to:

- Robust On-Board Guidance, Navigation and Control (GN&C) avionics. GN&C should be modular (including modular software architectures) and make use of modern architectures, including high-performance low-weight avionics hardware, and modern software tools. Emphasis is on low-weight architecture to allow maximum payload capacity.
- Range safety solutions and operational concepts to lower costs. These may include alternative solutions to expensive explosive destruct packages, including, but not limited to propulsion-cutoff systems, autonomous flight-abort systems, etc.

Phase 1 - Research should demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Plan a demonstration to validate the technologies/tools/processes. Bench or lab-level demonstrations showing concept viability is encouraged. Commercial applicability should be addressed.

Phase 2 - 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 space-worthy systems. When applicable, researchers should deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

S4.02 Secondary and Tertiary Launch Technologies

Lead Center: ARC

There are a growing number of secondary and tertiary flight opportunities for small spacecraft. These include Dual Payload Attach Fitting (DPAF) for the Delta launch vehicle, the EELV Secondary Payload Adapter (ESPA), as well as tertiary opportunities for spacecraft that are bolted to the upper stage of a booster (as was the case with GeneSat on the Minotaur launch vehicle). The Secondary and Tertiary Launch Technologies subtopic will particularly focus on adaptor and deployment technologies.

We specifically desire low-cost modular DPAF and ESPA solutions, which can be adapted for various nano and small-satellites. Solutions should have minimal impact on cost and schedule, protect the primary payload, and have clear and achievable paths to certification. Topics include, but are not limited to:

- Gentle non-explosive separation mechanisms;
- Autonomous or on demand deployment with build in safety factors;
- Robust, low-weight, and low-cost innovative deployment architectures for large numbers of nano- and small-satellites into predefined orbits.

Phase 1 - Research should demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Plan a demonstration to validate the technologies/tools/processes. Bench or lab-level demonstrations showing concept viability is encouraged. Commercial applicability should be addressed.

Phase 2 - 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 space-worthy systems. When applicable, researchers should deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

S4.03 Low-Cost, Rapid Spacecraft Design and Multi-Subsystem Functionality **Lead Center: ARC**

To achieve low-cost small spacecraft missions, the resources necessary for the conceptual and detailed design of the spacecraft should be proportional to other phases of the successful project. Novel approaches are encouraged to reuse development from other projects and design current projects with the foresight to be reused for future flight projects. The Low-Cost, Rapid Spacecraft Design and Multi-Subsystem Functionality subtopic encourages offerors to utilize open source software and hardware solutions to be utilized for other actors, including entrepreneurial and university teams, for reusability.

This subtopic is seeking proposals in the following, but not limited, areas:

- Methods and tools to enable a geographically distributed, concurrent design of system concepts and functions.
- Dynamic, open source, on-line database and collection system of COTS components and subsystems suitable for spacecraft – a database of components open to the public, can be used for conceptual design and to determine an accurate Master Equipment List (MEL), cost, and schedule based on the current market value and lead time for the components; a prospective model. Such a database should include an API where companies can:
 - Plug into a design tool, whether open source or proprietary, to utilize the database for a prospective model;
 - Link to their components already publicized on their own webpage to collect the data on one centralized location;
 - Utilize database to extend options from a proprietary database of components or designs.
- Modular and scalable subsystem design of spacecraft.
- Consolidation of spacecraft functions to reduce mass, power, volume and interfaces (i.e., multifunctionality) – integrating the functions of two or more onboard disciplines such as structure/mechanical, power, avionics, telecommunications, propulsion, thermal control and attitude control and determination. Also consider cross-functional spacecraft-to-payload capabilities in the areas of attitude determination, navigation, telecommunications and other mission level functions.
- Internal wireless data and command communications systems that alleviate need for wire harness.

Phase 1 - Research should demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Plan a demonstration to validate the technologies/tools/processes. Bench or lab-level demonstrations showing concept viability is encouraged. Commercial applicability should be addressed.

Phase 2 - 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 space-worthy systems. When applicable, researchers should deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

S4.04 Project Management, Systems Engineering and Mission Assurance Tools **Lead Center: ARC**

For cost effective management of multiple complex low-cost small spacecraft projects using distributed teams, management tools are required that integrate the various elements of management, systems engineering, and risk and mission assurance data. This subtopic is seeking tools where members of a spacecraft team are able exchange technical information and capture the salient decisions, trades, dependencies, etc. For a tool to be effective, it must make the job for each team member easier. There should be customizable views for each member so they are able to see the data that affects their job. This subtopic is seeking tools that:

- Simplify data integration resulting in top level roll-up or “dashboard” views as well as provide manager-friendly deep-drilling capability when depth of technical insight is required.
- Directly reflect the management and reporting requirements for NASA projects as defined in NPR7120.5D, NPR 7123.1A, NPR 8000.4, and related standards and directives.
- Facilitate or automate data entry for the Project Manager, Systems Engineer, and Risk and Mission Assurance Manager through secure web-based interfaces.
- Perform data integrity checks at the time of entry and upon request. Include automated e-mail notification of data integrity problems to responsible parties.
- Provide common-interface input portals and data library structures for data uploading from each project WBS element.
- Provide manager-controlled cross-linking of access to data resources from WBS to WBS.
- Provide the ability to specify and automatically generate and update metric and trend reporting on key performance measures, quantities and changes in requirements, documents, configuration items, risk databases, and cost tracking including Earned Value Management metrics and schedule critical path and resource loading metrics.
- Make it possible for reasonably experienced managers to train themselves on tool use.
- Provide data entry and presentation interfaces that are reliable, accepting and presenting data without lengthy uploads or downloads.
- Provide simple, user-modifiable linking to related, keyword searchable archives.
- Provide data translation and capture tools for integration of any data that can be provided in spreadsheet formats or common text documents.
- Aid in building re-usable reporting formats linked to data resources including metric analysis data, snapshots of discipline-specific report sheets, standard subsystem progress reports, and other manager specified data.
- Provide integrated management and team support tools such as Action Item tracking including automatic e-mail alerts to individual and groups, and customizable tracking status schemes.

Data resources to be linked include cost tracking spreadsheets, task plans, risk management databases, requirements databases, technical performance metrics and margins sheets, top level and WBS element schedules, and standard monthly status reports from WBS elements. The tool should be easily scalable for large or small projects and the number of WBS elements and features included or excluded for a given project should be user-selectable. User and group permission and access controls are required.

Phase 1 – Research should provide examples of proven cost benefits and project successes based on the use of integrated management tools for management of multiple simultaneous distributed projects. Architectures should be proposed for implementation of an integrated multi-project management tool.

Phase 2 – A management tool set will be implemented and demonstrated as part of an actual small satellite management project. The tool will be evaluated for ease of use, effectiveness as a NASA project set-up tool, management information tool, and reporting tool. Feasibility for a single manager to effectively manage and report on multiple simultaneous projects will be assessed. Project users from the WBS elements of the satellite project will evaluate ease of use of uploading data.

S4.05 Smart, Autonomous Command and Data Handling System, Algorithms and Data Management **Lead Center: ARC**

The cost of flight software, including algorithms and data management, is continuing to increase and multiply in complexity. Novel on-board data analysis can greatly decrease the bandwidth needed back to Earth, and can alert scientists for time sensitive information and follow-up investigations.

This subtopic is seeking proposals in the following, but not limited, areas:

- Innovative flight software development techniques
 - Planning and scheduling software
 - Modular routines for repeatability on future missions.
- Autonomous fault tolerant software development that acts in a repeatable, predictable manner.
- Automated system level testing.
- On board automated approaches for data compression and payload data analysis to enable low bandwidth communications to the ground station.
- Participatory, distributed analysis techniques utilizing public interest and resources (e.g., Stardust @ Home and HiRise data analysis).

Phase 1 - Research should demonstrate the technical feasibility and show a path towards a software demonstration. Bench or lab-level demonstrations showing concept viability is encouraged. Commercial applicability and modularity should be addressed.

Phase 2 - Emphasis should be placed on developing and demonstrating the software technology under relevant test conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into space-worthy systems. Researchers should deliver a demonstration package for functional evaluation by NASA at the completion of the Phase 2 contract.

S4.06 Advanced Avionics

Lead Center: ARC

This subtopic is seeking proposals to reduce the cost, mass, size, power and complexity of current spacecraft avionics systems, including processors, switch boxes, payload control units, mass storage devices, star trackers, IMUs, and power converters to support smaller (micro and nano) class space vehicles.

NASA has been studying methods to assemble space missions quicker and in a more straightforward manner using "plug and play" (PnP) approaches. Modern plug-and-play includes both the traditional boot-time assignment of I/O addresses and interrupts to prevent conflicts and identify drivers, as well as hot plug systems such as USB and Firewire. This SBIR will explore the hallmarks of next-generation avionics. A major challenge to achieving a usable and useful low cost small mission is the ability to rapidly compose the system to perform both the needed mission functionality using the available spacecraft components. Physical assembly of the PnP spacecraft components is a necessary, but insufficient condition for achieving a system. The assembled system needs to provide the functional capabilities to support the intended mission and also needs to provide the functional capabilities to ensure the operational health and safety of the resulting space mission. A preliminary architectural model to provide a reusable infrastructure is requested as part of effort this supports hard real time, soft real time and non-real time processes.

The objective of this SBIR effort is to prove the viability of modular, plug and play (PnP) spacecraft avionics architecture. This revolutionary architecture provides a near-term solution to modular, plug and play avionics while distributing power and data management functions. It enables full PnP modularity reducing spacecraft integration and test to a few days.

Areas of interest include:

- Low cost open architecture avionics systems;
- Plug and Play adapters that facilitate transition from traditional point to point proprietary control to an open architecture industry standard interface both hardware and software;
- Validate components by producing low cost standard plug and play components including processors, switch boxes, payload control units, mass storage devices, star trackers, IMUs, and power converters.

Phase 1 - Research should identifying and evaluating candidate telecommunications technology applications to demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Plan a demonstra-

tion to validate the technologies/tools/processes. Bench or lab-level demonstrations showing concept viability is encouraged. Commercial applicability should be addressed.

Phase 2 - Emphasis should be placed on developing and demonstrating the technology under simulated flight conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into space-worthy systems defining interfaces (both on the spacecraft and to candidate ground segments). When applicable, researchers should deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

S4.07 Mini-Micro Thrusters, LOX / Hydrocarbon Propulsion, and Attitude Control Systems

Lead Center: ARC

This subtopic is seeking proposals that explore uses of technologies that will provide superior performance in attitude control and overall orbit control.

Propellants play a vital role. The use of liquid oxygen / liquid hydrocarbon fuel (e.g., liquid propylene (LP) in small spacecraft for implementing attitude control and for orbital maneuvers is of interest. This subtopic is looking for candidate fuels that have superior performance to kerosene for on-orbit applications including storage stability and propulsion.

This subtopic is also seeking proposals in the following, but not limited, areas:

- Low-cost reaction wheels;
- Low-mass micro-propulsion systems;
- Propulsion systems that allow transfers from LEO or GTO to lunar orbit or other destinations;
- Propellantless means to achieve delta-V (e.g., momentum exchange, electrodynamic interaction with the Earth's magnetosphere) as a viable Cis-Lunar transport system;
- Flexible and modular (i.e., non-customized) tankage that is scalable to accommodate multiple mission delta-V requirements without safety and design re-qualification for each mission.

Phase 1 - Research should demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Plan a demonstration to validate the technologies/tools/processes. Bench or lab-level demonstrations showing concept viability is encouraged. Commercial applicability should be addressed.

Phase 2 - 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 space-worthy systems. When applicable, researchers should deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

S4.08 Low-cost Assembly, Integration, and Testing

Lead Center: ARC

Current programs take a step-wise approach to various phases of space missions that may lead to inconsistencies between conceptual development, design, assembly, integration, testing, and operations. This subtopic seeks to integrate these phases by providing a consistent software/hardware environment for spacecraft development to operations. Extensible/modular, standards-based, and COTS solutions for software and hardware to improve transition through the various phases, especially transition to operations, is highly encouraged.

One of the potential benefits of small spacecraft missions is transformation of the payload integration process. Traditionally payloads and experiments were delivered to payload integration facilities that were geographically close to the launch site.

This subtopic is looking for ways to streamline this process by reducing the need for this activity to be carried out to close proximity to the launch site. This will result in integration occurring at home facilities and reduced lead times due to a decrease in associated planning activities.

Similarly, to facilitate integration of spacecraft subsystems when using COTS products from multiple vendors, integration of the spacecraft subsystems themselves could benefit from the early use of flexible-standard smart interfacing hardware that can accommodate an array of interface standards including Ethernet, Spacewire™, USB 2.0, RS-422, and I2C.

This subtopic is seeking proposals in the following, but not limited, areas:

- Automated test equipment / automated Breakout boxes;
- Testing of subsystems in geographically distributed locations;
- Standardized interfaces with launch vehicles with frequent launch opportunities.

Phase 1 - Research should demonstrate the technical feasibility of systems-level approach to streamlining processes while simultaneously improving program consistency, repeatability, improved testing, and lower cost. Additionally, the scope of Phase 1 includes identification and evaluation of these alternative subsystem integration, test, and payload processing architectures, as well as the associated payload accommodations hardware and technologies that might be required. Commercial applicability should be addressed.

Phase 2 - Emphasis should be placed on developing and demonstrating the technology under test conditions based on emerging nanosat and small launch vehicles now in development or integration with secondary and tertiary payload launch opportunities. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into space-worthy systems. When applicable, researchers should deliver a demonstration unit for testing at the completion of the Phase 2 contract.

S4.09 Autonomous Multi-Mission Virtual Ground and Spacecraft Operations

Lead Center: ARC

Future ground and spacecraft operations for low-cost spacecraft missions must decrease the complexity, cost, and human intervention required for successful operations of missions.

This subtopic is seeking proposals in the following, but not limited, areas:

- Virtual ground stations;
- Internet-based protocol modules and architectures that will provide seamless network command and control continuity between terrestrial and space-based platforms and environments;
- Autonomous lights-out ground control software (e.g., the ground station operates autonomously without human intervention, and can have remote access);
- Alternate Ground station approaches (e.g., Antenna Arrays or Amateur Radio bands);
- Networked operations of distributed ground stations (e.g., University consortium);
- Software/methods enhancing multiple-mission consolidated operations.

Phase 1 - Research should demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Plan a demonstration to validate the technologies/tools/processes. Bench or lab-level demonstrations showing concept viability is encouraged. Commercial applicability should be addressed.

Phase 2 - 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 space-worthy systems. When applicable, researchers should deliver a demonstration package for functional and environmental testing at the completion of the Phase 2 contract.

TOPIC: S5 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 lander, a rover or balloon-borne experiment on Titan, a surface mission to Venus, and continued Mars exploration missions launching every 26 months including a network lander mission, an Astrobiology Field Laboratory, and other rover missions. Numerous new technologies will be required to enable such ambitious missions. The solicitation for in situ planetary instruments can be found in the in situ instruments section of this solicitation. See URL: <http://solarsystem.nasa.gov/missions/index.cfm> for mission information. See URL: <http://marstech.jpl.nasa.gov/> for additional information on Mars Exploration technologies.

In 2007 the emphasis for SBIR in robotic exploration will be in the following areas: (1) Surface and subsurface robotic exploration; (2) Sample collection, processing and handling devices; (3) Planetary entry, descent and landing technology; (4) Extreme environments technology; and (5) Planetary balloons and aerobots.

S5.01 Extreme Environments Technology

Lead Center: JPL

Participating Center(s): ARC, GRC, GSFC, MSFC

High temperature, high pressure, and chemically corrosive environments:

Proposals are sought for technologies that enable the in situ exploration of the surface and deep atmosphere of Venus and the deep atmospheres of Jupiter or Saturn for future NASA missions. Venus features a dense, CO₂ atmosphere completely covered by sulfuric acid clouds at about 55 km above the surface, a surface temperature of about 486°C and a surface pressure of about 90 atmospheres. Although already explored by various orbiters and short-lived atmospheric probes and landers, Venus retains many secrets pertaining to its formation and evolution. NASA is interested in expanding its ability to explore the deep atmosphere and surface of Venus through the use of long-lived (days or weeks) balloons and landers. Survivability in extreme high temperatures and high pressures is also required for deep atmospheric probes to giant planets. Technology advancements to permit operation and survivability in high-temperature/high-pressure planetary environments are sought in the following areas:

Thermal Control Systems: Survivability of electronic components in high temperature environments relies on three basic areas of thermal control: isolation, thermal capacitance and/or refrigeration. Specific improvements in are sought in the development of:

- Thermal energy storage systems with 300 - 1000 kJ/kg energy density through either phase changes or chemical heat absorption;
- High performance, low mass refrigeration cooling systems capable of pumping on the order of 100 Watts of heat from a 100°C source to the Venus sink temperature of 486°C. In this area, particular attention must be paid to the power source for such a system. A total systems approach must be considered as opposed to development of a particular component.

Pressure Vessel Components:

- Optical Window systems that are transparent in IR, Visible and UV wavelengths at Venus surface temperatures that remain sealed under expected mission temperature variations from -50°C to 486°C and from external pressure variation from 0 to 90 atmospheres.
- Pressure vessel flange seal technology compatible with materials such as stainless steels, titanium and beryllium. Seals shall exhibit leakage rates lower than 10⁻⁵ cc He/sec over the expected mission temperature

variations from -50°C to 486°C and from external pressure variation from 0 to 90 atmospheres. Clamping loads for the seals shall be less than 1500 pounds per linear inch.

Low temperature environments:

Moon equatorial regions experience wide temperature swings from -180°C to +130°C during the lunar day/night cycle, and the sustained temperature at the shadowed regions of lunar poles can be as low as -230°C. Mars diurnal temperature changes from about -120°C to +20°C. Low temperature survivability is also required for missions to Titan, surface of Europa and comets. Proposals are sought in the following specific areas:

- Wide temperature (-180°C to +130°C) and low-temperature (-230°C), radiation-tolerant and SEL immune, low power, mixed-signal circuits including analog-to-digital converters, digital-to-analog converters, low-noise pre-amplifiers, voltage and current references, multiplexers, power switches, microcontrollers, and integrated command/control/drive electronics for sensors, actuators, and communications transponders.
- Computer Aided Design (CAD) tools for predicting the electrical performance, reliability, and life cycle for low-temperature electronic systems and components.
- Physics-based transistor device models valid at temperature ranging from -230°C to +130°C to enable design, verification and fabrication of custom low power mixed-signal and analog circuits.
- Low-temperature (-230°C) circuit design methodologies facilitating novel layout designs for integrated mixed-signal and analog circuits.
- Selected hardware and support technologies for motors, drive systems and related mechanisms that will operate in low temperature environments. Specific areas of interest include gear boxes, suspension systems, material components (i.e., wiring, harnesses, insulating materials, and jackets/covers) that can operate in cryogenic environments; advanced lubricants and lubrication technology.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware/software demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

S5.02 Planetary Entry, Descent and Landing 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 Mars. This call is not for sensor processing algorithms. Sensing technologies are desired which determine the entry point of the spacecraft in the Mars atmosphere; provide inputs to systems that control spacecraft trajectory, speed, and orientation to the surface; locate the spacecraft relative to the Martian surface; evaluate potential hazards at the landing site; and determine when the spacecraft has touched down. Appropriate sensing technologies for this topic should provide measurements of physical forces or properties that support some aspect of EDL operations. NASA also seeks to use measurements made during EDL to better characterize the Martian atmosphere, providing data for improving atmospheric modeling for future landers. Proposals are invited for innovative sensor technologies that improve the reliability of EDL operations.

Products or technologies are sought that can be made compatible with the environmental conditions of spaceflight and the rigors of landing on the Martian surface. Successful candidate sensor technologies can address this call by:

- Providing critical measurements during the entry phase (e.g., pressure and/or temperature sensors embedded into the aeroshell);
- Improving the accuracy on measurements needed for guidance decisions (e.g., surface relative velocities, altitudes, orientation, localization);
- Extending the range over which such measurements are collected (e.g., providing a method of imaging through the aeroshell, or terrain-relative navigation that does not require imaging through the aeroshell);

- Enhancing the situational awareness during landing by identifying hazards (rocks, craters, slopes), or providing indications of approach velocities and touchdown;
- Substantially reducing the amount of external processing needed to calculate the measurements; and
- Significantly reducing the impact of incorporating such sensors on the spacecraft in terms of volume, mass, placement, or cost.

S5.03 Sample Collection, Processing, and Handling Devices

Lead Center: JPL

Participating Center(s): ARC, GSFC

Robust systems for sample acquisition from the subsurface of planetary bodies are critical to the next generation of robotic explorers. Limited spacecraft resources (power, volume, mass, computational capabilities, and telemetry bandwidth) demand innovative, integrated sampling systems that can survive and operate in challenging environments (extremes in temperature, pressure, gravity, vibration and thermal cycling).

Research should be conducted to develop compact, low-power, lightweight subsurface sampling systems with access to depths of 1 – 3 m below the surface. A relevant mission scenario for this type of drill would include drilling multiple holes from a mobile platform, such as a rover. For reference, current Mars-relevant rovers range in mass from 200 – 800 kg. Also of interest are integrated systems for 1-10 cm subsurface sampling.

Consideration should be given to potential failure scenarios for integrated systems. For example, recovery and mitigation techniques for platform slip and borehole misalignment should be addressed. Significant attention should be given to the sensing and automation required for real-time control, fault diagnosis and recovery. Additional areas of interest include understanding the limitations of dry drilling into mixed media such as icy mixtures of rock and regolith and hot subsurface materials at high pressure (up to 740 K in a 90 bar CO₂ environment).

Sample manipulation technologies are needed to enable handling and transfer of unstructured samples from a sampling device to instruments and sample processing systems. Shallow rock core and regolith samples may be variable in size and composition so a sample manipulation system needs to be flexible enough to handle the sample variability. Core samples will be on the order of 1 cm diameter and up to 10 cm long. Soil and rock fragment samples will be of similar volumes. Actual samples to be analyzed in instruments will likely be small subsamples so the means for subsampling and manipulation of the original sample and subsamples needs to be developed. Minimal size and mass components and systems have the greatest benefit.

Also of particular need are means of acquiring subsurface rock and regolith samples with minimum contamination. This contamination may include contaminants brought to the sample by the drill itself, material from one stratigraphic layer contaminating samples collected at another depth (sample cross-contamination), or Earth-source microorganisms brought to the Martian surface prior to drilling ('clean' sampling from a 'dirty' surface).

S5.04 Surface and Subsurface Robotic Exploration

Lead Center: JPL

Participating Center(s): ARC, GSFC

Technologies are needed to enable access to surface and subsurface sampling sites of scientific interest on Mars. Mobility technology is needed to enable access to difficult-to-reach sites such as access through steep terrain. Many scientifically valuable sites are accessible only via terrain that is too steep for state-of-the-art planetary rovers to traverse. Sites include crater walls, canyons, and gullies. Tethered systems, non-wheeled systems, and marsupial systems are examples of mobility technologies that are of interest. Tether technology could enable new approaches for deployment, retrieval and mobility. Innovative marsupial systems could allow a pair of vehicles with different mobility characteristics to collaborate to enable access to challenging terrain. It is envisioned that a 500-800 kg primary vehicle could provide long traverse to the vicinity of a challenging site and then deploy a smaller 20-50 kg vehicle with steep mobility access capability for access to the site.

Technologies to enable subsurface access and sampling in multiple holes at least 1 – 3 meters deep through rock, regolith or ice compositions are also sought. Subsurface access solutions to be integrated onto 500-800 kg stationary landers and mobile platforms are of interest. Consideration should be given for potential failure scenarios, such as platform slip and borehole misalignment for integrated systems, and the challenges of dry drilling into mixed media including icy mixtures of rock and regolith. Systems should ensure minimal contamination of samples from Earth-source contaminants and cross-contamination from samples at different depths.

Innovative low-mass, low-power, and modular systems and subsystems are of particular interest. Technical feasibility should be demonstrated during Phase 1 and a full capability unit of at least TRL level 4-6 should be delivered in Phase 2. Specific areas of interest include the following:

- Tether play-out and retrieval systems including tension and length sensing;
- Low-mass tether cables with power and communication;
- Steep terrain adherence for vertical and horizontal mobility;
- Modular actuators with 1000:1 scale gear ratios;
- Electro-mechanical couplers to enable change out of instruments on an arm end-effector;
- Drill, core, and boring systems for subsurface sampling at 1 to 3 meters.

S5.05 Planetary Balloons and Aerobots

Lead Center: JPL

Participating Center(s): GSFC

Innovations in materials, structures, and systems concepts have enabled buoyant vehicles to play an expanding role in NASA's Solar System Exploration Program. Balloons and airships will carry scientific payloads on Mars, Venus, Titan, and the outer planets in order to investigate their atmospheres in situ and their surfaces from close proximity. Their envelopes will be subject to extreme environments and must support missions with a range of durations. Proposals are sought in the following areas:

Aerial Deployment Modeling Tool

Many aerobot concepts for Mars, Titan, and Venus involve the aerial deployment and inflation of the balloon during parachute descent after arrival at the destination. Proposals are sought that would provide computer modeling tools that can simulate this complex process. Of particular importance is the ability to model the balloon shape and material stresses as a function of time, taking into account the aerodynamic forces generated by the parachute and by the uninflated or partially inflated balloon, as well as transient loads during balloon deployment from its storage container. The balloons can be either polymer film or polymer film plus reinforcing fabric laminates.

Metal Bellows for High Temperature Venus Balloons

Cylindrically-shaped metal bellows are a potential solution to the problem of making balloons that can tolerate the 460°C temperatures near the surface of Venus. Commercial off-the-shelf metal bellows are limited in diameter to approximately 0.4 m. NASA seeks proposals for metal bellows technology that can produce prototypes in the range of 1 - 2 m in diameter and 5 - 10 m long; tolerant of sulfuric acid; good fatigue properties at 460°C; and areal densities of up to 1 kg/m².

High Strength Envelope Materials for Titan Aerobots

NASA currently has viable cryogenic balloon materials based on polyester film plus fabric laminates. It is desired to have new, advanced materials that possess at least a 50% improvement in the strength to weight ratio while retaining comparable flexibility to the current polyester materials. The desired areal densities are in the range of 40-80 g/m² so as to support both superpressure and zero pressure balloon concepts. Of particular interest is the use of existing high strength fiber materials like Vectran, Spectra, Dyneema, PBO and Twaron/Kevlar to achieve the desired performance. Preference will be given to proposals that include significant material sample fabrication and cryogenic testing.

Ground-launched Mars Balloons

NASA is interested in small balloons with very light payloads (< 1 kg) that can be autonomously launched on the Martian surface from a lander or large rover. Proposals are sought for balloon designs and systems concepts to enable this. It is important that proposals directly address the difficult problem of not damaging the balloon despite proximity to landed equipment and surface rocks. Preference will be given to proposals that include experiments addressing key feasibility questions for the proposed approach.

TOPIC: S6 Information Technologies

Modeling and simulation are being used more pervasively and more effectively 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, and provide visualizations of datasets that are extremely large and complicated. Examples of past simulation successes include simulations of entry conditions for man-rated space flight vehicles, visualizations of distant planet topography via simulated fly-over and three-dimensional visualizations of coupled ocean and weather systems. In many of these situations, assimilation of real data into a highly sophisticated physics model is needed. Also use NASA missions and other activities to inspire and motivate the nation's students and teachers, to engage and educate the public, and to advance the scientific and technological capabilities of the nation.

S6.01 Modeling, Simulation and Analysis Technologies

Lead Center: ARC

This subtopic solicits proposals for technologies and systems that allow spacecraft and ground systems to robustly perform complex tasks in dynamic environments with minimal human direction. Areas of interest include support of decision support systems, distributed sensor webs and component systems, and the creation of automation loops connecting scientific modeling and analysis to mission planning, data collection, processing and operations. NASA is moving from a stove-pipe observational architecture to one that permits data interoperability and dynamic coordination of observational assets to generate desired data products. Technology innovations include:

- Automation and autonomous systems that support high-level command abstraction;
- Efficient and effective techniques assessing gaps in data collection to assure complete coverage;
- Intelligent searches of distributed data archives, and data discovery through searches of heterogeneous data sets and architectures; and
- Automation of routine, labor intensive tasks to that either increase reliability or throughput of current process.

Specific areas of interest include the following:

- Search agents that support applications involving the use of NASA data using emerging interoperability such as Sensor Model Language;
- Methods that support the planning and scheduling of sensor webs in support of data product processing when given a set of high-level goals and constraints;
- Autonomous data collection including the coordination of space or airborne platforms while adhering to a set of data collection goals and resource constraints;
- System and subsystem health and maintenance, both space- and ground-based;
- Distributed decision making, using multiple agents, and/or mixed autonomous systems;
- Automatic software generation and processing algorithms; and
- Control of Field Programmable Gate-Arrays (FPGA) to provide real-time products.

S6.02 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 Earth and astrophysical systems, as well as to conduct high-fidelity engineering analyses. The goal of this subtopic is to make NASA's supercomputing systems and associated resources easier to use, thereby broadening NASA's supercomputing user base and increasing user productivity. Specific objectives are to:

- Reduce the learning curve for using supercomputing resources;
- Minimize total time-to-solution (i.e., time to discovery, understanding, or prediction);
- Increase the scale and complexity of computational analysis and data assimilation;
- Accelerate advancement of system models and designs.

The approach of this subtopic is to develop intuitive, high-level tools, interfaces, and environments for users, and to infuse them into NASA supercomputing operations. Successful technology development efforts under this subtopic would be considered for follow-on funding by, and infusion into either of the NASA high-end computing projects, including the High End Computing Columbia (HECC) project at Ames and the NASA Center for Computational Sciences (NCCS) at Goddard. Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 prototype demonstration. Open Source software and open standards are strongly preferred.

Specific areas of interest include:

Application Development

With the increasing scale and complexity of supercomputers, users must often expend a tremendous effort to translate their physical system model or algorithm into a correct and efficient supercomputer application code. This subtopic element seeks intuitive, high-level application development environments, ideally leveraging high-level programming languages (e.g., parallel Matlab or IDL) to enable rapid supercomputer application development, even for novice users. This environment should dramatically simplify application development activities such as porting, parallelization, debugging, scaling, performance analysis, and optimization.

Results V&V

A primary barrier to effective use of supercomputing by novices is understanding the accuracy of their computational results. Errors in the input data, domain definition, grids, algorithms, and application code can individually or in combination produce non-physical results that a user may not detect. This subtopic element seeks tools and environments to help users with verification and validation (V&V) of simulation results. This could be accomplished by enabling comparison of results from similar applications or with known accurate results, access to results analysis tools and domain experts, or access to error estimation tools and training.

Data Analysis and Visualization

Supercomputing computations almost invariably result in tremendous amounts of data, measuring in the gigabytes or terabytes, and with many dimensions and other complexity aspects. This subtopic element seeks user-friendly tools and environments for analysis and visualization of large-scale, complex data sets typically resulting from supercomputing computations.

Ensemble Management

Conducting and fusing the results from an ensemble of related computations is an increasingly common use of supercomputers. However, ensemble computing and analysis introduces a new set of challenges for deriving full value from using supercomputing. This subtopic element seeks tools and environments for managing and automating ensemble supercomputing-based simulation, analysis, and discovery. Functions could include managing and

automating the computations, model or design optimization, interactive computational steering, input and output data handling, data analysis, visualization, progress monitoring, and completion assurance.

Integrated Environments

The user interface to a supercomputer is typically a command line or text window, where users may struggle to locate or develop applications, understand the job queue structure, develop scripts to submit jobs to the queue, manage input and output files, archive data, monitor resource allocations, and many other essential supercomputing tasks. This subtopic element seeks more intuitive, intelligent, and integrated interfaces to supercomputing resources. This integrated environment could include access to user training (e.g., tutorials, case studies, and experts), application development tools, standard (e.g., production, commercial, and Open Source) supercomputing applications, results V&V tools, computing and storage resources, ensemble management tools, workflow management, data analysis and visualization tools, and remote collaboration.

S6.03 On-Board Data Processing and Control

Lead Center: ARC

Participating Center(s): GSFC

Technology advances allow scientists to build devices that often collect more data than can be cost effectively transmitted or summarized within mission time constraints. NASA is developing sensor web capabilities which can require these data be analyzed for rapid decision making, either autonomously or with human in the loop controller. This subtopic enables sensor web capabilities and increases mission data return by developing on-board methods that can operate with very limited resources to increase the efficiency and scientific return of existing and future sensors. Approaches range from lossy data compression prior to transmission to some degree of "data understanding" that enables data management and prioritization based on potential science content. These software capabilities will enable sensor webs that operate semi-autonomously and are capable of reacting to what is being sensed and triggering notifications or additional actions. Algorithms can be embedded into an instrument or device or algorithms can target on-board computer resources for data management and /or transmission as part of the post collection data flow.

The selection of on-board methods to increase scientific return is highly dependent on mission objectives. Successful candidate technologies will need to demonstrate suitability to the general requirements of the proposed use scenario as they pertain to different instrument (or device) types. Generally, scientists do not want to throw away data given that significant discoveries have been made reinterpreting archived data. Methods that reduce information content such as lossy compression are often not desirable unless significant, new capabilities are enabled by this tradeoff. Examples exist where instruments are turned off and on and instances when sensor or camera data is saved and transmitted only when features are detected by on-board software. These instances occur when transmission costs, relative to available resources, are high. E.g., a Mars Exploration Rover was reprogrammed to detect and transmit camera images containing dust devils.

Algorithms can be designed to run on general purpose computing resources or specialized i.e., field programmable gate arrays (FPGA). Novel approaches that can leverage specialized, space qualified computing resources such as FPGAs that return order of magnitude reduction in data volume or screening capabilities are desirable. There is a trade-off between sensor volume and complexity against distance and degree of on-board autonomy needed for mission success so performance metrics are relative to the science mission scenario. Example sensor types include data intensive instruments such as hyperspectral, RADAR, and LIDAR but can include any sensor technology that is shown relevant to the board scope of science within the NASA science mission directorate.

For instance, aggressive metrics for compression and data volume are in Earth science the Decadal survey has the following requirements on data compression:

RADAR Missions	SMAP (RADAR)	DESDynI (RADAR)	SWOT (RADAR)
OBP Input data rate (MHz)	32	400	500
Processor Throughput (GFLOPS)	7	20	90
Data Compression Ratio	80:1	10:1	90:1

Where raw data sample spacing is 0.75 m x 1.5 m (16 bits per sample), and the output data sample spacing is 10 m x 10 m (16 bits per sample).

For Hyperspectral imaging instruments, here is an exemplar requirement on data compression on board feature detection.

Data Rate:	660 gigabits per orbit, 220 megabits per second
Data Compression Ratio:	> 3.0
On-board detection capability:	A quick look at the data for presence of cloud cover.

S6.04 Data Analyzing and Processing Algorithms

Lead Center: GSFC

This subtopic seeks technical innovation and unique approaches for the processing and analysis of data from NASA's space and Earth science missions. Analysis of NASA science data is used to understand dynamic systems such as the sun, oceans, and Earth's climate as well as to look back in time to explore the origins of the universe. Algorithms are used to consider data over time, at various energy ranges, and at different points in space. Complex algorithms and intensive data processing are needed to understand and make use of this data. What novel discoveries can be made with existing NASA data? What applications would benefit from the combination of NASA data with additional information and processing?

NASA seeks to exploit spatial tools in order to increase the utility of scientific research data, models, simulations, and visualizations. Of particular interest are innovative computational methods to dramatically increase algorithm efficiency and thus performance. Interpolation, clustering, and registration algorithms are examples of the type of algorithms of interest in this area, as well as real-time visualization and simulation algorithms. Tools to improve predictive capabilities, to optimize data collection by identifying gaps in real-time, and to derive information through synthesis of data from multiple sources are needed. The ultimate goal is to increase the value of data collected in terms of scientific discovery and application. Data analysis and processing must relate to advancement of NASA's scientific objectives.

We are soliciting proposals for software tools which access, fuse, process, and analyze image and vector data for the purpose of analyzing NASA's space and Earth science mission data. Tools can be plug-ins or enhancements to existing software or on-line services. Tools and products might be used for broad public dissemination or for communicating within a narrower scientific community. Tools can be new stand-alone applications or web services, provided that they are compatible with most widely-used computer platforms and exchange information effectively (via standard protocols and file formats) with existing, popular applications. The Phase 1 contract should demonstrate the feasibility of the approach. The Phase 2 contract should provide prototype software that can be demonstrated at the company and a prime contractor or NASA. It is desirable to have the development lead to software that is commercialized or infused into NASA program use.

To promote interoperability, tools shall use industry standard protocols, formats, and APIs, including compliance with the ISO, FDGC, and OGC standards as appropriate. For example a tool may manipulate XML of various types, such as GML, SensorML, KML; or use standard services, such as WSDL and UDDI. Applications may subset, filter, merge, and reformat existing spatial data; provide links to attribute data; or visualize results. Combining NASA research data with popular geospatial services is encouraged.

S6.05 Data Management - Storage, Mining and Visualization

Lead Center: GSFC

This subtopic focuses on supporting science analysis through innovative approaches to managing and visualizing collections of science data which are extremely large, complicated, and are highly distributed in a networked environment that encompasses large geographic areas. There are specific areas for which proposals are being sought:

3D Virtual Reality Environments

- 3D virtual reality environments for scientific data visualization that make use of novel 3D presentation techniques that minimize or eliminate the need for special user devices like goggles or helmets;
- Software tools that will enable users to 'fly' through the data space to locate specific areas of interest.

Distributed Scientific Collaboration

- Tools that enable high bandwidth scientific collaboration in a wide area distributed environment;
- Novel tools for data viewing, real-time data browse, and general purpose rendering of multivariate geospatial scientific data sets that use geo-rectification, data overlays, data reduction, and data encoding across widely differing data types and formats.

Distributed Data Management and Access

- Metadata catalog environments to locate very large and diverse science data sets that are distributed over large geographic areas;
- Dynamically configurable high speed access to data distributed and shared over wide area high speed network environments;
- Object based storage systems, file systems, and data management systems that promote the long term preservation of data in a distributed online (i.e., disk based) storage environment, and provide for recovery from system and user errors.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware/software demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

S6.06 Spatial and Visual Methods for Search, Analysis and Display of Science Data

Lead Center: SSC

This subtopic seeks technical innovation and unique approaches to exploit spatial tools in order to increase the use of NASA research data, models, simulations, and visualizations. The goal is to facilitate NASA's Science and Exploration Missions, and outreach to the interested public. These tools will be used by the NASA Applied Sciences Program managed by the Applied Research and Technology Project Office at Stennis Space Center. The tools should be easy to use by non-specialists, from scientists and policy makers to the general public. Tools and services will be prototyped for accessing and fusing (or mashing) image and vector data with popular Web-based or stand-alone applications. Tools can be plug-ins or enhancements to existing software or on-line services. Tools and the products might be used for broad public dissemination or for communicating within a narrower scientific community.

For example, an authoring tool may help a non-GIS expert to map a National Weather Service modeled hurricane path over a background of NASA MODIS sea surface temperatures, in turn draped on a visualization of the globe served by GoogleEarth.

To promote interoperability, tools shall use industry standard protocols, formats, and APIs. For example a tool may manipulate XML of various types, such as GML, SensorML, KML; or use standard services, such as WSDL and UDDI. Applications may subset, filter, merge, and reformat existing spatial data; provide links to attribute data; or

visualize results. Combining NASA research data with popular geospatial services is encouraged. Examples of popular applications and services currently include:

- Imagery servers: e.g., NASA DAACs, OGA servers (USGS, NOAA, DOI), Microsoft Terraserver, Google Maps;
- Mapping platforms: e.g., Google Earth, NASA WorldWind;
- Map servers: e.g., Census Bureau, EPA Maps, Google Maps, MapQuest, Yahoo Maps.

9.1.4 SPACE OPERATIONS

In 2004, President Bush announced a new space exploration vision for America's civil space program. "*A Renewed Spirit of Discovery: The President's Vision for U. S. Space Exploration*" included five objectives:

1. Implement a sustained and affordable human and robotic program to explore the solar system and beyond;
2. Extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations;
3. Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration;
4. Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests; and
5. Study the Earth system from space and develop new space-based and related capabilities for this purpose.

The Space Operations Mission Directorate provides the foundation for NASA's space programs — space travel for human and robotic missions, in-space laboratories, processing and operations of space systems, and the means to return data to the Earth. The role of the directorate is to provide the operational capabilities for the Agency. These capabilities must continue to evolve synergistically with the directorate guiding the development and enhancement of operational systems (e.g. communications, launch range safety and on-board operations). As the Agency moves forward, future spacecraft and missions that must be integrated into the evolving operational capability and have the potential to vary in size and complexity from micro satellites to manned missions. We provide space access for our customers with a high standard of safety, reliability, and affordability. In support of the President's Vision for Space Exploration, the Space Operations Mission Directorate will marshal its SBIR efforts around a key enabling transformational technology: Affordable communications for exploration, science and space access services and operations. We go forward as explorers and as scientists to understand the universe in which we live.

<http://www.hq.nasa.gov/osf>

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TOPIC: O1 Space Communications and Navigation

NASA's communications capability is based on the premise that communications shall enable and not constrain missions. Communications must be robust to support the numerous missions for space science, Earth science and exploration of the universe. Technologies such as optical communications, RF including antennas and ground based Earth stations, surface networks, access links, navigation and timing, reprogrammable communications systems, communications systems for EVAs, advanced antenna technology, transmit array concepts and communications in support of launch services including space based assets are very important to the future of exploration and science activities of the Agency. Emphasis is placed on size, weight and power improvements. Even greater emphasis is placed on these attributes as smaller spacecraft (eg., micro and nano satellite) technology matures. Innovative solutions centered around operational issues associated with the communications capability are needed. Communications that enable the range safety data from sensitive instruments is imperative. These technologies are to be aligned with the Space Communications and Navigation Architecture as being developed by the Agency. A typical approach for flight hardware would include: Phase 1 - Research should identify and evaluate candidate telecommunications technology applications to demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Plan a demonstration to validate the technologies/tools/processes. Bench or lab-level demonstrations showing concept viability is encouraged. Commercial applicability should be addressed. Phase 2 - Emphasis should be placed on developing and demonstrating the technology under simulated flight conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into space-worthy systems defining interfaces (both on the spacecraft and to candidate ground segments). When applicable, researchers should deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

O1.01 Coding, Modulation, and Compression

Lead Center: GSFC

Participating Center(s): GRC, JPL

Power and spectrum efficient solutions are needed for both near-Earth and deep-space science and exploration applications. Channel coding efficiency from 50% to 87%, combined with good bit-error/burst-error correction property will provide solutions to multiple missions. A high-speed, digital receiver capable of demodulating coded modulations in addition to uncoded modulations is needed for future missions. In compression, implementation of a high-speed decoder for decoding a standard embedded bit-stream offering tunable lossy compression to lossless compression is desired. Proposals are sought in the following specific areas:

Compression

High-speed decoder capable of decoding coded bit stream conforming to CCSDS 122.0-B-1 Image Data Compression standard (www.ccsds.org) is solicited. The decoder has to provide over 640 Mbits/sec decoding for up to 16-bit image data coded in an embedded bit stream. The implementation technology shall point to potential space-use feasibility.

Coding

1. Special emphasis is placed on a channel coding design suitable for near-Earth missions, operating at least at over 80% coding rate with an error floor lower than Bit-Error-Rate (BER) of $10e^{-10}$, and at least 8-bit burst-error correction property, with encoder/decoder complexity consistent with implementations at data rates close to 1 Gbps and power consumption smaller than a few watts. The new design when compared with current CCSDS Reed-Solomon (255,223) coder at BER of $10e^{-5}$ shall have over 2dB Eb/No gain. The preferred code block frame length is from 4K to 16K bits. Proposed implementation technology shall point to potential space-use feasibility.

2. High-speed FPGA decoder for a set of 10 recently proposed low-density parity-check (LDPC) codes specified in a CCSDS Orange Book CCSDS 131.1-O-1 (www.ccsds.org). These codes include 9 codes, of rates 1/2, 2/3, and 4/5 and input blocklengths 1024, 4096, and 16384, and a rate 7/8 code of input blocklength 7136. The design should be capable of switching in real-time between decoders for any of the 10 codes, and have a throughput of at least 50 Mbps. There may be opportunities to use partial, stand-alone FPGA solutions developed by NASA.

High-Rate Receiver

High-rate receiver capable of decoding coded and un-coded modulation suite (8-PSK, GMSK, filtered OQPSK) specified by CCSDS 413.0-G-1 April 2003 (www.ccsds.org) and 16-PSK, 16-QAM, 16-APSK with processing throughput greater than 300 Mbits/sec is desired. A desirable feature for the receiver output is 7 bits/sample that can be used as input to channel decoding algorithms based on soft-decision decoding.

01.02 Precision Spacecraft and Lunar/Planetary Surface Navigation and Tracking

Lead Center: GSFC

Participating Center(s): GRC, JPL, JSC

This call for proposals is meant to serve NASA's ever-evolving set of missions, which require precise tracking of spacecraft position and velocity in order to achieve mission success. The call seeks evolutionary improvements in modularity, sustainability, cost, and performance for current space navigation concepts that support the Vision for Space Exploration. This includes Projects Constellation, Mars Exploration Program, robotic servicing, and robotic Earth and space science missions. NASA also seeks disruptive navigation concepts that might not match the modularity, sustainability, cost, and/or performance of current technologies and their near-term evolution, but have convincingly demonstrable potential to overtake the evolution of current technologies within the future development of Project Constellation, and Earth and space science missions, in the 2015 - 2020 timeframes.

While the definition of "precise" depends upon the mission context, typical interplanetary scenarios have required Earth-based radiometric ranging accuracies of order 1-2m at 1 AU, Doppler to 0.03 mm/sec, and plane-of-sky angles to 2.5 nano-radians. While some legacy applications remain at 2.3 GHz, most current tracking is being done at 8.4 GHz. Forward looking demonstrations are being planned at 32 GHz. These radiometric techniques have been complimented by optical techniques which achieve ~1.5 micro-radian angular accuracy upon target approach. The accuracy of radio-based techniques is typically limited by one's ability to calibrate the path delay through intervening media (troposphere, ionosphere) and by the phase stability of electronics in both the spacecraft and ground systems. For both media and electronics, the stability goal is to achieve Allan standard deviations of $4e^{-15}$ at 100 seconds and $1.5e^{-15}$ at $1e^3$ to $1e^4$ seconds while maintaining, or improving upon, current levels of reliability.

Space navigation technology concepts should support launch and return to Earth, including range safety, early orbit operations, in-space assembly, cis-lunar and interplanetary transit, libration point transit and orbit, lunar and planetary approach and orbit, ascent and descent from lunar and planetary surfaces, including precision landing, automated rendezvous and docking, and formation flying spacecraft forming synthetic apertures for science imaging and interferometry. Surface navigation technology concepts should support communications and navigation surface networks involving rovers and/or astronauts on a lunar and/or other planetary environment.

NASA considers applicability to multiple operational regimes through modularity and/or missionization of common components a key element in its exploration strategy. Space navigation systems must produce accurate long-term trajectory predictions as well as definitive epoch solutions. Surface navigation systems must produce accurate dead-reckoning over long traverses. Where applicable, proposed concepts should be interoperable with and/or leverage the resources of NASA's space communications architecture. All navigation systems should be compatible, where applicable, to continuous or near-continuous trajectory perturbations generated by onboard spacecraft systems. All concepts must show some significant advantages over current techniques in at least one of the following areas: accuracy, cost, reliability, modularity, sustainability, or for onboard systems, mass, power, and volume.

Innovative technologies are sought in the following areas:

- Highly phase-stable RF ground systems are critical to high accuracy radiometric tracking. Present systems rely upon analog transmission over 0.5 to 10 km distances of a broadband (100 - 600 MHz) spectrum. Transmission induced phase errors could be greatly reduced by developing highly phase stable digital sampling and time tagging systems that can be placed near (~10m) to the RF feedhorn without measurably degrading the RF signal capture with spurious tones and noise. Phase stability goals are given above. The sampler should Nyquist sample the 100 - 600 MHz band with at least 8-bit resolution and be capable of digitally transmitting the resulting samples over fiber optic lines;
- The VLBI parameter estimation software used to build the radiometric reference frames used for precise tracking relies on a Square Root Information Filter that makes use of Householder transformation tech-

niques. These solutions often take several days of CPU time on a modern workstation. Block matrix techniques have the potential to optimize the interaction of the CPU and cache memory thereby greatly reducing the CPU time needed for solutions. The goal is a factor of three improvement in total solution time for problems with 7 million data points and 500,000 parameters, which include at least 5000 parameters that are active over the entire data set;

- Microwave radiometry of atmospheric emission lines (22 GHz H₂O, 60 GHz O₂) has been successful in demonstrating 1 mm level calibration of tropospheric path delay. However, the usefulness of this technique has been limited by the large mass and size of the instrument packages. Identifying/developing low mass, low cost implementations of this technique without significantly sacrificing accuracy would greatly enhance precise tracking;
- Develop low mass, (Less than 1 kg) low cost onboard radio frequency standards for generating highly phase-stable onboard radio signals which achieve Allan standard deviations of 1×10^{-15} at 1000 seconds and drift of less than 10^{-15} /day;
- Develop innovative tracking technologies using new wavelengths (X-ray, Infra-red, etc.), such as systems using celestial and planetary emissions and reflections (not limited to the visible spectrum) that can produce three-dimensional absolute and relative position and velocity in regions where Earth-based GPS measurements are not available. The technologies can exploit either ground based or on-board techniques;
- Develop innovative technologies for improving the state-of-the-art in terms of cost and performance in making spacecraft-to-spacecraft measurements, such as omni-directional range and bearing sensors and robotic-vision-based systems;
- Develop innovative navigation algorithms and software supporting analysis, design, and mission operations that will reduce operations costs and support multiple systems in simultaneous, tightly-coupled, non-quietest operations, such as robotic servicing, formation flying, or surface mobility.
- Systems and technologies for providing an EVA crewmember with real-time navigation and position information while traversing on foot or on a rover. This system will be especially useful when the suited crewmember is traversing on foot and cannot rely on the rover system and markers for walk-back navigation.
- Develop a highly integrated Ultra Wide Band (UWB) communications and tracking solution to reduce costs and provide robust performance, multipath immunity, long range one-way tracking, high precision short range tracking, high (broadband) capacity, and a transmit-only tag tracking system. RFID tags using UWB technology have been shown to provide sub-inch accuracy for close-in tracking. This precision tracking can be used to allow astronauts and robonauts to work in close proximity with reduced risk of collisions. The same UWB equipment can be used for long range tracking/wideband communications and the precise tracking at close ranges. Because of its mitigation properties, this impulse radio technology is well-suited for surface mobile area networks and reliable for simultaneous target tracking and high data rate communications in and around lunar craters. Commercial applications include precise tracking of moving oil-drill equipment, medical imaging, automobile collision-avoidance and surveillance through walls.

O1.03 Communication for Space-Based Range

Lead Center: GSFC

Participating Center(s): DFRC, GRC, KSC

Metric tracking of launch vehicles for range safety purposes is currently based on redundant radars, telemetry receivers, and uplink command transmitters at the launch site with additional assets deployed downrange in order to maintain line-of-sight communications with the vehicle as it passes over the horizon to orbital insertion.

The vision of space-based range architecture is to assure public safety, cut the costs of launch operations, enable multiple simultaneous launch operations, decrease response time, and improve geographic and temporal flexibility by reducing, or eliminating, these assets. In order to achieve this, a number of advancements in tracking and telemetry are required. Some of NASA's needs are:

GPS/IMU Metric Tracking and Autonomous Systems

Realization of a space-based range requires development of GPS receivers that incorporate:

- Low power consumption;
- Low mass/volume;

- Compliance with range safety standards;
- Flexible tracking loop programmability;
- Programmable output formats; and
- Operability in high G environments.

Other highly desirable GPS specific characteristics include open architecture supported by development software and the capability of being incorporated onto circuit boards designed for multiple functions.

Tactical grade inexpensive expendable IMUs are needed which can function on spin-stabilized rockets (up to 7 rps) and reliably function during sudden jerk and acceleration associated with launch and engine firings and can be coupled with GPS receivers.

Also needed are approaches to processing and merging the independent outputs of GPS and Inertial Navigation Sensors and combining them with rule-based systems for autonomous navigation and termination decision making.

Space-Based Telemetry

Small, lightweight, low cost transceivers capable of establishing satellite communications links for telemetry and control during the launch and ascent stages of flight are required to provide unbroken communications throughout the launch phase. These may enable use of the NASA TDRSS, or commercial communications satellite constellations. These transceivers are needed for use on suborbital and orbital platforms as well as for launch operations. While the communications support for launch vehicle operations may require continuous support for short durations in the order of less than 30 minutes other applications will be on platforms which require support for the duration the mission which could last for more than a month. Additionally it is highly desirable to limit the user burden to provide adequate EIRP and G/T for providing acceptable link margins between the constellation and the transceiver. Hence use of communications constellations in lower than GEO will be advantageous.

Techniques for multiplexing narrow bandwidth channels to permit increased bit rates and improved algorithms for ensuring smooth transition of support between communications satellites are also needed.

GPS Attitude Determination for Launch Vehicles

Investigate using inexpensive arrays of GPS antennas and receivers on small, expendable launch vehicles to determine the attitude angles and their rates of change as an alternative to traditional inertial measurement units.

The system should be contained entirely on the vehicle and not rely on ground-based processing. The attitude accuracy should be comparable to gyroscope-based systems and should be free of drift and gimble lock. The system must be able to maintain attitude output during periods of high dynamics and erratic flight. The attitude must be determined at a rate of least 10 Hz with minimal processing delay and must be output in a format compatible with vehicle telemetry systems.

Integrated small, low mass, low power consumption transceiver/sensor packages are needed which can provide bidirectional communication interfaces between flight platforms such as weather balloons via the internet for the purpose of measurement of wind profiles, and atmospheric weather parameters such as temperature, humidity and ozone levels.

O1.04 Antenna Technology

Lead Center: GRC

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

NASA seeks advanced antenna systems for use in spacecraft and planetary surface vehicles used in science, exploration systems, and space operations missions. Future human and robotic missions to the Moon and Mars will have stringent communication requirements. Highly robust communication networks will be established on-surface as part of a long-term, evolutionary mission set. Such networks will grow to consist of a large number of communication links that connect the various network nodes. Some of these nodes must also maintain continuous high data rate communication links between the surface and orbiting relays or directly to the Earth. Great demands will be placed on these communication systems to assure mission safety, robustness in harsh environments, and high reliability for long duration missions with diverse human and robotic elements.

Areas of interest include very large aperture, lightweight spacecraft antenna systems, including high-gain deployable antenna architectures, multi-frequency and dual polarized antennas, self-orienting systems, phased array antennas, adaptive beam correction and pointing control, reconfigurable antennas, novel concepts, and antennas that can adapt to failed components without compromising performance and operability (e.g., smart antennas that include structural health monitoring and active control). Antenna systems for novel navigation concepts (e.g., pulsar beacons) as well as integrated communications and navigation architectures are desirable.

Large inflatable membrane antennas to significantly reduce stowage volume, provide high deployment reliability, and significantly reduced mass density (i.e., $<1\text{kg/square meter}$) to provide communication links from the Moon/Mars surface to relay satellites or Earth. NASA is interested in large Gossamer antennas for future exploration scenarios. These membrane antennas are deployed from a small package via some inflation mechanism. For example, 20 meter class inflatable apertures may enable deep-space relays from a Jupiter Lagrange point, and 10 meter class apertures may be sufficient for Mars relay satellites. It is desirable to rigidize these membrane antennas along with their supporting structures so that make up gas is not required. This topic is interested in techniques for rigidizing these membrane antennas (e.g., ultraviolet curing), as well as thin-membrane tensioning and support techniques to achieve precision and wrinkle-free surfaces, in particular for Ka-band applications. In addition, this topic is also interested in novel materials (including memory matrix materials) and approaches to construct large, deployable or inflatable reflective and RF focusing surfaces for use as large aperture antennas. Low emissivity materials to enable passive microwave instrument application are also beneficial. Structural health monitoring systems and sensors are needed to support pre-flight integration and test activities as well as to assure appropriate deployment in-flight and continued reliability of the overall communication system.

High efficiency, miniature antennas with smaller than lambda square aperture size, to provide astronauts and robotics communications for surface to surface and surface to orbit for lunar, Mars, and planetary exploration missions are highly desirable. Recent new antenna research and development has shown that it is possible to design and build aperture antennas with smaller than the minimum effective aperture size of dipoles. This new class of antennas can provide higher antenna gains ($> 2.5\text{ dBi}$) than the dipole antenna in much smaller aperture size ($< .13\text{ lambda square}$). Because of its size and higher gain these antennas can be used reliably by astronauts and robots for communications in the UHF, VHF, and S- frequency bands for lunar or Mars exploration missions. In particular, highly flexible, low-mass, advanced spacesuit antennas are desired for Lunar and Mars surface exploration. Software Defined Radios are baselined for communication and telemetry between different surface elements. Bands of interest include UHF, S-band, and Ka-band. Antenna systems should provide high reliability over all bands with as little operational complexity as possible. Reconfigurability, UWB, multi-band, and e-textile solutions are possible approaches for consideration. For flexible antennas, approaches for reliable interfaces to conventional technologies (e.g., coaxial cables) are highly desired. This subtopic is interested in novel antenna concepts that address the aforementioned requirements.

There is also interest in space-to-surface links at 25.5 GHz and 37 GHz. The size of reflector antennas is limited by the accuracy of the reflector surface that can be achieved and maintained on-orbit. Development of special materials and structural techniques to control their environment, etc., reduces environmentally induced surface errors and increases the maximum useable reflector size. Distortions caused by thermal gradients are inherently a large scale phenomenon. The reflector surface is usually sufficiently accurate over substantially large local areas but these areas are not on the same desired parabolic surface. An array of feed elements can be designed to illuminate the reflector with a distorted spherical wave. This distortion can be used to compensate for large scale surface error introduced by thermal gradients, gravitational and other forces, as well as manufacturing. Topics of interest include but are not limited to: Compensating Feed System for an Antenna Reflector Surface With Large Scale Distortions; Techniques for the remote Measurement of Satellite Antenna Profile Errors; Determination of Orbiting S/C Antenna Distortion by Ground-Based Measurements; Measuring and Compensating Antenna Thermal Distortions; Reflector Measurements and Corrections using arrays; and Reflector Distortion Measurement and Compensation Using Array Feeds.

NASA is interested in low cost phased array antennas for suborbital vehicles such as sounding rockets, balloons, UAV's, and expendable vehicles. The frequencies of interest are S-band, Ku-band, and Ka-band. The arrays are required to be aerodynamic in shape for the sounding rockets, UAV's, and expendable platforms. The balloon vehicles primarily communicate with TDRS and can tolerate a wide range of mechanical dimensions.

Antenna pointing techniques and technologies for Ka-band spacecraft antennas that can provide spacecraft knowledge with sub-milliradian precision (e.g., <250 micro-radians) in order to point large spacecraft antennas (e.g., 10 meter diameter) at Mars are also desirable under this subtopic. Methods of dealing with extreme latency (e.g., 20 minutes) in beacon and monopulse systems are of interest.

NASA is designing arrays of ground-based antennas to serve the telecommunications needs of future space exploration. Medium-size (12m class) antennas have been selected for receiving, and arrays of hundreds of them are expected to be required. Applications include communication with distant spacecraft; radar studies of solar system objects; radio astronomy; and perhaps other scientific uses. A significant challenge is the implementation of an array for transmitting (uplinking), which may or may not use the same antennas that are used for receiving. The uplink frequency will be in the 7.1 - 8.6 GHz range (X-band) in the near term, and may be in the 31.5 - 33.0 GHz band (Ka-Band) in the future; it will likely carry digital modulation at rates from 10 kbps to 30 Mbps. An EIRP of at least 500 GW is required, and some applications contemplate an EIRP as high as 10 TW. It is also desirable to support as many as ten simultaneously-operating deep-space missions from one complex on Earth, and to have at least three geographically separated complexes so communication is possible with a given spacecraft at any time of the day. The major challenges in the uplink array design are:

- Minimizing the life-cycle cost of an array that produces a given EIRP by selecting the optimum combination of antenna size, transmitter power, and number of antennas. This becomes much more difficult if the option of using the same antenna for both uplink and downlink is considered.
- Identifying/developing low-cost, highly reliable, easily serviceable components for key systems. This could include highly integrated RF and digital signal processing electronics, including mixed-signal ASICs. It could also include low-cost, high-volume antenna manufacturing techniques. (For the receiving array, another key component is a cryogenic refrigerator for the 15 - 25K temperature range.) Also, low-cost transmitters, including medium-power of the order of 100's of watts amplifiers, are desirable.
- Phase calibration techniques are required to ensure coherent addition of the signals from individual antennas at the spacecraft. It is important to understand whether space-based techniques are required or ground-based techniques are adequate. In general, a target spacecraft in deep space cannot be used for calibration because of the long round-trip communication delay.
- Design of ultra phase-stable electronics to maintain the relative phase among antennas. These will minimize the need for continuous, extensive and/or disruptive calibrations.
- Understanding the effect of the medium (primarily the Earth's troposphere) on the coherence of the signals at the target spacecraft. Generally, turbulence in the medium tends to disrupt the coherence in a way that is time-dependent and site-dependent. A quantitative understanding of this is needed.
- Techniques for integrating a very low-noise, cryogenically-cooled receiver with a medium power (1W to 200W) transmitter. If transmitters and receivers are combined on the same antenna, the performance of each should be compromised as little as possible, and the low cost and high reliability should be maintained.

Research should be conducted to demonstrate technical feasibility during Phase 1 and it should show a path toward a Phase 2 hardware demonstration that will, when appropriate, deliver a demonstration unit for testing at the completion of the Phase 2 contract.

01.05 Reconfigurable/Reprogrammable Communication Systems

Lead Center: GRC

Participating Center(s): JPL, JSC, GSFC

NASA seeks novel approaches in reconfigurable, reprogrammable communication systems to enable the Vision for Space Exploration, Science, and Space Operations. Exploration of the Moon and Mars will require advancements in communication systems to manage the demands of the harsh space environment on space electronics, maintain flexibility and adaptability to changing needs and requirements, and provide flexibility and survivability due to increased mission durations. NASA missions can have vastly different transceiver requirements and available resources depending on the science objective, operating environment, and spacecraft resources. For example, deep space missions are often power constrained; operating over large distances, and subsequently have lower data transmission rates when compared to near-Earth or near planetary satellites. These requirements and resource

limitations are known prior to launch; therefore, the scalability feature can be used to maximize transceiver efficiency while minimizing resources consumed. Larger platforms such as vehicles or relay spacecraft may provide more resources but may also be expected to perform more complex functions or support multiple and simultaneous communication links to a diverse set of assets.

This subtopic seeks advancements in reconfigurable transceiver and component technology, providing flexible, reconfigurable capability while minimizing on-board resources and cost. The use of open standards within the software radio development is desirable while minimizing potential increased resources and inefficiencies. Topics of interest include the development of software defined radios or radio subsystems which demonstrate reconfigurability, flexibility, reduced power consumption of digital signal processing systems, increased performance and bandwidth, reduced software qualification cost, and error detection and mitigation techniques. Complex reconfigurable systems will provide multiple channel and simultaneous waveforms. Areas of interest can be divided as follows:

Signal Waveforms and On-Orbit Reconfiguration

Multiple waveforms and multiple channel support strive to reduce radio count to reduce power consumption of the overall communication system. Tradeoffs in radio count and radio complexity are considered in the analysis. Reconfiguration for software and firmware upgrades shall provide access control, authentication, and data integrity checks for the reconfiguration process. Partial reconfigurable logic allows simultaneous operation and upload of new waveforms or functions. Upon operator or automated load detection failure, capability to provide access back to a known, reliable operational state is needed. An automated restore capability ensures the system can revert to a baseline configuration, thereby avoiding permanent communications loss due to an errant reconfiguration process. Approaches should minimize size and power consumption for deep space transceivers incorporating fault tolerant, reprogrammable digital signal processing devices.

Implementations demonstrating the concept function, and benefits of dynamic or distributed on-board processing architectures to provide maximum reconfigurability and processing capacity are sought. A common processing system capacity for communications, science, and health monitoring is envisioned.

Demonstration of adaptive modulation and waveform recognition techniques are desired to provide capability to reconfigure to the waveform identified based on an on-board library or enable new waveform upload to the on-board library from the ground.

Software Architecture, Implementation, Modeling and Verification

Development and demonstration of low overhead, low complexity hardware and software architectures to enable software component or design reuse, or common testing standards that demonstrates cost or time savings. Emphasis on the application of open standards architecture to facilitate interoperability among different vendors to minimize the operational impact of upgrading hardware and software components.

Methods (i.e., Hardware Abstraction Layers) that enable portability among reconfigurable logic hardware devices among different vendors, different device families and types of digital processing technologies.

As the use of software and firmware increases with more flexible and portable software defined radio technologies, methods are sought to reduce the complexity and cost to space qualify and verify software operation for use in space yet maintain or increase on-orbit reliability.

Techniques to ensure reliable software execution and failure detection and self-correction.

One promise of software defined radios is software and design reuse maintained in a common repository. The cost or ability to reuse software depends on implementation, development practices, code complexity and other circumstances. This subtopic seeks the development and demonstration of software tools or tool chain methodologies to enable both design and software code reuse.

The Space Telecommunications Radio System (STRS) architecture incorporates the development of an open architecture for NASA Software Defined Radios for space. The STRS standard includes software/firmware and hardware compliance rules that must be followed to comply with the standard. A tools suite that autonomously

implements accurate and repeatable tests is required to verify infrastructure, waveform, and hardware STRS compliance. The tool suite must be extendable as the STRS architecture expands to incorporate additional requirements. Innovative solutions are sought under this solicitation to develop the requirements, top level design objectives, and top level design of the compliance tools. The recommended solutions must not incorporate proprietary products or solutions.

Fault Tolerance

The use of reconfigurable logic devices in software defined radios is expected to increase in the future to provide reconfigurability and on-orbit flexibility for waveforms and applications. As the densities of these devices continue to increase and feature size decreases, the susceptibility of the electronics to single event effects also increases. Novel approaches to mitigate single event effects caused by charged particles are sought that reduces power consumption and complexity compared to traditional approaches (i.e., voting schemes and constant updates (scrubbing)).

Techniques and implementations to provide a core waveform capability within the software defined radio in the event of failure or disruption of the primary waveform and/or system hardware. Communication loss should be detected and core or “gold” waveform automatically executed to provide control access to the diagnostic system and over-the-air reload operational waveform and control software.

Radio Architectures

Innovative solutions to provide software defined radio implementations to reduce power consumption and mass. Solutions should promote modularity and common, open interfaces.

Software defined radio implementations that enable future hardware scalability among different mission classes (e.g., low rate deep space to moderate or high rate near planetary, or relay spacecraft). Operational characteristics range from 1's to 10's Mbps at UHF and S-band frequency bands up to 10's to 100's Mbps at X, and Ka-band frequency bands.

Component Technology

Advancements in analog-to-digital converters or digital-to-analog converters to increase sampling and resolution capabilities while reducing power consumption.

Novel techniques to advance memory densities, reduce power consumption, and improve performance in harsh environments.

Advancements in reconfigurable logic technology including processing advancements, radiation hardened commercial technology and advancements in advanced computing such as polymorphous computing.

O1.06 Miniaturized Digital EVA Radio

Lead Center: JSC

Participating Center(s): GRC

With NASA now planning future sustained manned lunar outpost missions, the need is paramount for a reliable, robust, lightweight, and compact EVA software radio capable of achieving enhanced performance and efficiency on any of the following frequency bands of interest: UHF (401 - 402 Mhz, 25khz bandwidth), S-band (2.4 - 2.483 GHz), and Ka-band (22.55 - 23.55 GHz). Assume multi-point RF communications and simultaneous links to suit/vehicles at 10 km range and RF contingency voices at UHF half-duplex.

Due to menacing dust storms, frequency agility will be necessary during periods of disruptions. The programmable radio must support multiple bandwidths and data transmissions of telemetry, voice, and high-rate video. Assume bi-directional link and 20 Mbps maximum data rate. Solutions should include adaptive techniques to accommodate changing propagation and interference.

Small volume and low mass are always sought for human missions to enhance astronaut mobility on planetary surface. Operational scenarios dictate that EVA radios transmit audio, telemetry, and high-rate video to surface

rovers, lander, and habitats, and other astronauts. Proposers must address EVA radio relay communications to surmount obscurations or poor line-of-sight to any surface nodes described above.

Pioneering astronauts exploring the surface of the Moon will also require a network enabling not only communications but precision relative navigation to keep these explorers abreast of their position relative to each other and lunar assets out to a maximum of 10 km.

NASA needs systems and technologies to provide an EVA crewmember with real-time navigation and position information while traversing on foot or in a rover. This system will be apt when the suited crewmember is traversing on foot and cannot rely on the rover system and markers for walk-back navigation. Because EVA radio is battery operated, power consumption should be minimized.

This solicitation seeks to develop a highly integrated multi-band multi-mode EVA adaptive intelligent programmable radio, a network that enables navigation between mobile and fixed communicating nodes, and required middleware technologies. Assume a stand-alone overlay or perhaps an embedded layer in a pre-existing, CDMA, OCDMA, ODFM, VOFDM or TDMA packet communication environment. In addition, EVA radio must dynamically and adaptively conserve power consumption on the fly packet-by-packet while maintaining interoperability among nodes.

Both communication and navigation functions of the network must assure 3D tracking and navigation accuracy, a BER of $10e^{-8}$ or better, and graceful degradation. As a minimum, the proposed communications network concept must be capable of stand alone operation, independent of any other communication or navigation asset, and be capable of delivering high data rate or variable data rate digital communication ranging from voice to imagery transmissions while continually delivering bearing and pseudo-ranges between nodes within the network.

With ever-increasing versatility of the emerging programmable radios, NASA also needs a more potent approach to energy conservation – one that matches the QoS requirement, channel condition, and the interference environment to the most energy efficient operating point of the EVA radio. This requires an intelligent and/or cognitive middleware to draw QoS information from the application, plus channel and interference information from the PHY. Thus, the middleware identifies the unique PHY and MAC combinations that results in minimal energy operation.

As the number of modes delivered on the QoS increases, choosing the mode with the least energy profile must lead to substantial energy savings and battery life extension. The evolutionary use of Software Defined Radios and the emergence of technologies such as multi-antenna have resulted in radio systems that can easily support 1000s of unique modes. Coupled with the presence of heavy interference like dust storms and channel impairments, the minimal energy mode of operation must be identified. Proposed solutions must achieve energy consumption of 5x to 10x reduction in total power consumption, depending upon the richness of and diversity of modes available on the target radio. All software must be portable to any radio platform.

Phase 1 Deliverables:

Propose a robust multi-band miniaturized frequency-agile EVA software defined radio suitable for applications and bands. Address all technical MEMS challenges, pitfalls, and tradeoffs of EVA radio size, weight, power as well as reliability, complexity, and performance. Solutions should encompass a notional architecture, functional requirements, and building block concepts, demonstrating a reliable and simultaneous voice, telemetry, and video transmission as well as reconfigurability across multiple applications and frequency bands. Special interests include single-chip design/packaging and RF MEMs technologies to realize compact radios under 5 lbs.

Develop suitable communication and navigation 3D tracking network system and algorithms capable of demonstrating the feasibility of the approach. Integrated communication and navigation solutions must include tracking, locating, identifying tagging assets with multiple routes over an operational range of 10 km – even if they descend in craters. Based on a minimum of three nodes, simulate the performance of the proposed integrated communications and navigation network architecture and conduct sensitivity analysis for the selected implementation strategy.

Develop the required middleware to properly characterize it in simulation. Achieve minimal power consumption by proper mode selection and perform demonstrated with five unique radio models including EVA. Conduct trades and

identify the right set of required parameters for the ideal radio for such middleware. Quantify performance in terms of energy savings and the ability of the middleware to maximize connectivity and throughput in a mobile ad hoc network.

Phase 2 Deliverables:

Develop a EVA multi-band compact, lightweight, reconfigurable radio hardware prototype unit with multi-functional capabilities described in above.

Further enhance the concepts investigated in Phase 1 and demonstrate the feasibility of the approach on an actual platform.

Fabricate and test a prototype with a minimum of 3 nodes using an active multi-node integrated communication and navigation network. Simulate and refine navigation and/or power software algorithms for real time robust operations and characterize system performance in compliance with the design goals outlined in Phase 1.

O1.07 Transformational Communications Technology

Lead Center: GRC

Participating Center(s): JSC

NASA seeks revolutionary, highly innovative, "transformational" communications technologies that have the potential to enable order of magnitude performance improvements for exploration systems, science, and space operations mission applications. The promise of high-performance, multi-functional, nano-structured materials has led to intense interest in developing them for near-term applications for human spaceflight and exploration. These materials, notably single wall carbon nano-tubes, exhibit extraordinary mechanical, electrical, and thermal properties at the nano-scale and possess exceptionally high surface area. The development of ultra-capacitors and nano-scale communication devices and systems including FET arrays, nano-antennas, nano-transceivers are of interest for nano-space applications.

Phase 1 must convincingly show the proposed technology will have performance better than the equivalent legacy technology. For example, for a fixed-SAW oscillator part replacement, specific objectives include low power consumption (<15 mW), good stability (± 10 ppm), excellent phase noise (better than -120 dBc/ Hz at 10 kHz)/ jitter, small form factor ($< 3\text{mm} \times 3\text{mm} \times 2\text{mm}$), high reliability, high output power (> 10 dBm), low spurious output (harmonics attenuated by 30 dBc), low-voltage operation (<3 V), low-voltage operation (<3 V), and low cost. Follow on efforts in Phase 2 should then leverage the analysis and prototypes developed in Phase 1 to demonstrate the proposed technology and potentially deliver devices or units for testing. For instance, major concerns about the silicon clock resonators for NASA include packaging, reliability, and frequency stability over temperature cycling, aging, vibration, and shock. Detailed investigation of these space component specifications should be performed as part of these efforts.

Research interests focus on, but are not limited to, the following areas:

- Innovative methods of using X-ray or radio pulsar signals for precise navigation or positioning of spacecraft.
- Small, low mass, reliable detectors, improvements in position accuracy, digital signal processing advances for time of arrival, drift estimation, and position estimation.
- Development of nano-scale communication devices and systems (e.g., FET arrays, nano-antennas, nano-transceivers, etc.), which can enable nano-spacecraft applications.
- Quantum entanglement or other innovative breakthroughs in quantum information physics to specifically address curious effects and critical unknowns relevant to revolutionary improvements in communicating data, information or knowledge between independent entities across space-time are sought.
- Methods and techniques to demonstrate extremely novel means of effectively packaging, storing, encrypting, and/or transferring information or knowledge.
- Breakthrough power-efficiency in communications brought about through the use of natural phenomenon (e.g., soliton pulse/wave/energy propagation).

- RF Micro Electro-Mechanical Systems (MEMS) devices. Besides low spatial volume, lightweight, and low-power consumption, these devices are also attractive to operate as high Q components and perform frequency selectivity – namely, agile pre-selectors, multi-couplers, and diplexers. Selectivity, or Q, for band pass filters currently comes at an unacceptably high penalty in size and mass. For example, most high rejection diplexers for space-based radios are almost as enormous as the modern radio package itself. To build and design high performance, tightly coupled, low volume space radios, compact selectivity-determining devices are a critical enabler. Most high Q filters above 400MHz, such as inter-digital filters and others involving resonant cavities, are wholly mechanical assemblies which can be “folded” in their design and lend themselves to micro machining techniques
- Other rich areas of investigation may lie within the area between MEMS and Micro-Machined devices, including electromechanically tuned filters, 3D micro machined RF resonators, filter configurations consisting of cantilevered structures, as well as carbon nano-tube waveguides. Develop, apply and demonstrate advantages of RF MEMS circuitry that proliferate the implementation of next-generation lightweight communications systems (e.g., extravehicular activity (EVA) radios).

O1.08 Long Range Optical Telecommunications

Lead Center: JPL

Participating Center(s): GRC, GSFC

This subtopic seeks innovative technologies for long range Optical Telecommunications supporting the needs of space missions. Proposals are sought in the following areas:

- Systems and technologies relating to acquisition, tracking and sub-microradian pointing of the optical communications beam under typical deep-space ranges (to 40 AU) and spacecraft micro-vibration environments.
- Uncooled photon counting imagers with $>1024 \times 1024$ formats, ultra low dark count rates and 400 - 2000 nm sensitivity.
- Ultra-low ($<0.1\%$) fixed pattern non-uniformity NIR imagers with large format (1024×1024), low noise (<1 e- read, <1 ke/pix/sec dark) and high QE (>0.7).
- Nutating fiber pointing mechanisms with high precision (<0.01 urad) and high bandwidth (> 3 kHz).
- Compact, lightweight, low power, broad bandwidth (0 - 3 kHz) disturbance rejection and/or isolation platforms.
- Space-qualifiable, $> 20\%$ wall plug efficiency, lightweight, 20-500 psec pulse-width (10 to > 100 MHz PRF), tunable (± 0.1 nm) pulsed 1064-nm or 1550-nm laser transmitter fiber MOPA sources with >1 kW of peak power per pulse (over the entire pulse-repetition rate), with Stimulated Brillouin Scattering (SBS) suppression and > 10 W of average power, near transform limited spectral width, and <10 psec pulse rise and fall times. Description of approaches to achieve the stated efficiency is a must.
- > 2 -m diameter, <30 -nm bandpass optical filters on a membrane substrate to pass center. Wavelengths in the 1000 to 1600 nm band with $>90\%$ transmission.
- > 2 -m diameter f/1.1 primary mirror and Cassegrain focus of $\sim f/6$ optical communication receiver telescopes. Maximum RMS surface figure error of 1-wave at 1000 nm wavelength. Telescope is positioned with a 2-axis gimbal capable of 0.25 mrad pointing. Combined telescope and gimbal shall be manufacturable in quantity (tens) for $<\$400$ k each.
- Daytime atmospheric compensation techniques capable of removing all significant atmospheric turbulence distortions (tilt and higher-order components) on an uplink laser beam; and/or for a 2-m diameter downlink receiver telescope. Also of interest are technologies to compensate for the static and dynamic (gravity sag and thermal) aberrations of 2-m diameter telescopes with a surface figure of 10's of waves.
- Ground-based, relatively low-cost diode-pumped laser technology capable of reaching 100 kW average power levels in a TEM₀₀ mode, for uplink to spacecraft.
- Photon counting Si, InGaAs, and HgCdTe detectors and arrays for the 1000 to 1600 nm wavelength range with single photon detection efficiencies $> 60\%$ and output jitters less than 20 psec, active areas > 20 microns/pixel, and 1 dB saturation rates of at least 100 megaphotons (detected) per pixel and dark count rates of < 1 MHz / mm².

- Radiation hard (100 Mrad level) photon counting detectors and arrays for the 1000 to 1600 nm wavelength range with single photon detection efficiencies > 40% and 1 dB saturation rates of at least 30 mega-photons/pixel and operational temperatures above 220 K and dark count rates of < 10 MHz / mm.
- Single-photon-sensitive, high-bandwidth (1 GHz), linear mode, high gain (> 1000), low-noise (< 1 keps), large diameter (200 micron), HgCdTe avalanche photodiode and/or (small diameter) arrays for optical detection at 1060 nm or 1550 nm.

Research should be conducted to convincingly prove technical feasibility during Phase 1, with clear pathways to demonstrating and delivering functional hardware, meeting all objectives and specifications, in Phase 2.

O1.09 Long Range Space RF Telecommunications

Lead Center: JPL

Participating Center(s): GRC, GSFC

This subtopic seeks innovative technologies for long-range RF telecommunications supporting the needs of space missions. Proposals are sought in the following areas:

- Ultra-small, light-weight, low-cost, low-power, modular deep-space transceivers, transponders and components, incorporating MMICs and Bi-CMOS circuits;
- MMIC modulators with drivers to provide large linear phase modulation (above 2.5 rad), high-data rate (10 - 200 Mbps), BPSK/QPSK modulation at X-band (8.4 GHz), and Ka-band (26 GHz, 32 GHz and 38 GHz);
- High-efficiency (> 60%) Solid-State Power Amplifiers (SSPAs), of both medium output power (10 W - 50 W) and high-output power (150 W - 1 KW), using power combining techniques and/or wide-bandgap semiconductor devices at X-band (8.4 GHz) and Ka-band (26 GHz, 32 GHz and 38 GHz);
- Epitaxial GaN films with threading dislocations less than 1e6 per cm² for use in wide band-gap semiconductor devices at X- and Ka-Band;
- Utilization of nanomaterials and/or other novel materials and techniques for improving the power efficiency or reducing the cost of reliable vacuum electronics amplifier components (e.g., TWTAs and Klystrons);
- Long lifetime, radiation hard SSPAs, modulators and MMICs for 26 GHz Ka-band (lunar communication);
- TWTAs operating at higher millimeter wave frequencies (e.g., W-Band) and at data rates of 10 Gbps or higher;
- Ultra low-noise amplifiers (MMICs or hybrid) for RF front-ends (< 50 K noise temperature); and
- MEMS-based RF switches and photonic control devices needed for use in reconfigurable antennas, phase shifters, amplifiers, oscillators, and in-flight reconfigurable filters. Frequencies of interest include VHF, UHF, L-, S-, X-, Ka-, V-band (60 GHz) and W-band (94 GHz). Of particular interest is Ka-band from 25.5 - 27 GHz and 31.5 - 34 GHz.

O1.10 Surface Networks and Orbit Access Links

Lead Center: GRC

Participating Center(s): GSFC, JPL, JSC

Surface Networks

Exploration of lunar and planetary surfaces will require short-range (~ 25 km), bi-directional, and robust multiple point links to provide on-demand, disruption-tolerant, and autonomous interconnection among surface-based assets. Some of the nodes will be fixed, such as base stations and relays to orbital assets, and some will be moving, such as rovers and humans. The ability to meet the demanding environment presented by lunar and planetary surfaces will encompass the development and integration of a number of communication and networking technologies and protocols, including:

- Low power, space-rated Application-Specific Integrated Circuits (ASICs) and Field Programmable Gate Arrays (FPGAs) for wireless network products: short range (< 1 km) access point, base stations, and wireless router bridges for extending surface network coverage;
- Fixed, long range (< 50 km) wireless network terminals for extending high data rate communications which are designed to be cycled for years through the extreme lunar temperature variations;

- Integrated tracking, timing, and navigation services which will determine locations of human and robotic assets on the lunar surface, providing them to relevant entities;
- Self-healing, ad hoc, disruption tolerant network protocols for intelligent, autonomous link management and reliability;
- Non-line-of-sight communication between stationary and moving assets, outside or inside lunar craters;
- Autonomous surface navigation and hazard avoidance systems for robotic and fixed assets;
- Analog voice-only radio service to the lunar outpost and the lunar relay satellite at the highest network priority for HF, UHF, or S-band.

In addition, to meet the stringent demands of continuous interoperable communications, human exploration needs to develop delay and tolerant networking (DTN) protocols that exploit persistent storage on mobile and stationary nodes to ensure timely and reliable delivery of data even when no stable end-to-end paths exist. Many networks straddle a continuum of disruption, from an almost-always connected network where a contemporaneous end-to-end path does exist, to highly intermittently connected networks where such a path seldom exists. More than disruption tolerant, solutions must exploit stability when it exists to nearly approximate the performance of conventional Mobile *Ad hoc* NETWORK (MANET) protocols. Proposals should address the following areas:

- Technical challenges posed by the design considerations enumerated above and assess tradeoffs of disruption, load, storage, topology, and delivery ratio;
- Demonstrate adaptive DTN routing via simulations;
- Develop proof-of-concept nodes complete with the networking algorithms developed as part of the funded work;
- Demonstrate unique communications in networks that suffer from severe disruptions and delays with adaptive routing developed in Phase 1;
- Develop a prototype convergence layer adapter plug-in for an Extra-Vehicular Activity (EVA) radio.

Orbit Access Links

Lunar and planetary surface networks will need to seamlessly interface with communications access terminals and orbiting relays that can provide autonomous and disruption tolerant connectivity to Earth-based assets. The access link communications system will encompass the development and integration of a number of communications and networking technologies and protocols such as:

- Autonomously reconfigurable receivers capable of automatic link configuration and management;
- Microwave ranging hardware built into the communication system for rendezvous and collision avoidance;
- Ad hoc, long-range spacecraft-to-spacecraft network protocols to initialize links on demand such that each node can route data through to another node.

The effort will leverage on the following technologies addressed under other SBIR subtopics:

- Antennas for surface and orbital access communications required for the aforementioned goals shall be developed under subtopic O1.04.
- Radios for surface and orbital communications required for the aforementioned goals shall be developed under subtopic O1.06.
- Optical transceivers required for the aforementioned goals shall be developed under subtopic O1.08.
- Any high rate, low power, efficient amplifiers or transponders required for the aforementioned goals shall be developed under subtopic O1.09.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward Phase 2 hardware demonstration that will, when appropriate, deliver a demonstration unit for testing at the completion of the Phase 2 contract.

01.11 Software for Space Communications Infrastructure Operations

Lead Center: JPL

Participating Center(s): ARC, GRC, GSFC

The current infrastructure for NASA Space Communications provides services for near-Earth spacecraft and deep-space planetary missions. The infrastructure assets include the Deep Space Network (DSN), the Ground Network (GN), and the Space Network (SN). Recent planning for the Vision for Space Exploration (VSE) for human exploration to the Moon and beyond as well as maintaining vibrant space and Earth science programs resulted in a new concept of the communications architecture. The future communications architecture will evolve from the present legacy assets and with the addition of new assets (e.g., new large scale arrays under consideration, for further information see Space Communications Architecture Working Group report – link below).

New technology is sought to improve resource optimization and the user interface of planning and scheduling tools. The software created should have a commercialization approach with the new modules fitting into an existing or in-development planning and scheduling tool. Proposals are sought in the following three areas:

Intelligent Assistants

In order to automate the user's provision of requirements and refinement of the schedule, "intelligent assistant" software should manage the user interface. Assistants should streamline access and modification of requirement and schedule information. By modeling the user, this software can adjust the level of autonomy by determining what decisions should be made by the user or the automated system. Assistants should try to minimize user involvement without making decisions the user would prefer to make. The assistants should adapt to the user by learning their control preferences. This technology should apply to local/centralized and collaborative scheduling.

In a conflict-aware scheduling system (especially in a collaborative scheduling environment), conflicts are prevalent. With the concept of one big schedule from the beginning of time, real time, to the end of time, resolving conflicts become a difficult task especially since resolving conflicts in a local sense may affect the global schedule. Therefore, an intelligent assistant may provide decision support to the system or the users to assist conflict resolution. This may involve a set of rules combining with certain local/global optimization to generate a list of options for the system or users to choose from.

Resource Optimization

The goal of schedule optimization is to produce allocations that yield the best objectives. These may include maximizing DSN utilization, minimizing loss of desired tracking time, and optimizing project satisfaction. Each project may have their own definition of satisfaction such as maximal science data returned, maximal tracking time, best allocation of the day/week, etc. The difficulty is that we may not satisfy all of these objectives during the optimization process. Obviously, optimal solution for one objective may produce worse results for the other objectives. One possible solution is to map all of these objectives to an overall system goal. This mapping is normally non-linear. Technology needs to be developed for this non-linear mapping for scoring in addition to regular optimization approaches.

Multiple Agents

In an environment where all system variables can be controlled by a single controller, an optimal solution for the objective function can be achieved by finding the right set of variables. In a collaborative environment with multiple decision makers where each decision maker can only control a subset of the variables, modeling and optimization become a very complex issue. In the proposed collaborative scheduling approach, there are many users/agents that will control their own allocations with interaction with the others. How we model their interactions and define system policy so the interaction can achieve the overall system goal is an important topic. The approach for multiple decision-maker collaboration has been studied in the area of Game Theory. The applications cover many areas including economics and engineering. The major solutions include Pareto, Nash, and Stackelberg. There are many new research areas including incentive control, collaborative control, Ordinal Games, etc.

Note that intelligent assistants and multiple agents represent different points on the spectrum of automation. Current operations utilize primarily manual collaborative scheduling, intelligent assistants would enhance users ability to participate in this process and intelligent agents could more automate individual customers scheduling. Ideally, proposed intelligent assistants and distributed agents would also be able to represent customers who do not wish to

expose their general preferences and constraints. A start for reference material on this subtopic may be found at the following:

<http://ai.jpl.nasa.gov> in the publications area;
<http://scp.gsfc.nasa.gov/gn/gnusersguide3.pdf>, NASA Ground Network User's Guide, Chapter 9 Scheduling;
<http://scp.gsfc.nasa.gov/tdrss/guide.html>, Space Network User's Guide, SpaceOps Conference Proceedings; and
<https://www.spacecomm.nasa.gov/spacecomm/>, Space Communications Architecture Working Group Report.

The proposal should explicitly include an operations scenario of before and after the inclusion of the new technology.

TOPIC: O2 Space Transportation

Achieving space flight can be astonishing. It is an undertaking of great complexity, requiring numerous technological and engineering disciplines and a high level of organizational skill. Overcoming Earth's gravity to achieve orbit demands collections of quality data to maintain the security required of the range. The harsh environment of space puts tight constraints on the equipment needed to perform the necessary functions. Not only is there a concern for safety but the 2004 Space Transportation Policy directive that states that the U.S. maintains robust transportation capabilities to assure access to space. Given this backdrop, this topic is designed to address technologies to enable a safer and more reliable space transportation capability. Automated collection of range data, automated tracking and identification of objects, and instrumentation for space transportation system testing are all required. The following subtopics are required secure technologies for these capabilities.

O2.01 Optical Tracking and Image Analysis

Lead Center: KSC

Participating Center(s): DFRC, MSFC

GPS or Radar-aided Autofocus

Investigate using range information from radar, GPS, or other sources, for autofocusing long-range optics systems. Optical tracking provides valuable data during aerospace operations, but large distances between the target and the optical system can lead to distortions caused by atmospheric disturbances. Range information might be useful for a computer-controlled optical focusing system to decrease this distortion. The initial investigation will determine if this approach could be useful using one or multiple cameras, how it might be implemented, and if range information could be combined with other distortion-reduction techniques.

New Optical Tracking Systems

Investigate innovative and unconventional ways to use optical or hyperspectral imaging systems to visualize and track vehicles during launch and landing operations. Possibilities might include, but are certainly not limited to, unmanned aerial vehicle platforms or balloons. The system must be implemented unobtrusively in a spaceport environment. The initial investigation should result in a proof-of-concept demonstration in an appropriately scaled environment.

O2.02 Space Transportation Propulsion System and Test Facility Requirements and Instrumentation

Lead Center: SSC

Participating Center(s): GRC, MSFC

Ground testing of propulsion systems continues to be critical in meeting NASA's strategic goals. Relevant ground testing technologies and capabilities are crucial to the development, qualification, and acceptance process of validating cargo launch vehicles and human rated vehicles including Crew Exploration Vehicles (CEV), CEV Launch Systems, Cargo Launch Vehicle (CLV), and Lunar Surface Access Modules propulsion systems. The ability to quickly and efficiently perform system certification greatly impacts all space programs. Proposals are sought in the following areas:

Instrumentation and Sensors

NASA's Stennis Space Center (SSC) is concerned with expanding its suite of non-intrusive technologies that provide information on propulsion system health, the environments produced by the plumes and the effects of plumes and constituents on facilities and the environment. Current capabilities include non-intrusive optical methods of monitoring plumes for metallic contamination from erosion and wear, measuring the radiative and acoustic energies and as well as measuring the concentrations of environmentally sensitive species. SSC also requires facility health management technologies to monitor the physical health of testing infrastructure to improve the sustainability and reliability of the test facilities and components.

Engine Health Monitoring

Innovative, standalone sensors for non-intrusively measuring physical properties of rocket engine plumes. Measurements of interest include, but are not limited to, species, temperature, density, velocities, combustion stability and O/F measurement.

Plume Environments Measurements: Advanced instrumentation and sensors to monitor the near field and far field effects and products of exhaust plumes. Examples are the levels of acoustic energy, thermal radiation and final exhaust species that will effect the environment.

Facility Monitoring

Advanced instrumentation and sensors for process monitoring in high pressure 12,000 psi and high flow rate 100 lb/sec gas and cryogenic environments. Applications include cryogenic level sensing, fast response/high accuracy cryogenic temperature sensors. Facility response and analysis capabilities for monitoring facility structure, process systems and test article interaction. These include dynamic response, structural fatigue and pipe system health.

Integrated System Health Management (ISHM) Capability for Rocket Engine Testing and Ground Operations

ISHM capability is achieved by integrating data, information, and knowledge (DlaK) that might be distributed throughout the system elements (which inherently implies capability to manage DlaK associated with distributed sub-systems). DlaK must be available to any element of a system at the right time and within proper context. ISHM capability is measured by how well a system performs the following functions:

- Detect anomalies;
- Diagnose causes;
- Predict future anomalies/failures;
- Provide the user with an integrated awareness about the condition of every element in the system and guide user decisions.

The technologies of interest to this topic include:

- Algorithms/approaches/methodologies for anomaly detection;
- Approaches and methodologies for root-cause analysis to diagnose causes of anomalies;
- Approaches and methodologies for prediction of future anomalies;
- Architectures/Taxonomies/Ontologies (management of DlaK - where management implies distributed storage, sharing, processing, maintenance, configuration);
- Software environments that integrate contributing technologies in a modular plug-and-play fashion, adhering to a defined architecture/taxonomy/ontology;
- User interfaces to provide the user integrated system awareness;
- Intelligent elements (e.g., sensors, valves, pumps, etc.).

Computational Modeling Tools and Methods

Developing and verifying test facilities is complex and expensive. The wide range of pressures, flow rates, and temperatures necessary for engine testing result in complex relationships and dynamics. It is not realistic to physically test each component and the component-to-component interaction in all states before designing a system. Currently, systems must be tuned after fabrication, requiring extensive testing and verification. Tools using computational methods to accurately model and predict system performance are required that integrate simple interfaces

with detailed design and/or analysis software. SSC is interested in improving capabilities and methods to accurately predict and model the transient fluid structure interaction between cryogenic fluids and immersed components to predict the dynamic loads, frequency response of facilities.

Plume Environments

Improved capabilities to predict and model acoustic and thermal energy produced by exhaust plumes and interaction/coupling with facilities. Exhaust constituents and far field buoyant plume modeling for environmental impact assessment.

Component Design, Prediction and Modeling

Improved capabilities to predict and model the behavior of components (valves, check valves, chokes, etc.) during the facility design process. This capability is required for modeling components in high pressure 12,000 psi, high flow 100 lb/sec cryogenic environments and must address two-phase flows.

Process System Design, Prediction and Modeling

Improved capabilities to predict and model process systems. The capability should incorporate the previous two areas to accurately model the process systems and test articles.

O2.03 Automated Collection and Transfer of Launch Range Surveillance/Intrusion Data

Lead Center: KSC

Participating Center(s): GSFC, MSFC

Range surveillance is a primary focus of launch range safety and often cost and schedule drivers as well. Launch delays due to difficulty in verifying a cleared range are common and will increase as development encroaches on existing spaceports and as spaceports are built in new areas. Proposals are sought for innovative sensors, instrumentation platforms, and communication technologies which expedite range clearance by providing real-time situational awareness for range operations such as launches, hazardous processing, and recovery.

Instrumentation platforms will provide mobile or transportable surveillance assets for broad area coverage to meet range needs. These platforms should be capable of a high degree of self-sufficiency and autonomy for unattended, long-term operations. During operations the platform must maintain stability so that instruments are not required to compensate for unique environmental characteristics surrounding the operations. Platforms may include, but are not limited to, Unpiloted Aerial Vehicles (UAV), High Altitude Airships (HAA), buoys, etc.

Instrumentation and sensors would include but not be limited to a wide spectrum of optical, infrared, Radio Frequency (RF), and millimeter wave. These would provide for the detection, recognition, and identification of persons and objects that have intruded areas of the range that must be cleared in order to conduct safe launch operations. In addition, multiple sensors and instruments may be used, or combined through the use of neural networks and data fusion, for accurate identification, and time and position of entities.

Centric and integrated communications schemes that adhere to widely accepted standards will enable a scalable architecture for range instrumentation that supports launch operations. Data rates and bandwidth requirements may vary greatly depending on instrumentation and sensors that are incorporated on a range. These constraints and the distributed nature of a range dictate the need to include multiple communication media such as free-space optics, Wi-Fi, and terrestrial and space-based communications links in order to transport the collected data. Novel and innovative approaches to this architecture are sought.

TOPIC: O3 Processing and Operations

The Space Operations Mission Directorate (SOMD) is responsible for providing mission critical space exploration services to both NASA customers and to other partners within the U.S. and throughout the world: from flying the Space Shuttle, to assembling the International Space Station; ensuring safe and reliable access to space; maintaining secure and dependable communications between platforms across the solar system; and ensuring the health and safety of our Nation's astronauts. Each of the activities includes both ground-based and in-flight processing and operations tasks. Support for these tasks that ensures they are accomplished efficiently and accurately enables successful missions and healthy crew.

O3.01 Crew Health and Safety Including Medical Operations

Lead Center: JSC

Participating Center(s): ARC, GRC

Medical Operations is responsible for all operational activities related to crew health issues during all mission phases, with the specific purpose to optimize crew health and performance and prevent negative health consequences from space flight.

This subtopic seeks innovative technologies for procedure management. In each crew, a crewmember is designated as a crew medical officer. This person is responsible for managing in-flight medical issues with the support of a ground-based flight surgeon as well as reference materials that reside onboard an operational vehicle. The medical checklist is the main in-flight resource for medical procedures. It is a large document with many references to medical hardware and interconnections between procedures. Currently the default form of the document is paper with an electronic version also being available to the crew. Current procedure construction, validation, and maintenance is accomplished through a word processing program. Procedures must comply with a standard format. Software is sought that will enable easy construction and maintenance of the procedures, including changes to procedures, changes to hardware, changes to resulting format of the procedures, and validation of the procedures. The ultimate goal is to be able to merge this software with other elements to create an in-flight medical decision support system, including medical data display that supports decision making and just-in-time training.

O3.02 In-helmet Speech Audio Systems and Technologies

Lead Center: GRC

Participating Center(s): ARC, JSC, KSC

The space suit environment presents a unique challenge for capturing and transmitting speech communications to and from a crewmember. The in-suit acoustic environment is characterized by highly reflective surfaces, causing high levels of reverberation, as well as spacesuit-unique noise fields. Known sources of noise within the suit are both stationary and transient in nature. Noise within the suit can be acoustically borne or it can originate from structure-borne vibration. Noise originates from suit machinery, footfalls, suit arm and hip bearing, body movement noise and turbulent flow noise from devices such as oxygen spray bars and breath noise. Static pressure levels within the spacesuit can range from a small fraction of an atmosphere during Extravehicular Activity (EVA) operations to strong hyperbaric conditions that exist during terrestrial field-testing. These changes in static pressure level have significant effects on acoustic transduction. Additionally, in some spacesuits, the crewmember is afforded a wide range of motion within the torso of the suit. The wide range of motion means that the acoustic path between a crewmember's mouth or ear and the microphone or helmet mounted speaker varies significantly with movement, resulting in decreased sound pressure levels at the microphone and/or increased interference from competing background noise sources. In addition, vehicular operations can generate high levels of noise that are not fully attenuated by the spacesuit, helmet or headsets. Due to these factors, the quality of speech delivered to and from the inside of a spacesuit helmet can be low and can have a negative effect on inbound and outbound speech intelligibility and the performance of Automatic Speech Recognition (ASR) systems.

The traditional approach to overcome the challenges of the spacesuit acoustic environment is to use a skullcap-based system of microphones and speakers. Cap-based solutions mitigate many of the acoustic problems associated with in-helmet communications systems through the very short and direct acoustic transmission paths between the crewmember and the speakers and microphones. The skullcap's headsets and noise canceling microphones can also

afford some degree of acoustic isolation for the crewmember from noise generated inside the spacesuit. Cap-based systems are less successful, however, in attenuating high noise levels generated outside the spacesuit (e.g., during launch, descent, burn activities, or emergency aborts), even when coupled with the launch/entry helmet. The use of noise canceling microphones can improve speech intelligibility, but only if the microphones are in close proximity to the crewmember's mouth. Many logistical issues exist for head-mounted caps. Crewmembers are not able to adjust the skullcap, headset or microphone booms during EVA operations (which can last from four to eight hours) or during launch/entry operations. Interference between the protuberances of the cap and other devices, such as drinking/feeding tubes, is a recognized issue during EVA. Comfort, hygiene, proper positioning and dislocation are major concerns for head-mounted caps. Wire fatigue and blind mating of the connectors are also problems with the cap-based systems. In order to accommodate anthropometric variations in crew heads, multiple cap sizes are required. Issues have recently been identified with existing communications systems regarding adjustment of microphone boom lengths, proper function over the wide ranges of static pressure experienced during suited operations, flow noise over the microphone elements, and integration with advanced helmet designs.

NASA is seeking systems, subsystems and/or technologies in support of improvements in speech intelligibility, speech quality, listening quality and listening effort for in-helmet aural and vocal communications. In addition, improvements in hearing protection are sought to protect the crew during all mission phases, in case hazardous acoustic levels and conditions occur.

The specific focus of this SBIR subtopic is on improving the interface between crewmember and the acoustic pickup (i.e., microphones) and generation (i.e., speaker) systems. Systems and devices are sought to improve or resolve acoustic, physical and technical problems (listed above) that have been associated with skullcap-mounted speakers and microphones, or allow for the elimination of skullcap-mounted speakers and microphones. In particular, voice communications systems are sought that have provided crewmembers with adequate speech intelligibility over background noise within, and external to, the spacesuit. Overall system performance must provide Mean Opinion Score (MOS) for Listening Quality (Lq) and Listening Effort (Le) of 3.9 or greater, or Articulation Index (AI) of .7 or better or 90% Intelligibility in the crewmember's native language for both inbound and outbound speech communication. Specific technologies of interest include, but are not limited to:

- Acoustic modeling of the in-suit acoustic environment, including the ability to model structure-borne vibration in helmet and suit structures as well as transduction to and from the acoustic medium.
- Low-mass, low-volume, low-distortion, space-qualified speakers with low variation in sensitivity with static pressure. Changes in speaker sensitivity should be less than 2 dB over the speech band with changes in static pressure between 3 and 18 psia.
- Low-mass, low-volume, low-distortion high-sensitivity (> 5 mV/Pa), space-qualified noise canceling microphones with low variation in sensitivity with static pressure. Changes in microphone sensitivity should be less than 2 dB over the speech band with changes in static pressure between 3 and 18 psia.
- Attenuation of external noise by passive hearing protection that is comfortable for crewmembers during extended use.

In-helmet devices will need to be compatible with high humidity, low humidity and pure oxygen environments. Devices should be able to fit a wide anthropometric range of head and physical features found within the astronaut corps.

Additionally, demonstrations of novel system concepts for in-helmet audio communication are of strong interest. A partial list of such concepts includes:

- Near-field beamforming systems;
- Optical microphone systems;
- Highly directive sound production systems such as parametric sound systems;
- Active noise cancellation systems for hearing protection;
- Bone conduction microphones.

Systems and devices must include appropriate computer processing systems. The expectation is that a working and fully functional system or device will be delivered at the end of Phase 2.

O3.03 Vehicle Integration and Ground Processing

Lead Center: KSC

Participating Center(s): MSFC, SSC

NASA is concerned with creating new and innovative technology solutions for assembly, test, integration and processing of spacecraft, payloads, and flight science experiments; end-to-end launch services; and research and development, design construction, and operation of spaceport services. These include the following areas:

Corrosion Control

Corrosion is the deterioration of materials due to reactions with their environment. Corrosion can have catastrophic consequences when it is not prevented, detected, and controlled. New technologies are needed to build/maintain spaceport systems that are cost-efficient, safe, reliable, and easy to inspect. Corrosion can be minimized by proper selection of materials, coatings, detection methods, and maintenance procedures in the design stage. Corrosion detection is important to avoid catastrophic failures. NASA is seeking technologies for prevention, detection, and mitigation of corrosion in spaceport facilities and ground support equipment. Technologies and tools for the evaluation and detection of hidden corrosion, including a system to detect corrosion under paint on either side of the structure without requiring removal of any components or thermal protection system elements covering the structure. Development of new coatings and qualification of existing coatings for corrosion protection.

Non-Destructive Evaluation/Non-Intrusive Inspection Technologies

Non-destructive evaluation (NDE) technologies for cryogenic foam insulating materials. Tools and techniques for defect detection in composite materials. Non-destructive methods to determine structural integrity of bonded assemblies, especially non-metallic composites and thermal protection system (TPS) materials. Non-intrusive inspection of vacuum-jacketed piping to survey long distances of piping without compromising the vacuum. Nondestructive evaluation/inspection techniques for graphite epoxy composite over-wrapped pressure vessels (COPVs) or Kevlar COPVs. Definitive techniques do not currently exist for determining if there are broken fibers, voids, or delaminations which could result in a decreased safety factor for COPVs. Failure to detect a defect could result in a COPV rupture leading to loss of life, loss of mission, and/or damage to flight hardware, facilities, and ground support equipment (GSE).

Propellant Loading/Servicing/Storage

Lightweight and versatile cryogenic storage and distribution technologies. Energy-efficient cryogenic insulation approaches to achieve operationally effective, integrated refrigeration and storage systems. Increased propellant quantity requirements for Constellation Systems will require larger storage vessels and longer transfer lines. Advanced cryogenic loading technologies, including systems that combine advances in component health management, automated process control, instrumentation, resource conservation, and improved seals. Advanced propellant system umbilicals and quick-disconnect fittings for a variety of fluid interfaces.

O3.04 Mission Operations

Lead Center: ARC

Participating Center(s): JSC, MSFC

The objective of this subtopic is to develop advanced capabilities for mission operations software, with particular emphasis on providing situational awareness and decision-making assistance for mission and flight controllers. Earlier phases of mission operations include pre-planning phases, procedure development, contingency development, and other preparatory tasks. Flight phases include telemetry analysis, state determination, situational assessment, plan revisions, decision-making, commanding, fault responses, and procedure execution. Support phases include data management, plan and procedure revisions, changes to operations practices and rules, etc.

Proposals in the following technical areas are of high interest:

- Situational awareness capabilities for controllers and crew: This subject includes a wide range of capabilities, such as: (1) Methods to determine situational information from multiple data sources, possibly noisy and incomplete, and present those to the user; (2) Methods to track user intent and provide the appropriate

situational information; and (3) Methods to track actions of other users or systems, including automated systems, and keep user aware of the situation.

- Mission operations planning and plan management: Methods and tools for creating, validating, evaluating, and revising operations plans, taking into account collaborative aspects, complex flight rules, resource limitations and need for one-time constraints and exceptions.
- Plan, procedure and sequence validation: Techniques for checking or simulating plans, procedures, sequences and other combinations of commands and actions, in order to acquire a level of trust or assurance that the combination is correct and will satisfy desired safety properties in actual execution.
- Telemetry management and visualization: Methods for acquiring, evaluating, and displaying telemetric information, so as to provide users with flexibility and easy access to desired information in desired format.
- Adjustable automation for operations: Development of approaches and supporting tools for adjustable automation in operations. Includes specification of automation information, mechanisms for controlling degree of automated/manual control, and tools for transitioning control between user and automation with minimal loss of context and situational awareness.
- Plug-and-play technologies for operations software: Development of software frameworks or architectures, as well as exemplars of tools, interfaces and applications, that enable re-use of functionality across disciplines and software systems.

9.2 STTR Research Topics

The STTR Program Solicitation topics correspond to strategic technology research areas of interest at the NASA Centers. Two subtopics per topic reflect the current highest priority technology thrusts of the Centers in their particular area of interest.

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TOPIC: T1 Information Technologies for System Health Management and the Study of Space Radiation Environments and Associated Health Risks

This topic seeks advances in the design, development, and operation of complex aerospace systems to enable safe operation in the event of system failures, innovative technologies for radiation detection and measurement, and emerging technologies that will enable the determination and management of the health of advanced aircraft and space exploration crews and vehicles.

T1.01 Information Technologies for System Health Management, Autonomy, and Scientific Exploration **Lead Center: ARC**

Information technology is a key element in the successful achievement of NASA's strategic goals. Modern tools and techniques have the capability to redefine many design and operational processes as well as enable grand exploration and science investigations. This subtopic seeks innovative solutions to the following information technology challenges:

- Onboard methods that monitor system health and then automatically reconfigure to respond to failures and sustain progress toward high-level goals. Special emphasis will be on computational techniques that enable lifecycle consistency in system characterization during design through operations with engineering and data models. Proposals should focus on data analysis and interpretation rather than development of new sensors.
- Onboard, real-time health management systems that perform quickly enough to monitor a flight control system (including spacecraft and fixed or rotary wing aircraft) in a highly dynamic environment and respond to anomalies with suggested recovery or mitigation actions.
- Data fusion, data mining, and automated reasoning technologies that can improve risk assessments, increase identification of system degradation, and enhance scientific understanding.
- Techniques for analyzing and reasoning from development and operational data sets to identify degradation of components and predict remaining useful life.
- Techniques for interconnecting and understanding large heterogeneous or multidimensional data sets or data with complex spatial and/or temporal dynamics.
- Computational and human/computer interface methodologies for inferring causation from associations and background knowledge for scientific, engineering, control, and performance analyses.

T1.02 Space Radiation Dosimetry and Countermeasures

Lead Center: ARC

As NASA embarks on its exploration agenda, the study of space radiation environments and associated health risks to astronauts will continue to guide radiation detection technology development and mitigation strategies. The development of suitable radiation detection technologies (both physical and biological) is vital to the success of long-term manned spaceflight. As NASA returns to the Moon and then on to Mars, a series of small, unmanned missions are anticipated followed by manned missions, including long-term (6 months) stays on the surface of the Moon. It is anticipated that the unmanned missions (e.g., small satellites that may even land on the Moon) will provide test beds for new and emerging miniaturized technologies that can be further evaluated on manned missions including on the lunar base. Prior to testing in space, the technologies must be tested using simulated space radiations available at the National Space Radiation Laboratory (NSRL), a NASA funded facility at the Brookhaven National Laboratory in New York. The NSRL is capable of generating high-energy particle radiation from protons to 56Fe nuclei. NASA also supports a facility at Loma Linda University Medical Center capable of generating energetic protons. These facilities enable research studies and technology development in support of NASA funded research. NASA is seeking innovative technologies in the areas described below.

Radiation Measurement Technologies for Small Spacecraft

NASA Ames is interested in flying small spacecraft payloads that measure radiation levels alone as well as in combination with biological payloads. In support of this objective, NASA Ames is seeking:

- Small radiation detectors that measure total dose equivalent;
- Miniaturized, radiation-hardened electronics;

- Technologies for combined radiation and biology payloads.

These technologies must minimize the use of power, volume, and mass, and provide what is needed to interface to a spacecraft bus. In the case of biological payloads, a pressurized environment, and environmental control including consideration of gas, thermal control, and humidity needed to support the biology experiment, must be provided. Biological experiments ranging from cells to small organisms are of interest.

Radiation Health Monitoring Techniques

Technologies are needed to monitor the adverse effects of spaceflight radiation on human health. The following are of interest:

- Methods that are minimally invasive to the crew and provide monitoring of the biological effects of radiation;
- Application of high throughput analyses and genomic, proteomic, and metabolomic approaches used for other biological problems to space radiation effects;
- Concept and technology development of miniaturized spaceflight devices from existing laboratory-based devices to support the analyses described above.

TOPIC: T2 Atmospheric Flight Research of Advanced Technologies and Vehicle Concepts

Flight Research separates "the real from the imagined" and makes known the "overlooked and the unexpected." NASA's flight research mission is to prove unique and novel concepts through discoveries in flight. The chief areas of research interests encompass aerospace flight research and technology integration; validation of space exploration concepts; airborne sensing and science; and mission support for the Shuttle and International Space Station. This topic solicits innovative proposals that would advance aerospace technologies for the nation in all flight regimes.

T2.01 Aerospace Vehicles Flight Dynamic Modeling and Simulation

Lead Center: DFRC

This subtopic solicits proposals for innovative, linear or non-linear, aerospace vehicles dynamic systems modeling and simulation techniques. In particular:

Research and development in simulation algorithms for revolutionary aerospace flight projects involving computational fluid dynamics (CFD), structures, heat transfer, and propulsion disciplines: Emphasis is placed on the development and application of state-of-the-art, novel, and computationally efficient solution schemes that enable effective simulation of complex modern flight vehicles, like the Space Shuttle, the Constellation (Aries and Orion), light-weight highly flexible structures, as well as more routine problems encountered in recurring atmospheric flight testing on a daily basis. Furthermore, the effective use of high-performance computing equipment and computer graphics development is also considered an important part of this topic.

Aeroelasticity and aeroservoelasticity, linear and non-linear: Vehicle design and stability analysis are an important aspect of this topic. Primary concern is with the development and application of novel, multi-disciplinary, simulation software using finite element and other associated techniques.

T2.02 Foundational Research for Aeronautics Experimental Capabilities

Lead Center: DFRC

This subtopic is intended to be broad and to solicit and promote technologies for the following:

- Automated online health management and data analysis;
- 21st Century air-traffic management;
- Modeling, identification, simulation, and control of aerospace vehicles in-flight test, flight sensors, sensor arrays and airborne instruments for flight research, and advanced aerospace flight concepts.

The emphasis of this subtopic is the feasibility, development, and maturation of advanced flight research experiments that demonstrate advanced or revolutionary methodologies, technologies, and concepts. It seeks advanced flight techniques, operations, and experiments that promise significant leaps in vehicle performance, operation, safety, cost, and capability; and that require a demonstration in an actual-flight environment to fully characterize or validate advances.

Proposals in any of these areas will be considered.

Online health monitoring is a critical technology for improving aviation safety. Safe, affordable, and more efficient operation of aerospace vehicles requires advances in online health monitoring of vehicle subsystems and information monitoring from many sources over local and wide area networks. Online health monitoring is a general concept involving signal-processing algorithms designed to support decisions related to safety, maintenance, or operating procedures. The concept of online emphasizes algorithms that minimize the time between data acquisition and decision-making.

The challenges in Air Traffic Management (ATM) are to create the next generation systems and to develop the optimal plan for transitioning to future systems. This system should be one that seamlessly supports the operation of ROAs. This can only be achieved by developing ATM concepts characterized by increased automation and distributed responsibilities. It requires a new look at the way airspace is managed and the automation of some controller functions, thereby intensifying the need for a careful integration of machine and human performance. As these new automated and distributed systems are developed, security issues need to be addressed as early in the design phase as possible.

Safer and more efficient design of advanced aerospace vehicles requires advancement in current predictive design and analysis tools. The goal is to develop more efficient software tools for predicting and understanding the response of an airframe under the simultaneous influences of structural dynamics, thermal dynamics, steady and unsteady aerodynamics, and the control system. The benefit of this effort will ultimately be an increased understanding of the complex interactions between the vehicle dynamics subsystems with an emphasis on flight test validation methods for control-oriented applications. Proposals for novel multidisciplinary nonlinear dynamic systems modeling, identification, and simulation for control objectives are encouraged. Control objectives include feasible and realistic boundary layer and laminar flow control, aeroelastic maneuver performance and load control (including smart actuation and active aerostructural concepts), autonomous health monitoring for stability and performance, and drag minimization for high efficiency and range performance. Methodologies should pertain to any of a variety of types of vehicles ranging from low-speed, high-altitude, long-endurance to hypersonic and access-to-space aerospace vehicles.

Real-time measurement techniques are needed to acquire aerodynamic, structural, control, and propulsion system performance characteristics in-flight and to safely expand the flight envelope of aerospace vehicles. The scope of this subtopic is the development of sensors, sensor systems, sensor arrays, or instrumentation systems for improving the state-of-the-art in aircraft ground or flight-testing. This includes the development of sensors to enhance aircraft safety by determining atmospheric conditions. The goals are to improve the effectiveness of flight testing by simplifying and minimizing sensor installation, measuring new parameters, improving the quality of measurements, minimizing the disturbance to the measured parameter from the sensor presence, deriving new information from conventional techniques, or combining sensor suites with embedded processing to add value to output information. This topic solicits proposals for improving airborne sensors and sensor-instrumentation systems in all flight regimes – particularly transonic and hypersonic. These sensors and systems are required to have fast response, low volume, minimal intrusion, and high accuracy and reliability.

TOPIC: T3 Technologies for Space Exploration and Human Research

This topic seeks to solicit advanced innovative technologies and systems in space power and propulsion to fulfill our Nation's goal of space exploration. Space exploration will require the presence of humans on the planets and NASA will need to insure the general health of the astronauts through development of advanced biomedical sensors that will diagnose and monitor astronaut health. The above anticipated technologies should advance the state-of-the-art or feature enabling technologies to allow NASA to meet future exploration goals.

T3.01 Space Power and Propulsion

Lead Center: GRC

Development of innovative technologies and systems are sought that will result in robust, lightweight, ultra-high efficiency, lower cost, power and in-space propulsion systems that are long-lived in the relevant mission environment and that enable future missions. The technology developments being sought would, through highly-efficient generation and utilization of power and in-space propulsion, significantly increase the system performance.

Innovations are sought that will significantly improve the efficiency, mass specific power, operating temperature range, radiation hardness, stowed volume, flexibility/reconfigurability, and autonomy of space power systems. In power generation, advances are needed in photovoltaic cell structure including the incorporation of nanomaterials; module integration including monolithic interconnections and high-voltage operation; and array technologies including ultra-lightweight deployment techniques for flexible, thin-film modules, and concentrator techniques. In energy storage systems, advances are needed in batteries-primary and rechargeable-regenerative fuel cells. Advances are also needed in power management and distribution systems, power system control, and integrated health management.

Innovations are sought that will improve the capability of spacecraft propulsion systems. In solar electric propulsion technology, radioisotope electric propulsion advances are needed for ion, Hall, including cathodes, neutralizers, electrode-less plasma production, low-erosion materials, high-temperature permanent magnets, and power processing. Innovations are needed for xenon, krypton, and metal propellant storage and distribution systems. In small chemical propulsion technology, advances are sought for non-catalytic ignition methods for advanced monopropellants and high-temperature, reactive combustion chamber materials. Also, advances are sought for chemical, electrostatic, or electromagnetic miniature and precision propulsion systems.

T3.02 Bio-Technology and Life Support

Lead Center: GRC

The new Vision for Space Exploration (VSE) entails the eventual presence of humans on the planetary surfaces of both the Moon and Mars. The physiological effects of prolonged space exposure (to both the microgravity environment of interplanetary space as well as the reduced gravity environments of the Moon and Mars) need to be quantified in order to minimize mission risk, as well as insure the general health of astronauts both in space and upon their return to Earth. Biomedical sensors to monitor astronaut health that maximize diagnostic capability while reducing up-mass and power requirements are of significant interest for exploration missions. For longer duration missions on the Moon and the journey to Mars, the astronauts' continued health maintenance and fitness evaluation for mission critical activities will need to be performed routinely. Similarly, medical diagnostics are required to evaluate acute events like fatigue fractures. As a result, there is an acknowledged need for compact, robust, multi-function diagnostic biomedical sensors to reduce levels of risk in exploration class missions. To fully quantify space-normal physiology, these biomedical sensors must be supplemented by advanced analytical tools, such as high-resolution microscopy and lab-on-a-chip instrumentation (for blood or urine analysis). In addition, computational models (incorporating the direct physiological data) are needed that allow comparison to 1G values and determination of secondary physiological quantities (e.g., cardiac dysrhythmia and renal stone formation, as related to measured calcium levels). These computational models will also enable physicians to predict, diagnose and treat pathologies that are either not present in a 1G environment or are induced by synergies with spaceflight stressors. Specific innovations required for this task include:

- Noninvasive or minimally invasive sensors to detect health parameters such as: metabolic rate, heart rate, ECG, oxygen consumption rate, CO₂ generation rate, core and/or skin temperature, radiation monitoring, oxygen saturation level, intra-cranial pressure, and ocular blood flow rates;
- Novel analytical capabilities such as high resolution microscopy and lab-on-a-chip analysis of blood and urine;
- Technologies for IV fluid mixing and medical grade water generation from the onboard potable water supply;
- Novel approaches to noninvasive measurement of cephalad fluid shift and bone density measurements on astronauts in space is desired to understand and mitigate adverse effects of space environment on astronaut health and performance.

Although the Moon and Mars differ vastly in their origins and near-surface environments, common to both is the ubiquitous presence of fine particulates in the surface regolith. The objectives of the VSE specify missions of unprecedented duration and complexity, posing new classes of technical and operational challenges. One such challenge is managing the effects arising from the finest particulate fractions, commonly referred to as dust. The detailed experiences afforded by the series of Apollo missions provide valuable insights into the problems attributable to Lunar dust. Both anecdotal descriptions provided in situ by the crew members and analysis after the fact provide a lengthy testimony to the numerous technical issues associated with dust. Innovative technologies are needed to monitor the presence of dust, separation of dust from the cabin environment, removal of dust from EVA suit and mitigation of any adverse effects on astronaut health. Specific innovations required include:

- Novel approaches (and instrumentation) for detecting the presence of fine particulates in the cabin and air-lock environments and effective regenerative technologies for removing them are required;
- Technologies to effectively and safely remove dust particles from EVA suits and from the surface of any equipment that needs to be transported from the Lunar surface into the cabin environment are needed;
- Technologies and novel approaches to mitigate any adverse effects of dust on the performance of life support equipment and processes are also needed.

Low mass, high reliability, robustness, low power consumption, long life, ease of usage and easy interface with the onboard data acquisition and control system are highly desirable attributes for all candidate technologies.

TOPIC: T4 Innovative Sensors, Detectors and Instruments Technology Needs for Earth Science, Space Science and Exploration

This topic solicits innovative sensors, detectors and instruments that support the research in Earth and its environment, the solar system, and the universe through observations from space. To assure that our Nation maintains leadership in this endeavor, we are committed to excellence in scientific investigation, in the development and operation of space systems, and in the advancement of essential technologies.

T4.01 Earth Science Sensors and Instruments

Lead Center: GSFC

As part of its mission, NASA seeks to develop a scientific understanding of the Earth system and its responses to natural and human-induced changes to enable improved prediction of climate, weather, and natural hazards for present and future generations. By using breakthrough technologies for terrestrial, airborne, and spaceborne instrumentation, we seek to observe, analyze, and model the Earth system to discover how it is changing and the consequences for life on Earth.

This STTR subtopic seeks to help provide advanced remote sensing technologies to enable future Earth Science measurements. Systems and approaches will be considered that demonstrate a capability that is scalable to space or can be mounted on a relevant platform (UAV or aircraft). New systems and approaches are sought that will:

- Enable new Earth Science measurements;
- Enhance an existing measurement capability by significantly improving the performance (spatial/temporal resolution, accuracy, range of regard); and/or
- Substantially reduce the resources (cost, mass, volume, or power) required to attain the same measurement capability.

Lidar Remote Sensing Instruments

Lidar remote sensing systems are required to meet the demanding measurement requirements for future Earth Science missions. A particular emphasis is placed on instruments that can be used on UAV platforms such as the NASA Ikhana or Altair platforms. Instruments are solicited that enable or support the following Earth Science measurements:

- High spatial and temporal resolution observations of the land surface and vegetation cover (biomass);
- Profiling of clouds and aerosols, with emphasis on multiple beam systems to provide horizontal coverage;
- Wind measurements (direct-detection technology only);
- Tropospheric and stratospheric ozone and CO₂ (profiling and total column).

Active Remote Sensing Instruments (Radar) for Aircraft and Unmanned Aerial Vehicles (UAVs)

Active microwave remote sensing instruments are required for future Earth Science missions with initial concept development and science measurements on aircraft and UAVs. New systems, approaches, and technologies are sought that will enable or significantly enhance the capability for: (1) tropospheric wind measurements within precipitation and clouds at X- through W-band, (2) precipitation and cloud measurements, and (3) large aperture ground penetrating radars (GPR) at P-band and lower. Systems and approaches will be considered that demonstrate a capability that can be mounted on a relevant platform (UAV or aircraft). Specific technologies include:

- High efficiency, solid state power amplifiers (>10W at Ka-band and >30W at Ku-band);
- High performance, low power, compact, real-time radar processors, FPGA-based digital receivers, data processing algorithms and data reduction techniques;
- Implementation of radar transmitters/receivers using digital signal synthesis;
- High power, low sidelobe (better than -30 dB) scanning phased array antennas (X, Ku, Ka or W-band) for high-altitude operation (65,000 feet);
- Wide-bandwidth (≥ 400 MHz), high efficiency FM chirp/linear pulse signal generator with amplitude modulation; and
- High power (30W at Ka-band , 5W at W-band), high speed ($\leq 250\mu\text{s}$), high isolation (≥ 40 dB) and low insertion (1.5 dB at Ka and 2 dB at W-band) switch.

Data Compression

To complement data compression, data decompression processors are needed to decode compressed data streams. To target multiple missions, implementations should conform to the Consultative Committee for Space Data Systems (CCSDS, www.ccsds.org) recommendation CCDDS 122.0-B 1. This solicitation seeks development of new data decompression processors that can:

- Process instrument data at over 20 Mpixels/sec decoding rate for instruments that employ compression for either direct broadcast or during nearly real-time ground processing after telemetering the data to ground stations;
- Decode up to 16-bit of science data; and
- Decode embedded compression bit stream following the format described in CCSDS 122.0-B.1 (www.ccsds.org).

T4.02 Space Science and Exploration Sensors and Instruments

Lead Center: GSFC

This subtopic focuses on key component and subsystem technologies for space science and exploration sensors and instruments. The focus is on innovative, lower TRL technologies which may have a longer term development time. The technology focus in this solicitation is for cryogenic cooling technologies, in situ sensors for miniaturized planetary instruments, optical subsystems and wavefront sensing and control, and detectors for the IR, far IR, submillimeter, and millimeter wave regions.

Cryogenic Cooling Technologies for Space Science and Space Exploration

Cryogenics systems are enabling technologies for cutting edge space science including infrared imaging and spectroscopy and x-ray spectroscopy. Cryogenic cooling is also needed to enable the long term storage of the cryo-propellants needed for space exploration missions. Improvements in cryogenic technologies enable space science and exploration missions at lower cost with reduced mass, reduced volume and reduced risk.

New concepts that would provide cooling with improved thermodynamic efficiency for the following applications are sought.

- Coolers for long term cryo-propellant storage with cooling power in the range of 50 to 100 Watts at 100 K and 20 Watts at 25 K to 30 K;
- Low vibration coolers for space science instruments with approximately 0.1 Watt of cooling power at 4 K;
- Highly efficient sub-Kelvin cooling technologies capable of cooling detectors to 50 milliKelvin.

In Situ Sensors for Planetary Science

Instruments for in situ investigations are required for NASA's planned and potential planetary science missions. Instruments are required for the characterization of the atmosphere, surface and subsurface regions of planets, satellites, and small bodies. These instruments may be deployed for in situ measurements on surface landers and rovers, and airborne platforms. These instruments must be capable of withstanding operation in space and planetary environmental extremes, which include temperature, pressure, radiation, and impact stresses. A focus is on developing components and subsystems for miniaturized instruments.

- Enabling instrument component and support technologies for a miniaturized mass spectrometry/gas chromatography instrument with improved capabilities over the SAM instrument on the Mars Science Laboratory. These include miniaturized pumps, sample inlet systems, valves, integrated bulk sample handling and processing systems, and microfluidic technologies for sample preparation.

Optical Subsystems and Wavefront Sensing and Control

This subtopic solicits technology for collecting and controlling star light with advanced optical telescopes and telescope arrays. This topic includes innovative optical subsystems, devices and components that directly collect and process optical signals and images for all regions of the electromagnetic spectrum from X-ray to UV to Visible to Far-IR/Sub-MM. Pre-detection technologies of interest include capabilities to preprocess or analyze an optical wave front or signal to extract time-dependent, spectral, polarization and spatial information from scenes or signals prior to detection. Specific technology areas of interest include: high reflectance UV coatings and uniform polarization coatings for all wavelengths; high angular resolution imaging enabled via large-baseline segmented-aperture telescopes and sparse aperture telescopes/interferometers. Component-level technology needed to enable the characterization and combination of wavefronts from multiple apertures. Innovative technology needed to integrate, assemble, align and control test large aperture segmented mirrors for x-ray, ambient and cryogenic applications.

Proposals in the following areas are specifically solicited:

- Optical coatings: broad-band polarization preserving and polarizing for UV to Far-IR/Sub-MM; high-reflectivity EUV; large area, high acceptance angle narrow-band optical filters; broad-band wide-acceptance angle UV anti-reflection on PMMA substrates; environmentally stable protected silver.

- Innovative mounting/support and metrology/control technologies to integrate, assemble, align and control large aperture lightweight low-cost segmented mirrors for x-ray, ambient and cryogenic normal incidence applications – also, systems with extreme alignment tolerances such as PIAA.
- Techniques to mitigate optical surface errors includes phase retrieval and wavefront sensing and control techniques and instrumentation, optical systems with high-precision controls, active and/or adaptive mirrors, shape control of deformable telescope mirrors, and image stabilization systems; techniques to sense/control segmented primary mirrors.

Detector Technology for IR, far IR, Submillimeter, and Millimeter

Advances in detectors, readout electronics, and other technologies enabling polarimetry and large format imaging arrays for the IR, far submillimeter and millimeter and spectroscopy with unprecedented sensitivity are sought.

Innovations are sought in detector capability for the following wavelength ranges:

- 1-30 microns: Increased sensitivity and larger array size; Large format cryogenic readout multiplexers; large format (>1000 x 1000) array hybridization techniques. Technologies for assembly of large format focal plane arrays. Photon counting detector arrays with fast readout electronics.
- 100 microns - 3 mm: Noise equivalent power (NEP) of $10e^{-20}$ W/Hz $^{-1/2}$ in a 1,000 pixel spectroscopic array with low-power readout electronics, and NEP $10e^{-18}$ W/Hz $^{-1/2}$ in a 10,000 pixel photometric imaging array. Capabilities for photon counting, polarimetry, and energy resolving detection.
- RF (GHz to THz) MEMS switches with low insertion loss.
- (< 0.5 dB), high isolation (>18 dB), capable of switching with speeds of >100 Hz at cryogenic temperatures (below 10 K) for $10e^8$ or more cycles.

T4.03 Large Telescopes

Lead Center: JPL

Proximity Glare Suppression for Astronomical Coronagraphy

This subtopic section 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 and innovative advanced wavefront sensing and control for cost-effective space telescopes. 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 infrared wavelengths. The ultimate application of these instruments is to operate in space as part of a future observatory mission. Much of the scientific instrumentation used in future NASA observatories for the astrophysical sciences will require control of unwanted radiation (thermal and scattered) across a modest field of view. The performance and observing efficiency of astrophysics instruments, however, must be greatly enhanced. The instrument components are expected to offer much higher optical throughput, larger fields of view, and better detector performance. The wavelengths of primary interest extend from the visible to the thermal infrared. 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 are not limited to, the following areas:

Starlight Suppression Technologies

- Advanced starlight canceling coronagraphic instrument concepts;
- Advanced aperture apodization and aperture shaping techniques;
- Pupil plane masks for interferometry;
- Advanced apodization mask or occulting spot fabrication technology controlling smooth density gradients to 10^{-4} with spatial resolutions $\sim 1 \mu\text{m}$, low dispersion, and low dependence of phase on optical density;

- Metrology for detailed evaluation of compact, deep density apodizing masks, Lyot stops, and other types of graded and binary mask elements. Development of a system to measure spatial optical density, phase inhomogeneity, scattering, spectral dispersion, thermal variations, and to otherwise estimate the accuracy of masks and stops is needed;
- Interferometric starlight cancellation instruments and techniques to include aperture synthesis and single input beam combination strategies;
- Single mode fiber filtering from visible to 20 μm wavelength;
- Methods of polarization control and polarization apodization; and
- Components and methods to insure amplitude uniformity in both coronagraphs and interferometers, specifically materials, processes, and metrology to insure coating uniformity.

Wavefront Control Technologies

- Development of small stroke, high precision, deformable mirrors (DM) and associated driving electronics scalable to 10^4 or more actuators (both to further the state-of-the-art towards flight-like hardware and to explore novel concepts). Multiple DM 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;
- Development of instruments to perform broad-band sensing of wavefronts and distinguish amplitude and phase in the wavefront.
- Adaptive optics actuators, integrated mirror/actuator programmable deformable mirror;
- Reliability and qualification of actuators and structures in deformable mirrors to eliminate or mitigate single actuator failures;
- Multiplexer development for electrical connection to deformable mirrors that has ultra-low power dissipation.
- High precision wavefront error sensing and control techniques to improve and advance coronagraphic imaging performance; and
- Highly reflecting broadband coatings.

Precision Deployable Optical Structures and Metrology

Planned future NASA Missions in astrophysics, (such as the Single Aperture Far-IR (SAFIR) telescope, Life Finder, and Submillimeter Probe of the Evolution of Cosmic Structure (SPECS), and the UV Optical Imager (UVOIR) require 10 - 30 m class cost effective telescopes that are diffraction limited at wavelengths from the visible to the far IR, and operate at temperatures from 4 - 300 K. The desired areal density is 1 - 10 kg/m^2 . Static and dynamic wavefront error tolerances may be achieved through passive means (e.g., via a high stiffness system) or through active control. 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 L2.

This subtopic section solicits proposals to develop enabling, cost effective component and subsystem technology for these telescopes. Research areas of particular interest include: precision deployable structures and metrology, i.e., innovative active or passive deployable primary or secondary support structures; innovative concepts for packaging fully integrated (i.e., including power distribution, sensing, and control components), distributed and localized actuation systems; deployment packaging and mechanisms; active control distributed on or within the structure (downstream corrective and adaptive optics are not included in this topic area); actuator systems for alignment of reflector panels (order of cm stroke actuators, lightweight, submicron dynamic range, nanometer stability); mechanical, inflatable, or other deployable technologies; new thermally-stable materials ($\text{CTE} < 1\text{ppm}$) for deployables; innovative ground testing and verification methodologies; and new approaches for achieving packable depth in primary mirror support structures.

Also of interest are innovative metrology systems for direct measurement of the optical elements or their supporting structure. Requirements for micron level absolute and subnanometer relative metrology for tens of points on the primary mirror. Also measurement of the metering truss. Innovative systems which minimize complexity, mass, power and cost are sought.

The goal for this effort is to mature technologies that can be used to fabricate 20 m class, lightweight, ambient or cryogenic flight-qualified telescope primary mirror systems. Proposals to fabricate demonstration components and

subsystems with direct scalability to flight systems (concept described in the proposal) will be given preference. The target launch volume and expected disturbances, along with the estimate of system performance, should be included in the discussion. A successful proposal shows a path toward a Phase 2 delivery of demonstration hardware on the scale of 3 m for characterization.

T4.04 Communications

Lead Center: JPL

Long Range Optical Telecommunications

The adaptation of current standard laboratory techniques for deployment on planetary missions is a focus. Proposers are strongly encouraged to relate their proposed technology development to future planetary exploration goals. These goals include geochemical, geophysical and astrobiological objectives.

Instruments for in situ investigations are required for NASA's planned and potential solar system exploration missions. Instruments are required for the characterization of the atmosphere, surface and subsurface regions of planets, satellites, and small bodies. These instruments may be deployed for in situ measurements on surface landers and rovers, and airborne platforms. These instruments must be capable of withstanding operation in space and planetary environmental extremes, which include temperature, pressure, radiation, and impact stresses.

This subtopic seeks advances in instruments and critical components in the following areas:

- X-Ray Diffraction and X-Ray Fluorescence (XRD/XRF) instruments, with capabilities beyond those currently planned for the CHEMIN instrument on the Mars Science Laboratory (MSL - 2009), with a focus on elemental and mineralogical analysis in the Venus surface environment (90 bars CO₂, 450°C);
- Scanning electron microscopy with chemical analysis capability;
- Mass spectrometry/Gas chromatography with improved capabilities over the SAM instrument on MSL or applicability to in situ atmospheric measurements on Venus or Titan;
- Geochronology, with a focus on isotopic dating of planetary surfaces in the 100 Ma to 4.5 Ga timeframe with better than 10% accuracy;
- Gamma-Ray Spectroscopy, with a focus in short duration (<1 hr) measurements that could be made from a rover or Venus surface lander;
- X-Ray Photoelectron Spectroscopy (XPS) and Auger Electron Spectroscopy (AES).

Astrobiology includes the study of the origin, evolution, and distribution of life in the universe. New technologies are required to enable the search for extant or extinct life elsewhere in the solar system, to obtain an organic history of planetary bodies, to discover and explore water sources elsewhere in the solar system, and to detect microorganisms and biologically important molecular structures within complex chemical mixtures.

Astrobiology solicits new measurement concepts, advances in existing instrument concepts, and advances in critical components in the following areas:

- Instrumentation focused on assessments of the identification and characterization of biomarkers of extinct or extant life, such as prebiotic molecules, complex organic molecules, biomolecules, or biominerals. At this time we are not soliciting DNA and RNA analysis techniques.
- High sensitivity (femtomole or better) characterization of molecular structure, chirality, and isotopic composition of biogenic elements (H, C, N, O, S) embodied within individual compounds and structures.

In addition, enabling instrument component and support technologies for the above, such as miniaturized pumps, sample inlet systems, valves, integrated bulk sample handling and processing systems, and fluidic technologies for sample preparation, are also solicited. These must be presented in the context of a complete instrument system.

Long Range Space RF Telecommunications

This subtopic seeks innovative technologies for long-range RF telecommunications supporting the needs of space missions. Proposals are sought in the following areas:

- Ultra-small, light-weight, low-cost, low-power, modular deep-space transceivers, transponders and components, incorporating MMThe adaptation of current standard laboratory techniques for deployment on planetary missions is a focus. Proposers are strongly encouraged to relate their proposed technology development to future planetary exploration goals. These goals include geochemical, geophysical and astrobiological objectives.

Instruments for in situ investigations are required for NASA's planned and potential solar system exploration missions. Instruments are required for the characterization of the atmosphere, surface and subsurface regions of planets, satellites, and small bodies. These instruments may be deployed for in situ measurements on surface landers and rovers, and airborne platforms. These instruments must be capable of withstanding operation in space and planetary environmental extremes, which include temperature, pressure, radiation, and impact stresses.

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- Instrumentation focused on assessments of the identification and characterization of biomarkers of extinct or extant life, such as prebiotic molecules, complex organic molecules, biomolecules, or biominerals. At this time we are not soliciting DNA and RNA analysis techniques.
- High sensitivity (femtomole or better) characterization of molecular structure, chirality, and isotopic composition of biogenic elements (H, C, N, O, S) embodied within individual compounds and structures;

In addition, enabling instrument component and support technologies for the above, such as miniaturized pumps, sample inlet systems, valves, integrated bulk sample handling and processing systems, and fluidic technologies for sample preparation, are also solicited. These must be presented in the context of a complete instrument system. ICs and Bi-CMOS circuits;

- MMIC modulators with drivers to provide large linear phase modulation (above 2.5 rad), high-data rate (10 - 200 Mbps), BPSK/QPSK modulation at X-band (8.4 GHz), and Ka-band (26 GHz, 32 GHz and 38 GHz);
- High-efficiency (> 60%) Solid-State Power Amplifiers (SSPAs), of both medium output power (10 W - 50 W) and high-output power (150 W - 1 KW), using power combining techniques and/or wide-bandgap semiconductor devices at X-band (8.4 GHz) and Ka-band (26 GHz, 32 GHz and 38 GHz);
- Epitaxial GaN films with threading dislocations less than 1e6 per cm² for use in wide band-gap semiconductor devices at X- and Ka-Band;
- Utilization of nanomaterials and/or other novel materials and techniques for improving the power efficiency or reducing the cost of reliable vacuum electronics amplifier components (e.g., TWTAs and Klystrons);

- Long lifetime, radiation hard SSPAs, modulators and MMICs for 26 GHz Ka-band (lunar communication);
- TWTAs operating at higher millimeter wave frequencies (e.g., W-Band) and at data rates of 10 Gbps or higher;
- Ultra low-noise amplifiers (MMICs or hybrid) for RF front-ends (< 50 K noise temperature); and
- MEMS-based RF switches and photonic control devices needed for use in reconfigurable antennas, phase shifters, amplifiers, oscillators, and in-flight reconfigurable filters. Frequencies of interest include VHF, UHF, L-, S-, X-, Ka-, V-band (60 GHz) and W-band (94 GHz). Of particular interest is Ka-band from 25.5 - 27 GHz and 31.5 - 34 GHz.

TOPIC: T5 Innovative Technologies and Approaches for Space

To accomplish the Agency's goals and objectives for a robust space exploration program, innovative technologies and approaches are needed to meet these major challenges for human space explorers. This topic solicits advancing the technologies in communication systems' filters and antennas; new dynamic radiation sensors; better and longer range no-power radio frequency (RF) sensors-tag for identification, position and sensor data; and highly effective algorithms for autonomous robotic handling to increase the flexibility and efficacy of robots deployed to the surface of the Moon and Mars missions. The new technologies being solicited include means to improve operational capabilities; improve crew safety; increase human productivity; reduce the size, weight and power; reduce the Extravehicular Activity (EVA) time required to setup and deploy outposts, habitats, science packages, and others; and abilities to enhance the success of future human exploration missions. The anticipated proposed technologies shall have a dramatic impact on achieving these goals of the Space Exploration Vision.

T5.01 MEMS-Enabled Filters, Antennas, and Sensors

Lead Center: JSC

Given the great demands placed upon communication transceivers to assure crew safety and robustness in mobile environments, NASA seeks to develop novel techniques to reduce the size, weight, and power (SWAP) for long duration manned missions. Such high analog-to-digital conversion power consumption, large form factor, and expensive components pose challenges for power and weight constrained in software defined radios. Thus, significant technical advances are needed in the area of high performance channel select filter banks, tunable filters with low-loss and high-rejection, and reconfigurable and multi-band antennas.

First, this solicitation seeks substantial improvements over state-of-the-art technologies and aims at the development of banks of low loss and high rejection filters in the UHF (401 - 402 MHz, 25 kHz bandwidth), S-band (2.4 - 2.483 GHz), and Ka- bands (25.25 - 27.5 GHz). Closely spaced (in frequency) narrow band (<2 %) channel-select filters with high rejection (> 50 dB) and low insertion loss (<3 dB) that can continuously span across all the bands of interest are to be developed. Once allocated an authorized center frequency, one can assume it remains unchanged. Multi-band filter bank solutions that offer a reconfigurable or tunable bandwidth are also sought. Smaller form factor, lower cost, and lower weight than existing devices are to be demonstrated employing MEMS resonators (e.g., electrostatic, piezoelectric, tunable dielectric) or other new classes of MEMS devices.

Second, to complement an existing software programmable radio, NASA needs to develop a compact, lightweight, multi-band (UHF, S-band, and Ka-band – see above frequencies) antenna solution that enables robust surface-to-surface communications among mobile and fixed nodes (rovers, astronauts, lander, habitat) at operational range 10 km.

Assume audio, telemetry, and high-rate video delivery transmission, bi-directional link, and 20 Mbps data rate. Assume omnidirectional and multi-band RF communications and simultaneously links to suit/vehicle and RF contingency voice on UHF – half-duplex. MEMS-enabled reconfigurable, multi-band antennas promise significant reductions in form factor, lower power consumption, and enhanced reliability. This new class of miniaturized antennas should provide high antenna gains with small aperture sizes. Smart antenna technologies with self-monitor and calibration capability are also of interest for adapting to harsh environmental threats including dust storms.

Third, this solicitation seeks to develop robust radiation sensors capable of omni-directional micro-dosimeter measurements and discriminating both charged particles and neutrons that simulate tissue volumes spanning a few 10nm to monitor crew radiation exposure in space. While current Tissue Equivalent Proportional Counters (TEPCs) are limited to measuring integral radiation effects at the cell nucleus scale ($\sim 10\text{ }\mu\text{m}$), or at chromosome level ($\sim 1\text{ }\mu\text{m}$), contemporary radiobiological concepts elicit differential measurements at the sub-micron scale of chromatin fiber ($\sim 25\text{ nm}$) or even DNA molecule (2 nm).

Fourth, NASA needs to demonstrate robust no-power RF sensor-tag systems capable of providing identification, position and sensor data in and on aerospace vehicles through wireless interrogation and receivers up to several meters away. Systems must provide additional vehicle capability and modularity, increasing redundancy while decreasing cost and schedule as they minimize cabled connectivity to sensors. Projects must demonstrate and compare standard instrumentation approaches to no-power RF sensor-tag approaches over a vehicle life-cycle for the following: ground and flight test instrumentation, operational health and status monitoring, and control of systems.

Below are expected outcomes corresponding to the four tasks:

Phase 1:

(1) Propose a reconfigurable multi-band MEMS tunable filter solution for the above frequency bands. Develop notional architecture, conceptual approach, and implementation strategy, anticipating insertion into a future frequency-agile EVA software defined radio. Compared with traditional approaches, assess MEMS RF tunable filter trade-offs with mass, power, size, flexibility, and complexity. Offer solutions to vibration, temperature, and gravitational changes commonly associated with MEMS devices for long-duration missions.

(2) Delineate through a combination of analysis and demonstrated prototypes that the multi-band compact, light-weight, and flexible multi-band antenna solutions can achieve robust, high performance operation in a mobile environment. Conduct antenna trades on power consumption, sensitivity, form factor, weight, and reliability for a EVA UHF, S-band, and Ka- multi-band helmet-mounted option.

(3) Validate through a combination of analysis and demonstrated prototypes that the proposed TEPC detection solution can achieve robust, high performance omni-directional operation in radiation environment. Assess detectors performance and compare it with traditional approaches. Develop feasible concepts and assess technical pitfalls/challenges of infusing this technology into the Exploration radiation monitoring program.

(4) Submit report and recommendations for follow-on applications based on test results and life-cycle cost analyses that compare the application of various no-power RF sensor-tag technologies against standard wired approaches for at least one relevant vehicle/vehicle test in NASA's Exploration Program.

Phase 2:

Leverage results in Phase 1 and demonstrate feasibility on actual hardware prototype units for space applications. To ensure robust operation and MEMS reliability, conduct testing across harsh temperature, vibration, shock, and other conditions similar for space operations and survivability.

Commercial Potential:

Broad commercial applications for channel select filter banks span cellular and wireless LAN communication links, cognitive radios, and ultra-wide band ADCs.

TEPC detectors can be harnessed in nuclear facilities; no-power RF sensor tags in aerospace industry, replacing cables between data acquisition systems and sensors.

T5.02 Algorithms for Autonomous Robotic Materials Handling

Lead Center: JSC

The focus of this subtopic is to solicit new technologies that will increase the flexibility and efficacy of robots deployed to the surface of the Moon and Mars. Robots are expected to make an important contribution to future Moon and Mars missions by decreasing the EVA time required to set up and deploy outposts, habitats, science packages, etc. An important part of this robot activity will be autonomously or semi-autonomously handling a variety of materials such as cables, connectors, solar arrays, inflatable modules, samples, payloads, and trusses. Semi-autonomous robot handling will allow these activities to be controlled from Earth so that they can take place before astronauts arrive and to continue after they leave.

Based on the above planetary applications, proposals are solicited for the development of algorithms that address one of the following:

- Atonomous robotic grasping, manipulation, and dexterity;
- Tool use; or
- Combining mobility and manipulation.

Emphasis should be placed on techniques that can be effective in unmodeled or unplanned for situations. Some important issues related to autonomous robotic grasping, manipulation, and dexterity include: positioning of the manipulator and grasp contacts relative to the object, determining good manipulator configurations for grasping, adhering to grasp and task constraints on action sequencing during grasping and manipulation, using whole-arm/body contact surfaces, sensing relevant data, simultaneous sensing and action, and the control of forces during manipulation. Some important issues relating to tool use are: representing and utilizing the affordances of tools, representing the task constraints on grasp, modeling the interactions between the tool and the environment, representing the function of the tool in a larger (planetary repair) task, and using tools to adapt to contingencies imposed by the task or environment. Some important issues related to combining mobility and manipulation are: coordinating the use of mobility and manipulator DOFs to achieve a common manipulation purpose, coordinating multiple mobile manipulators so as to achieve a common goal, grasping or manipulating an object so that it can be transported.

Some areas of research and development that are expected to be relevant to the above problems are:

- Continuous or discrete control;
- Machine vision or tactile sensing; and
- Machine learning and robot development.

The proposal should target advancements in aspects of the above areas of research and development that are relevant to robotic materials handling. The proposed approach should take advantage of the specific constraints and simplifications that result from the materials handling problem.

Proposals should identify the specific problem(s) that are to be addressed and a brief outline of the proposed approach. In addition, proposals should outline a plan for testing key aspects of the approach on robotic hardware. Preference will be given to approaches that appear to be practical given realistic sensor and hardware limitations.

TOPIC: T6 Launch Site Technologies

The purpose of this Topic is to develop technologies and concepts that will improve launch processing safety, make launch operations more cost- and time-efficient, and improve reliability of ground equipment. Improvements in launch site operations can enable airport-like efficiencies at reduced cost and shortened processing turnaround time, thereby contributing significantly to the goal of a sustained and affordable space exploration program. Topic areas that will be emphasized for improvements in launch site operations include:

- Wireless surface acoustic wave (SAW) sensors that can monitor, for example, pressure, strain, near-by impacts/structural acoustic events, acceleration, proximity, magnetic field sensors, current, electric field, hypergols (monomethyl-hydrazine or nitrogen tetroxide), and moisture;
- Active vibration isolation system effective in protecting ground processing equipment from launch environment effects to significantly reduce life cycle costs and enhance equipment reliability.

T6.01 Wireless Surface Acoustic Wave (SAW) Sensor Arrays

Lead Center: KSC

Wireless surface acoustic wave (SAW) sensor arrays may have significant application in the ground processing of future spacecraft. These sensors do not require an embedded power source; instead they are powered by an RF interrogation pulse. Consequently, they have the promise of being essentially maintenance free, allowing them to be installed in normally inaccessible areas and provide environmental information for many years. In addition, as opposed to microprocessor based transponders, SAW devices can be designed to operate from cryogenic temperatures up to about 1000°C. These characteristics have resulted in interest in this technology, not only for ground processing, but recently from both the NASA research and flight centers.

The Kennedy Space Center has been supporting the development of wireless SAW sensor arrays through prior STTR activities. A new communication system has been demonstrated, namely Orthogonal Frequency Coding, that allows access to an array of SAW sensors, each with its own unique identifier. Also, temperature sensors, cryogenic level sensors, and hydrogen sensors have been demonstrated under prior year funding. These are all of interest to the ground processing community, but further development in other types of wireless SAW sensors is desired. This call requests proposals for wireless SAW sensors that can monitor, for example, pressure, strain, near-by impacts/structural acoustic events, acceleration, proximity, magnetic field sensors, current, electric field, hypergols (monomethyl-hydrazine or nitrogen tetroxide), and moisture. This list is not exclusive and other sensors may also be of interest as well. In addition, alternative communication or multiplexing concepts are of interest, and enabling technologies, such as antenna design for SAW sensors, are welcome.

Applications for these sensors are diverse. When a vehicle is moved to the pad on a mobile launch platform strain sensors and accelerometers monitor the vehicle's sway, pressure sensors could be placed under sprayed on foam insulation to ensure bonding integrity up to launch, moisture sensors could be used to determine if water has migrated into inaccessible areas. Electric field sensors might help with lightening warnings, chemical sensors can improve safety, and magnetic field or current sensors can monitor valve performance. The goal is to maximize the ability to acquire information on these and other parameters while minimizing the need for cabling, maintenance, and operator labor. Wireless SAW sensor arrays appear to promote this goal.

T6.02 Active Vibration Control for Ground Support Equipment

Lead Center: KSC

Equipment located near a major rocket launch is exposed to extreme environments including heat, unsteady rocket plume impingement, acoustics and vibration. NASA's experience shows that considerable attention to the protection of critical electronic ground support equipment housed in a mobile launch platform or on adjacent tower structures is required.

The effect of high acoustic and exhaust blast loading on the launch structures results in large amplitude motions of the structural panels, including floors supporting racks of electronics. Measured acceleration spectra vary considerably from area to area but a general characterization is that the peak frequencies lie in the range below 100 Hz and amplitudes of several g's rms or higher. Typically, electronic systems are housed in a rack structure, for example a 19-inch rack, which might be 2 meters tall and weigh in the vicinity of 500 kg. Passive vibration isolator systems required to support this weight often have natural resonance within the broad excitation spectrum of the floor, resulting in less than desirable equipment protection. One consequence is the need for extensive check out of systems after each launch and often repairs. Another consequence is the need for extensive design and qualification testing to ensure the survivability of this equipment. Development of an effective vibration isolation system will significantly reduce life cycle costs and enhance equipment reliability.

The relatively short duration of the high vibration environment suggests that an active vibration control system using locally stored energy could provide a significant improvement in suppressing vibration effects. This call requests proposals for vibration control systems that would be highly reliable and capable of sensing and reducing vibration effects in ground support electronic racks. This technology is envisioned to consist of some type of platform with actuators, passive elements (springs, dampers), sensors, and a local energy source (if required). Alternately, active isolator kits could be developed that attach to the corners of a larger platform to allow designers to support a row of racks but a method of integration to allow the control of all 6 degrees-of-freedom of the complex assembly must be provided.

Applications of this technology go beyond launch equipment to any environment requiring vibration isolation of critical equipment from episodic and intense events. These range from earthquake protection and transportation to military applications. The goal is to have a platform system that can be applied to expensive equipment where the specific vibration excitation is intense and somewhat poorly defined so that a designer can specify the system with confidence and without detailed analysis, and without requiring extensive testing of the components being protected.

TOPIC: T7 Aerospace and Atmospheric Research for Improving Quality of Life

To accomplish the Agency's goals and objectives in atmospheric research new innovations are required in the areas of optical detectors arrays for lidar and passive remote sensing and fabrication techniques for high temperature composites. This STTR Topic will deliver validated technology, scientific knowledge, and understanding of the Earth's atmosphere.

T7.01 Optical Detector Arrays with Unusual Geometrical Shapes for Lidar and Passive Remote Sensing Applications

Lead Center: LaRC

Innovative or improved concepts are solicited for the development of detectors and detector arrays formed into unusual shapes. Of immediate interest are detector formats with cylindrical symmetry, where the detecting surface is on the curved portion of a cylinder and extends entirely (or nearly entirely) around the circumference of the cylinder. The detecting element need not be continuous, but could be a series of discrete elements. The ultimate goal of this solicitation is the development and production of a stacked array of cylindrical detecting elements.

NASA has interest in developing PV or PC IR detector arrays, but is especially interested in the development of visible/NIR photon-counting detectors constructed in a stacked cylindrical format. The stacked arrays should be sensitive across a broad spectral range. If cooling is required, the contact point to the cooler must be at one end of the array stack.

Arrays eventually employed will have a small size (cylindrical diameter ~ 1 centimeter or less, total length ~ 2-5 centimeters) and a moderately large number of axial elements (~ 32-128.) Fill factor of the array should be optimized to have as little non-detector surface area as possible. Electronics required to read the devices should also be developed as part of the project unless these are readily obtainable elsewhere.

Ultimately these detectors will be used as part of novel lidar systems and passive IR/visible spectrometers.

Proposals should describe the expected sensitivities/efficiencies of the proposed devices in terms of signal levels and wavelength dependencies. Limitations on the eventual size and power requirements of fully developed devices should be indicated in the proposal along with a discussion of any potential environmental constraints on their operation.

T7.02 Innovative Fabrication Techniques for High Temperature Composites

Lead Center: LaRC

Innovative concepts are being solicited for the development of fabrication techniques for high temperature composites capable of operating within the range of 350°F for at least 50,000 hours to 600°F for 1000 hours. The highest priority is structural materials that are capable of being used at the above temperature regimes for aerospace applications. Emphasis is focused on cost effective and highly automated high temperature composite manufacturing concepts. Composite processing techniques that do not require autoclave processing are of key importance. Fabrication techniques include resin infusion (VARTM, RTM), tow/tape placement, e-beam curing and other non-autoclave processing techniques. Innovative and novel composite fabrication approaches are sought for the following materials and structural systems:

- Polymer matrix composites;
- Fiber metal laminates;
- Hybrid composites;
- Thermal protection and insulation systems;
- Complex composite and hybrid structural systems; and
- Low-density and high-temperature materials.

Proposals should address the following performance metrics as appropriate:

- Processing techniques of lightweight, high temperature composites;
- Resin development;
- Reinforcement development;
- Out of Autoclave fabrication technologies;
- Aerospace quality structural application;
- Characterization of material properties;
- Elevated use temperature capability;
- Damage tolerance;
- Solvent resistance;
- Long term durability;
- Scalability.

TOPIC: T8 Space Exploration and Transportation

Implementing the NASA Vision for Space Exploration will require improving materials and engine throttling capabilities. NASA is interested in innovative manufacturing technologies that enable sustained and affordable human and robotic exploration of the Moon, Mars, and solar system to reduce cost and weight of systems and components while increasing safety. Versatile space propulsion engines that can operate over a wide range of thrust levels (throttling) are needed for space transportation. High specific impulse deep-throttling space propulsion engines may be required for controlled spacecraft descent to planetary surfaces, and a significant degree of throttling may also be required for ascent and in-space transfer maneuvers.

T8.01 Manufacturing Technologies for Human and Robotic Space Exploration

Lead Center: MSFC

Continued technological innovation is critically linked to a strong manufacturing sector in the United States economy. NASA is interested in innovative manufacturing technologies that enable sustained and affordable human and robotic exploration of the Moon, Mars, and solar system. Specific areas of interest in this solicitation include innovative manufacturing, materials, and processes relevant to propulsion systems and airframe structures for next-generation launch vehicles, crew exploration vehicles, lunar orbiters and landers, and supporting space systems. Improvements are sought for increasing safety and reliability and reducing cost and weight of systems and compo-

nents. Only processes that are environmentally friendly and worker-health oriented will be considered. Proposals are sought, but are not limited to, the following areas:

Polymer Matrix Composites (PMCs)

Large-scale manufacturing; innovative automated processes (e.g., fiber placement); advanced non-autoclave curing (e.g., e-beam, ultrasonic); damage-tolerant and repairable structures and self-healing technologies; advanced materials and manufacturing processes for both cryogenic and high-temperature applications; improved thermal protection systems (e.g., integrated structures, integral cryogenic tanks and insulations).

Ceramic Matrix Composite (CMCs) and Ablatives

CMC materials and processes are projected to significantly increase safety and reduce costs simultaneously while decreasing system weight for space transportation propulsion. Of interest are innovative material and process technology advancements that are required to enable long life, reliable, and environmentally durable materials.

Metals and Metal Matrix Composites (MMCs)

Advanced manufacturing processes such as pressure infiltration casting (for MMCs); laser-engineered near-net shaping; electron-beam physical vapor deposition; in situ MMC formation; solid-state and friction stir welding, which target aluminum alloys, especially those applicable to high-performance aluminum-lithium alloys and aluminum metal-matrix composites; advanced materials such as metallic matrix alloys compositions, which optimize high ductility and good joinability; functionally graded materials for high- or low-temperature application; alloys and nanophase materials to achieve more than 120 ksi tensile strength at room temperature and 60 ksi at elevated temperature above 500° F; new advanced superalloys that resist hydrogen embrittlement and are compatible with high-pressure oxygen; innovative thermal-spray or cold-spray coating processes that substantially improve material properties, combine dissimilar materials, application of dense deposits of refractory metals and metal carbides, and coating on nonmetallic composite materials; and materials and processes for conversion of nuclear thermal energy into electric energy.

Manufacturing Nanotechnology

Innovations that use nanotechnology processes to achieve highly reliable or low-cost manufacturing of high-quality materials for engineered structures.

Fiber-Based and Inflatable Systems

Fabrics and films may be appropriate materials for some space structures, but significant research is required to investigate the benefits, challenges and failure modes of such systems. Where fiber-based or inflatable structures have been demonstrated as potentially valuable to NASA, quality-controlled manufacture of these structures will be a strong focus and interaction between designers, manufacturing specialists and performance analysts can lead to better products; innovative procedures for manufacturing improvements and concepts are of interest.

Advanced NDE Methods

Portable and lightweight NDE tools that take advantage of nanotechnology for noninvasive, noncontact area inspection and characterization of polymer, ceramic and metal-matrix composites. Areas include, but are not limited to, microwaves, millimeter waves, infrared, laser ultrasonics, laser shearography, terahertz, and radiography.

T8.02 Component Development for Deep Throttling Space Propulsion Engines

Lead Center: MSFC

Implementing certain aspects of the NASA Vision for Space Exploration will require versatile space propulsion engines that can operate over a wide range of thrust levels, a capability known as throttling. The ability of a rocket engine to reliably produce a small fraction of the maximum thrust on command during flight is referred to as deep throttling. High specific impulse deep-throttling space propulsion engines may be required for controlled spacecraft descent to planetary surfaces, and a significant degree of throttling may also be required for ascent and in-space transfer maneuvers.

This subtopic solicits partnerships between academic institutions and small businesses in the development of components, design tools, and performance databases for engines in the 5,000-15,000 pound thrust range that use

liquid hydrogen and liquid oxygen as propellants and which can be throttled to as little as 7% of the maximum thrust value. Examples of specific areas where innovations are sought include:

- High-throttle-response engine concepts;
- Low-cost regeneratively cooled chamber designs and demonstrations of such;
- Injectors that can provide stable engine performance with two-phase (gas/liquid) flow of propellants, especially during start-up transients;
- Ignition systems that can operate reliably over a wide fuel/oxidizer mixture ratio;
- Propulsion system or component technologies that do not require thermal conditioning prior to ignition;
- Zero net positive suction pressure pump design concepts and demonstrations of such;
- Performance databases for small turbopumps and turbomachinery components;
- Design and analysis tools that accurately model small valves and turbopumps, and data required for code validation;
- Alternatives to the use of turbopumps for achieving chamber pressures of 1000 pounds per square inch; and
- Instrumentation for integrated vehicle health management.

TOPIC: T9 Rocket Propulsion Testing Systems

In support of NASA's plans and visions for current space activities and future exploration goals, ground and simulated altitude testing of all large rocket propulsion systems are conducted at the John C. Stennis Space Center (SSC). Current testing includes the Space Shuttle Main Engine and the Rocketdyne RS68 engine. Existing test facilities are being modified and a new test stand is being built to test the Rocketdyne J-2X engine for the Constellation program.

This topic solicits advanced technologies: that support an Integrated Health Management (ISHM) capability for rocket engine testing and ground operations; for innovative non-intrusive sensors for measuring combustion instability, fluid properties under extreme conditions of pressure, temperature, and velocity; rocket plume sensors capable of measuring gas species, temperature, and velocity for hydrogen and hydrocarbon fuels. Specifically, sensors capable of measuring hot gas velocity up to Mach 5 in a vacuum and the heat flux impinging on the inside surface of a pipe during altitude simulation are needed to support J-2X engine testing. Computational tools to accurately model and predict rocket engine test stand components and system performance are also desired.

T9.01 Rocket Propulsion Testing Systems

Lead Center: SSC

Proposals are sought for innovative technologies in the area of propulsion test operations. Proposals should support the reduction of overall propulsion test operations costs (recurring costs) and/or increase reliability and performance of propulsion ground test facilities and operations methodologies. Specific areas of interest in this subtopic include the following:

Facility and Test Article Health-Monitoring Technologies

Innovative, non-intrusive sensors for measuring gas velocity, temperature, pressure, molecular and metallic plume constituents, and environmentally sensitive effluent gas detection. Low-millisecond to sub-millisecond response time is required. Temperature sensors must be able to measure cryogenic temperatures of fluids (as low as 160R for LOX and 34R for LH₂) under high pressure (up to 15,000 psi), high flow rate conditions (2000 lb/s 82 ft/s for LOX; 500 lb/s 300 ft/s for LH₂). Flow rate sensors must have a range of up to 2000 lb/s (82 ft/sec) for LOX and 500 lb/sec (300 ft/s) for LH₂. Pressure sensors must have a range up to 15,000 psi. Rocket plume sensors should be capable of measuring gas species, temperature, and velocity for H₂, O₂, hydrocarbon and hybrid fuels.

Rugged, high accuracy (0.2%), fast response, temperature measuring sensors and instrumentation for very high pressure, high flow rate cryogenic piping systems. Temperature sensors must be able to measure cryogenic temperatures of fluids (as low as 160R for LOX and 34R for LH₂) under high pressure (up to 15,000 psi), high flow rate conditions (2000 lb/s 82 ft/s for LOX; 500 lb/s 300 ft/s for LH₂). Response times must be on the order of a few milliseconds to sub-milliseconds.

Modeling, sensors, and instrumentation for prediction, characterization, and measurement of rocket engine combustion instability. Sensor systems should have bandwidth capabilities in excess of 100 kHz. Emphasis is on development of non-intrusive optical-based sensors.

Test Facility Modeling Tools and Methods

Developing and verifying test facilities is complex and expensive. The wide range of pressures, flow rates, and temperatures necessary for engine testing result in complex relationships and dynamics. It is not realistic to physically test each component and the component-to-component interaction in all states before designing a system. Currently, systems must be tuned after fabrication, requiring extensive testing and verification.

Tools using computational methods to accurately model and predict system performance are required that integrate simple interfaces with detailed design and/or analysis software. SSC is interested in improving capabilities and methods to accurately predict and model the transient fluid structure interaction between cryogenic fluids and immersed components to predict the dynamic loads, frequency response of facilities.

Component Design, Prediction and Modeling - Improved capabilities to predict and model the behavior of components (valves, check valves, chokes, etc.) during the facility design process. This capability is required for modeling components in high pressure 12,000 psi, high flow 100 lb/sec cryogenic environments and must address two-phase flows.

Process System Design, Prediction and Modeling - Improved capabilities to predict and model process systems. The capability should incorporate the previous two areas to accurately model the process systems and test articles.

T9.02 Field Sensors, Instruments, and Related Technologies


Lead Center: SSC

Coastal environments and their natural resources are vital to our Nation's economy, security, commerce and recreation. These environments are strongly impacted by severe weather and other natural hazards. Because most of the world's population lives in coastal regions, these important and dynamic environments are also significantly impacted by human-induced events. Moreover, they are also especially sensitive to the initial effects of global climate change.

This subtopic solicits innovative field measurement technologies and analytical tools to support NASA's remote sensing technologies used in coastal research and applications. Specific interests at SSC include the following:

- Coupling of land and ocean processes (run-off, air quality, material flux);
- Coral reef mapping and health;
- Algal blooms (detection and monitoring);
- Sea level rise (measuring and forecasting effects);
- Sediment and contaminant transport (measuring and monitoring);
- Natural disasters such as tropical systems, tsunamis, and floods (planning, impact assessment, mitigation, and recovery).

Appendix A: Example Format for Briefing Chart

NASA SBIR/STTR Technologies Title of Proposal PI: PI's Name / Firm – City, ST Proposal No.: 07-1 ____ . ____ - ____		
<u>Identification and Significance of Innovation</u> Expected TRL Range at the end of Contract (1-9):	<Place Picture Here>	
<u>Technical Objectives and Work Plan</u>	<u>NASA and Non-NASA Applications</u> <u>Contacts</u>	
NON-PROPRIETARY DATA		

Appendix B: Technology Readiness Level (TRL) Descriptions

Technology Readiness Level - (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 or application formulated	Invention begins, practical application is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture.	Invention begins, practical application is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture. Underlying Algorithms are clarified and documented.	Documented description of the application/concept that addresses feasibility and benefit
3	Analytical and/or experimental critical function 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 or breadboard validation in laboratory	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 or breadboard validation in a relevant environment	A mid-level fidelity system/component breadboard is built and operated to demonstrate overall performance in a simulated operational environment with realistic support elements that demonstrates overall performance in critical areas. Performance predictions are made for subsequent development phases.	End to End Software elements implemented and interfaced with existing systems conforming to target environment, including the target o software environment. End to End Software System, Tested in Relevant Environment, Meets Predicted Performance. Operational Environment Performance Predicted.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of scaling requirements
6	System/subsystem 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 software partially integrated with existing hardware/software systems and demonstrated on full-scale realistic problems.	Documented test performance demonstrating agreement with analytical predictions
7	System prototype demonstration in space	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 is fully integrated with operational hardware/software systems demonstrating operational feasibility.	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).	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).	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.	The final product is successfully operated in an actual mission.	Documented mission operational results

Appendix C: NASA SBIR-STTR Technology Taxonomy

Avionics and Astrionics

- Airport Infrastructure and Safety
- Attitude Determination and Control
- Guidance, Navigation, and Control
- On-Board Computing and Data Management
- Pilot Support Systems
- Spaceport Infrastructure and Safety
- Telemetry, Tracking and Control

Bio-Technology

- Air Revitalization and Conditioning
- Biomass Production and Storage
- Biomedical and Life Support
- Biomolecular Sensors
- Sterilization/Pathogen and Microbial Control
- Waste Processing and Reclamation

Communications

- Architectures and Networks
- Autonomous Control and Monitoring
- Laser
- RF

Cryogenics

- Fluid Storage and Handling
- Instrumentation
- Production

Education

- General Public Outreach
- K-12 Outreach
- Mission Training

Electronics

- Highly-Reconfigurable
- Photonics
- Radiation-Hard/Resistant Electronics
- Ultra-High Density/Low Power

Extravehicular Activity

- Manned-Maneuvering Units
- Portable Life Support
- Suits
- Tools

Information

- Autonomous Reasoning/Artificial Intelligence
- Computer System Architectures
- Data Acquisition and End-to-End-Management
- Data Input/Output Devices
- Database Development and Interfacing
- Expert Systems
- Human-Computer Interfaces
- Portable Data Acquisition or Analysis Tools
- Software Development Environments
- Software Tools for Distributed Analysis and Simulation

Manufacturing

- Earth-Supplied Resource Utilization
- In-situ Resource Utilization
- Microgravity

Materials

- Ceramics
- Composites
- Computational Materials
- Metallics
- Multifunctional/Smart Materials
- Optical & Photonic Materials
- Organics/Bio-Materials
- Radiation Shielding Materials
- Semi-Conductors/Solid State Device Materials
- Superconductors and Magnetic
- Tribology

Microgravity

- Biophysical Utilization
- Combustion
- Liquid-Liquid Interfaces

Power and Energy

- Biochemical Conversion
- Energy Storage
- MHD and Related Conversion
- Nuclear Conversion
- Photovoltaic Conversion
- Power Management and Distribution
- Renewable Energy
- Thermodynamic Conversion
- Thermoelectric Conversion
- Wireless Distribution

Propulsion

- Aerobrake
- Aircraft Engines
- Beamed Energy
- Chemical
- Electromagnetic Thrusters
- Electrostatic Thrusters
- Feed System Components
- Fundamental Propulsion Physics
- High Energy Propellants (Recombinant Energy & Metallic Hydrogen)
- Launch Assist (Electromagnetic, Hot Gas and Pneumatic)
- MHD
- Micro Thrusters
- Monopropellants
- Nuclear (Adv Fission, Fusion, Anti-Matter, Exotic Nuclear)
- Propellant Storage
- Solar
- Tethers

Robotics

- Human-Robotic Interfaces
- Integrated Robotic Concepts and Systems
- Intelligence
- Manipulation
- Mobility
- Perception/Sensing
- Teleoperation

Sensors and Sources

- Biochemical
- Gravitational
- High-Energy
- Large Antennas and Telescopes
- Microwave/Submillimeter
- Optical
- Particle and Fields
- Sensor Webs/Distributed Sensors
- Substrate Transfer Technology

Structures

- Airframe
- Airlocks/Environmental Interfaces
- Controls-Structures Interaction (CSI)
- Erectable
- Inflatable
- Kinematic-Deployable
- Launch and Flight Vehicle
- Modular Interconnects
- Structural Modeling and Tools
- Tankage

Thermal

- Ablatives
- Control Instrumentation
- Cooling
- Reuseable
- Thermal Insulating Materials

Verification and Validation

- Operations Concepts and Requirements
- Simulation Modeling Environment
- Testing Facilities
- Testing Requirements and Architectures
- Training Concepts and Architectures

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