SBIR/STTR 2005-1

National Aeronautics and Space Administration

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

Program Solicitations

Opening Date: July 7, 2005
Closing Date: September 7, 2005

An electronic version of this document is located at: **http://sbir.nasa.gov**

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2005 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 2005 Solicitation period for Phase 1 proposals begins July 7, 2005, and ends September 7, 2005.

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.

To be eligible for selection, a proposal must be based on an innovation having high technical or scientific merit that is responsive to a NASA need described herein and which offers potential commercial application. Proposals must be submitted via the Internet (http://sbir.nasa.gov) and include all relevant documentation. Unsolicited proposals will not be accepted. NASA plans to select for award those proposals offering the best value to the Government and the Nation.

Subject to the availability of funds, approximately 300 SBIR and 40 STTR Phase 1 proposals will be selected for negotiation of fixed-price contracts in November 2005. 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.

1.2 Program Authority and Executive Order

SBIR: This Solicitation is issued pursuant to the authority contained in P.L. 106-554. Government wide SBIR policy is provided by the Small Business Administration (SBA) through its Policy Directive. 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. Government wide STTR policy is provided by the SBA through its Policy Directive. The current law authorizes the program through September 30, 2009.

Executive Order: President Bush issued an Executive Order 13329 on 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 Exploration Systems Mission Directorate provides overall policy direction for the NASA SBIR/STTR programs. The Program Management Office is hosted at Goddard Space Flight Center. The Procurement Management Office is hosted at Glenn Research Center.

The SBIR Program Solicitation is aligned with NASA's Mission Directorates (http://www.nasa.gov). The research development interests of all Mission Directorates are reflected in the subtopics identified in Section 9.

The STTR Program Solicitation research areas correspond to the central underlying technological competencies of each participating NASA Center. The Jet Propulsion Laboratory (JPL) does not participate in the management of the STTR Program.

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

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

NASA Installations	
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 with a relatively small NASA investment before consideration of further Federal support in Phase 2. Successful completion of Phase 1 objectives is a prerequisite to Phase 2 consideration.

Phase 1 must concentrate on establishing the scientific or technical merit and feasibility of the proposed innovation and on providing a basis for continued development in Phase 2. 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	$ 70,000	$ 100,000
Maximum Period of Performance	6 months	12 months

1.4.2 Phase 2. The objective of Phase 2 is to continue the Research or Research and Development (R/R&D) effort from Phase 1. 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.

1.4.3 Phase 3. NASA may award Phase 3 contracts for products or services with non-SBIR/STTR funds. The competition for SBIR 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 an SBIR 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 SBIR 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 award and 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 2.14, are eligible to participate in these programs. Socially and economically disadvantaged and women-owned SBCs are particularly encouraged to propose.

STTR: To be eligible, 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 2.18). 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 that 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. 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 2005 SBIR/STTR Program Solicitation is available via the NASA SBIR/STTR homepage **(http://sbir.nasa.gov)**. SBCs are encouraged to check the SBIR/STTR homepage for program updates. 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 Homepage: **http://sbir.nasa.gov**

(2) Each of the NASA field installations has its own homepage, including strategic planning and program information. Please consult these homepages as noted in Section 1.3 for more details on the technology requirements within the subtopic areas.

(3) Help Desk. For inquiries, requests, and help-related questions, contact via:

e-mail: sbir@reisys.com
telephone: 301-937-0888 between 8:00 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:

Paul Mexcur, Program Manager
NASA SBIR/STTR Program Management Office
Code 408, Goddard Space Flight Center
Greenbelt, MD 20771-0001
Winfield.P.Mexcur@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 answered during the Phase 1 solicitation period. Only questions requesting clarification of proposal instructions and administrative matters will be answered.

2. Definitions

2.1 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.

2.2 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.

2.3 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.

2.4 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.

2.5 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.

2.6 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.

2.7 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.

2.8 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 2.12), 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.

2.9 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.

2.10 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.

2.11 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.

2.12 SBIR/STTR Technical Data

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

2.13 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.

2.14 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.

2.15 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).

2.16 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.

2.17 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.

2.18 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.

2.19 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 submit any number of proposals, 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 all such proposals being rejected without evaluation.*

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.

End Deliverables. The deliverable item at the end of a Phase 1 contract shall be a comprehensive report that justifies, validates, and defends the experimental and theoretical work accomplished and may include delivery of a product or service.

Deliverable items for Phase 2 contracts include products or services in addition to required reporting of further developments or applications of the Phase 1 results. These deliverables may include prototypes, models, software, or complete products or services. The reported results of Phase 2 must address and provide the basis for validating the innovation and the potential for implementation of commercial applications.

Reporting shall be submitted electronically via the SBIR/STTR homepage. NASA requests that all deliverable items be submitted in PDF format. Other acceptable formats are MS Word, MS Works, and WordPerfect.

3.2 Phase 1 Proposal Requirements

3.2.1 General Requirements

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. 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**), including all graphics, with a table of contents,
(5) Briefing Chart (Optional – 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. *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 Section 8.

Potential NASA and non-NASA commercial applications of the technology should 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.

3.2.3.3 Budget Summary (Form C). The offeror shall complete the Budget Summary, following the instructions provided with the form (Section 8). 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 during Phase 1 is not normally allowed to prove technical merit and feasibility of the proposed innovation. However, where the offeror deems travel to be essential for these purposes, it is necessary to limit it to one person, one trip to the sponsoring NASA installation. Proposed travel must be described as to purpose and benefits in proving feasibility, and is subject to negotiation and approval by the Contracting Officer. Trips to conferences are not allowed under the Phase 1 contract.

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 Innovation. The first paragraph of Part 2 shall contain:

(1) A clear and succinct statement of the specific innovation proposed, and why it is an innovation, and
(2) A brief explanation of how the innovation is relevant and important to meeting the technology need described in the subtopic. The initial paragraph shall contain no more than 200 words. NASA will reject proposals that lack explanation of the innovation. In subsequent paragraphs, Part 2 may also include appropriate background and elaboration to explain the proposed innovation.

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. The plan should indicate what will be done, where it will be done, and how the R/R&D will be carried out. The plan should address the objectives and the questions cited in Part 3 above. Discuss in detail the methods planned to achieve each objective or task. 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 concise bibliographic references in support of the proposal if they are confined to activities directly related to the proposed work.

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 2005 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 Phase 2 or 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 continuation.

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 bring a resulting product or service to market must be indicated. Qualifications of the offeror in marketing related products or services or in raising capital should 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 that will be funded with SBIR dollars, the offeror must provide a) an explanation of 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.

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 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 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 forecast both the NASA and the non-NASA commercial potential of the project assuming success through Phase 2. The offeror, in the Phase 2 proposal, will be required to provide more detailed information regarding product development and potential markets (Section 3.3.4).

Part 11: Similar Proposals and Awards. A firm may elect to submit proposals for essentially equivalent work to other Federal program solicitations (Section 2.4). Firms may also choose to resubmit previously unsuccessful 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:

(a) 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);
(b) Dates of such proposal submissions or awards;
(c) Title, number, and date of solicitations under which proposals have been or will be submitted or awards received;
(d) The specific applicable research topic for each such proposal submitted or award received;
(e) Titles of research projects;
(f) 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;
(g) 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 (Optional). All technically meritorious proposals will be advocated to NASA senior management prior to selection. To assist NASA personnel in preparing information to advocate your proposal, a single-page briefing chart, as described in the on-line electronic handbook, is strongly encouraged. Submission of the briefing chart is optional, is not counted against the 25-page limit, and *must not* contain any proprietary data. An example chart has been provided in Appendix B.

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.

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. 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 (Optional – 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. *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 Section 8.

Potential NASA and non-NASA commercial applications of the technology should 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.

3.3.3.3. Budget Summary (Form C). The offeror shall complete the Budget Summary, following the instructions provided with the form (Section 8). 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 during Phase 2 is not normally allowed to prove technical merit and feasibility of the proposed innovation. However, where the offeror deems travel to be essential for these purposes, it is necessary to limit it to one person, one trip to the sponsoring NASA installation. Proposed travel must be described as to purpose and benefits in proving feasibility, and is subject to negotiation and approval by the Contracting Officer. Trips to conferences are not allowed under the Phase 2 contract.

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 2: Identification and Significance of the Innovation and Results of the Phase 1 Proposal. Provide a brief explanation of the specific innovation and describe how it is relevant to meeting NASA's technology needs. In addition, describe how the Phase 1 effort has proven the feasibility of the innovation, provided a rationale for both NASA and commercial applications, and demonstrated the ability of the offeror to conduct the required R/R&D.

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. Describe plans for Phase 3 commercialization (including applications/sales back to NASA) in terms of each of the following areas:

(1) Market Feasibility and Competition: Describe the target market of the product or service, the unique competitive advantage of the product, the potential market size (Government and/or non Government), the offeror's estimated market share after first year of sales and after 5 years, and, competition from similar and alternative technologies and/or competing domestic or foreign entities.

(2) Strategic Relevance to the Offeror: Describe the role the product or service has in the company's current business plan and in its strategic planning for the next 5 years.

(3) Key Management, Technical Personnel and Organizational Structure: Describe (a) the skills and experiences of key management and technical personnel in bringing innovative technology to the market, (b) current organizational structure, and (c) plans and timelines for obtaining needed business development expertise and other necessary personnel.

(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 dedicated to development of product or service (both business development and technical development) to date. Describe the expected financial needs and potential sources to meet those needs that will be necessary to bring product or service to market. Provide evidence of current financial condition, e.g., standard financial statements including a current cash flow statement.

(6) Intellectual Property: Describe patent status, technology lead, trade secrets or other demonstration of a plan to achieve sufficient IP protection to realize the commercialization stage and attain at least a temporal competitive advantage.

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

This section shall also provide adequate information to allow the 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) an explanation of 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.

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	STTR Phase 2 Proposal
A minimum of one-half of the work (contract cost less profit) must be performed by the proposing SBC.	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). Describe both the potential NASA and non-NASA commercial applications of the project assuming successful development of the proposed objectives.

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 (Optional). All technically meritorious proposals will be advocated to NASA senior management prior to selection. To assist NASA personnel in preparing information to advocate your proposal, a single-page briefing chart, as described in the on line electronic handbook is strongly encouraged. Submission of the briefing chart is optional, is not counted against the 50-page limitation, and *must not* contain any proprietary data. An example chart has been provided in Appendix B.

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 voluntarily 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 engineers or scientists to determine the most promising technical and scientific approaches. Each proposal will be judged on its own merit. The Agency 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 do not seek additional information. Evaluations will be performed by NASA scientists and engineers at the Centers identified in the Solicitation for each subtopic. 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 any potential commercial applications in the private sector or for use by the Federal Government, as evidenced by the SBC's record of commercializing SBIR or other research, the existence of second phase funding commitments from private sector or non-SBIR funding sources, the existence of third phase follow-on commitments for the subject of the research, and the presence of other indicators of the commercial potential of the innovation.

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. Each Center will make recommendations for award among those proposals that it evaluates. Center recommendations 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. Recommendations provided by the Centers do not guarantee selection for award. 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 Homepage (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 uses a peer review panel to evaluate commercial merit. Panel membership will include non-NASA personnel expert 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. NASA will assess the proposed commercialization plan in terms of its credibility, objectivity, reasonableness of key assumptions and awareness of key risk areas and critical business vulnerabilities, as applicable to the following factors:

(1) Commercial potential of the technology: This includes assessment of (a) a well-defined commercial product or service; (b) a realistic target market niche; (c) a commercial product or service that has strong potential for uniquely meeting a well-defined need within the target market; and (d) a commitment of necessary financial, physical, and/or personnel resources.

(2) Commercial intent of the offeror: This includes assessing the commercial venture 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 success in bringing SBIR/STTR or other innovative technology to commercial application; (b) the offeror's business plan; (c) the likelihood that the offeror will be able to obtain the remaining necessary financial, technical, and personnel-related resources; and (d) the current strength and continued financial viability of the offeror.

In applying these commercial criteria, NASA will assess proposal information in terms of credibility, objectivity, reasonableness of key assumptions, independent corroborating evidence, internal consistency, demonstrated awareness of key risk areas and critical business vulnerabilities, and other indicators of sound business analysis and judgment.

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.

Each Center will make recommendations for award among those proposals that it evaluates. The Center recommendations 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). Recommendations provided by the Centers do not guarantee selection for award. The Source Selection Official has the final authority for choosing the specific proposals for contract negotiation.

Note: Companies with Prior NASA SBIR Awards

NASA has instituted a comprehensive commercialization survey/data gathering process for companies with prior NASA SBIR awards. Information received from SBIR companies 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 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. The offeror will be contacted by the appropriate Field Center for debriefing within 60 days of the selection announcement. If you have not received your debriefing by this time, contact the appropriate SBIR/STTR Field Center Program Manager.

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
➢ NASA plans to announce the selection of approximately 300 proposals resulting from this Solicitation, for negotiation of Phase 1 contracts with values not exceeding $70,000. 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 plans to announce the selection of approximately 40 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 SBIR 2005 Solicitation will be selected for Phase 2. Phase 2 agreements are fixed-price contracts with performance periods not exceeding 24 months and funding not exceeding $600,000.	➢ NASA anticipates that approximately 40 percent of the successfully completed Phase 1 projects from the STTR 2005 Solicitation will be selected for Phase 2. Phase 2 agreements are 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 homepage (http://sbir.nasa.gov) at the time of the selection announcement. **From the time of proposal selection until the award of a contract, only the Contracting Officer is authorized to commit the Government, and all communications must be through the Contracting Officer.**

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 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 homepage.

5.3 Payment Schedule for Phase 1

Payments are commonly 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 by NASA. The first two payments will be made 30 days after receipt of valid invoices. The final payment will be made 30 days after acceptance of the final report, the New Technology Report, and other deliverables as required by the contract. Electronic funds transfer will be employed and offerors will be required to submit account data if selected for contract negotiations.

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 the property of the offeror, and NASA will protect it from public disclosure to the extent permitted by law including the Freedom of Information Act.

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 Optional 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 2.14. A statement of how the work load 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 that follows 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 note that NASA has adopted a software engineering procedural requirement. Developers should comply with the requirements of NASA Procedural Requirements (NPR) 7150.2, "NASA Software Engineering Requirements." In particular, the requirements of Sections 5.27 and 5.28 should be noted as compliance will be required. NPR 7150.2 is available online at http://nodis3.gsfc.nasa.gov/lib_docs.cfm?range=7___.

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) an explanation of 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.

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 utilizes a paperless, electronic process for management of the SBIR/STTR programs. This management approach requires that a proposing firm have Internet access and an e-mail address. Paper submissions are not accepted.

An Electronic Handbook for submitting proposals via the internet is hosted on the NASA SBIR/STTR Homepage (http://sbir.nasa.gov). The handbook will guide the firms through the various steps required for submitting an SBIR/STTR proposal. All electronic handbook submissions are through a secure connection. Communication between NASA and the firm is through a combination of electronic handbooks and e-mail.

6.2 Submission Process

To begin the submission process, SBCs must first register in the handbook. 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, and C must be submitted via the Submissions Handbook located on the NASA SBIR/STTR website.

a. Forms A, B, and C are to be completed online.
b. The technical proposal is uploaded from your computer via the Internet utilizing secure communication protocol.
c. Firms are encouraged to upload an optional 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 purposes. Therefore, NASA requests that technical proposals be submitted in PDF format, and encourages companies to do so. Other acceptable formats are MS Works, MS Word, and WordPerfect. Unix and TeX users please note that due to PDF difficulties with non-standard fonts, 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).

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 Electronic Handbook. Directions will be provided to assist users. All transactions via the electronic handbook 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 Wednesday, September 7, 2005, via the NASA SBIR/STTR homepage (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. 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 2005 Phase 1 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 (Optional) 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 18, 2005, and will be posted via the SBIR/STTR homepage (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 homepage (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:

Paul Mexcur, Program Manager
NASA SBIR/STTR Program Management Office
Code 408, Goddard Space Flight Center
Greenbelt, MD 20771-0001
Winfield.P.Mexcur@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 SBIR/STTR Homepage

Detailed information on NASA's SBIR/STTR Programs is available at: http://sbir.nasa.gov.

7.2 NASA Commercial Technology Network

The NASA Commercial Technology Network (NCTN) contains a significant amount of on line information about the NASA Commercial Technology Program. The address for the NCTN homepage is: http://nctn.hq.nasa.gov/

7.3 NASA Technology Utilization Services

The **National Technology Transfer Center (NTTC)**, sponsored by NASA in cooperation with other Federal agencies, serves as a national resource for technology transfer and commercialization. NTTC has a primary role to get Government research into the hands of U.S. businesses. Its gateway services make it easy to access databases and to contact experts in your area of research and development. For further information, call 800-678-6882.

NASA's network of **Regional Technology Transfer Centers (RTTCs)** provides business planning and development services. However, NASA does not accept responsibility for any services these centers may offer in the preparation of proposals. RTTCs can be contacted directly as listed below to determine what services are available and to discuss fees charged. Alternatively, to contact any RTTC, call 800-472-6785.

Northeast:
Center for Technology Commercialization
Massachusetts Technology Park
1400 Computer Drive
Westboro, MA 01581-5043
Phone: 508-870-0042
URL: http://www.ctc.org

Southeast:
Georgia Institute of Technology
151 6th Street
216 O'Keefe Building
Atlanta, GA 30332-0640
Phone: 404-894-6786
URL: http://www.edi.gatech.edu/nasa/

Mid-Continent:
Mid-Continent Technology Transfer Center
Texas Engineering Extension Service
301 Tarrow Street
College Station, TX 77840-7896
Phone: 979-845-8762
URL: http://www.mcttc.com/

Mid-Atlantic:
TECC – The Technology Commercialization Center
144 Research Drive
Hampton, VA 23666
Phone: 757-766-9200
URL: http://www.teccenter.org

Mid-West:
Great Lakes Industrial Technology Center
25000 Great Northern Corporate Center
Suite 260
Cleveland, OH 44135
Phone: 216-898-6400
URL: http://www.glitec.org

Far-West:
Far-West Technology Transfer Center
University of Southern California
3716 South Hope Street, Suite 200
Los Angeles, CA 90007-4344
Phone: 800-642-2872
URL: http://www.usc.edu/dept/engineering/TTC/NASA

7.4 United States Small Business Administration

The Policy Directives for the SBIR/STTR Programs, which also state the SBA policy for this Solicitation, may be obtained from the following source. SBA information can also be obtained at: http://www.sba.gov/.

Office of Innovation, Research and Technology
U.S. Small Business Administration
409 Third Street, S.W.
Washington, DC 20416
Phone: 202-205-7701

7.5 National Technical Information Service

The **National Technical Information Service**, an agency of the Department of Commerce, is the Federal Government's central clearinghouse for publicly funded scientific and technical information. For information about their various services and fees, call or write:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Phone: 703-605-6040
URL: http://www.ntis.gov

8. Submission Forms and Certifications

Form A – SBIR Cover Sheet

Subtopic Number

1. PROPOSAL NUMBER: **05 -** _ _ . _ _ _ _ _ _
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 Number of employees: _____	Yes	No
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 $70,000 (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, 5.17). 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 **05 -** _ _ . _ _ _ _ _ _.

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. Technical Abstract (Limit 2,000 characters, approximately 200 words)/Technology Taxonomy (Select only the technologies relevant to this specific proposal)

7. Potential NASA Application(s): (Limit 1,500 characters, approximately 150 words)

8. Potential Non-NASA Commercial Application(s): (Limit 1,500 characters, approximately 150 words)

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/MS and include all required contact information.

6. **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.

   Technology Taxonomy: Selections for the Technology Taxonomy are limited to technologies supported or relevant to the specific proposal.

7. **Potential NASA Application(s):** Summary of the direct or indirect NASA applications of the project, assuming the goals of the proposed R/R&D are achieved. Limit your response to 100 words or 1,500 characters, whichever is less.

8. **Potential Non-NASA Commercial Application(s):** Summary of the direct or indirect NASA applications of the project, assuming the goals of the proposed R/R&D are achieved. Limit your response to 100 words or 1,500 characters, whichever is less.

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 homepage (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 .3x50,000=$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 $70,000.

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 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. Certifications in Form A are completed.
6. Proposed funding does not exceed $70,000. (Sections 1.4.1, 5.1.1).
7. Proposed project duration should not exceed 6 months. (Sections 1.4.1, 5.1.1).
8. Entire proposal including Forms A, B, and C submitted via the Internet.
9. Form A electronically endorsed by the SBC Official.
10. **Proposals must be received no later than 5:00 p.m. EDT on Wednesday, September 7, 2005** (Section 6.3).

Form A – STTR Cover Sheet

1. PROPOSAL NUMBER: **05 - _ _ . _ __ _ _ _ _**
2. RESEARCH TOPIC:
3. PROPOSAL TITLE:
4. SMALL BUSINESS CONCERN (SBC)
   NAME:
   ADDRESS:
   CITY/STATE/ZIP:
   PHONE: FAX:
   EIN/TAX ID:
   DUNS + 4: CAGE CODE:

   RESEARCH INSTITUTION (RI)
   NAME:
   ADDRESS:
   CITY/STATE/ZIP :
   PHONE: FAX:
   EIN/TAX ID:
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 Number of employees: ____	Yes	No
b. Socially and economically disadvantaged SBC	Yes	No
c. Woman-owned SBC	Yes	No
d. HUBZone-owned SBC	Yes	No
As described in Section 2.10 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 **05 -** _ _ . _ _ _ _ _ _.

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. Technical Abstract (Limit 2,000 characters, approximately 200 words)/Technology Taxonomy (Select only the technologies relevant to this specific proposal)

8. Potential NASA Application(s): (Limit 1,500 characters, approximately 150 words)

9. Potential Non-NASA Commercial Application(s): (Limit 1,500 characters, approximately 150 words)

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. **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.

   Technology Taxonomy: Selections for the Technology Taxonomy are limited to technologies supported or relevant to the specific proposal.

8. **Potential NASA Application(s):** Summary of the direct or indirect NASA applications of the project, assuming the goals of the proposed R/R&D are achieved. Limit your response to 100 words or 1,500 characters, whichever is less.

9. **Potential Non-NASA Commercial Application(s):** Summary of the direct or indirect NASA applications of the project, assuming the goals of the proposed R/R&D are achieved. Limit your response to 100 words or 1,500 characters, whichever is less.

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 (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 homepage (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.

<u>Example</u>: 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 .3x50,000=$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, <u>subject to any rights of the Government therein</u>, 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 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 topic 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. Certifications in Form A are completed.
6. Proposed funding does not exceed $100,000. (Sections 1.4.1, 5.1.1).
7. Proposed project duration should not exceed 12 months. (Sections 1.4.1, 5.1.1).
8. Cooperative Agreement has been electronically endorsed by both the SBC Official and RI. (Sections 3.2.5, 6.2).
9. Entire proposal including Forms A, B, C, and Cooperative Agreement 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 Wednesday, September 7, 2005** (Section 6.3).
12. Signed Allocation of Rights Agreement available for Contracting Officer at time of selection.

Example Format for Briefing Chart

NASA SBIR/STTR Technologies

Title of Proposal

PI: PI's Name / Firm – City, ST
Proposal No.: 05-1 _ _ . _ _ - _ _ _ _

Identification and Significance of Innovation	<Place Picture Here>
Technical Objectives and Work Plan	NASA and Non-NASA Applications Contacts

NON-PROPRIETARY DATA

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-Manuvering 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 Propellents (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

9. Research Topics for SBIR and STTR

9.1 SBIR Research Topics

Introduction

The SBIR Program Solicitation topics are developed in coordination with the NASA management structure organized by four Mission Directorates (http://www.nasa.gov).

The Mission Directorates (MDs) identify, at the most fundamental level, what NASA does and for whom. Each MD is analogous to a strategic business unit employed by private-sector companies to focus on and respond to their customers' needs. Each MD has a unique set of goals, objectives, and strategies. These are the following:

Aeronautics Research
Exploration Systems
Science
Space Operations

In August of 2004, the Mission Directorate structure was created, replacing the Enterprise structure.

Biological and Physical Research became part of Exploration Systems, and is reflected this year in Topics X11-X14. **Earth Science** and **Space Science** were combined under Science. The **Space Flight** Enterprise, which was reflected in the Exploration Systems Enterprise in last year's Solicitation, became Space Operations.

9.1.1 AERONAUTICS RESEARCH

The Aeronautics Research Mission Directorate (ARMD) provides some of the most advanced aeronautics research in the world. ARMD keeps America the most advanced nation in commercial, scientific, and defense use of aeronautics and greatly increases aviation safety, security, and ability. Additionally, the results of ARMD research are used in other NASA endeavors.

http://www.aerospace.nasa.gov/

TOPIC: A1 Aviation Safety and Security

The worldwide commercial aviation accident rate has been nearly constant over the past two decades. Although the rate is very low, increasing traffic over the years may result in the absolute number of accidents also increasing. Without improvements, doubling or tripling of air traffic by 2017 could lead to 50 or more major accidents a year. This number of accidents would have an unacceptable impact on the air transportation system. The goal of NASA's Aviation Safety and Security Program (AvSSP) is to develop and demonstrate technologies that contribute to a reduction in the fatal aviation accident rate. Research and technology will address accidents involving hazardous weather, controlled flight into terrain, human-error-caused accidents and incidents, and mechanical or software malfunctions. The Program will also develop and integrate information technologies needed to build a safer aviation system and provide information for the assessment of situations and trends that indicate unsafe conditions before they lead to accidents. NASA researchers are also looking at ways to adapt aviation technologies already being developed to improve aviation security. The AvSSP is focusing on areas where NASA expertise could make a significant contribution to security: 1) the hardening of aircraft and their systems, 2) secure airspace operation technologies, 3) improved systems to screen passenger and cargo information, and 4) sensors designed to better detect threats. NASA seeks highly innovative proposals that will complement its work in Aviation Safety and Security in the following subtopic areas:

A1.01 Crew Systems Technologies for Improved Aviation Safety
Lead Center: LaRC

NASA seeks highly innovative, 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 ensuring appropriate access to airspace as constrained by safety and security concerns. We require 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 and in operationally-valid contexts. Therefore, NASA also seeks tools and methods for measuring and evaluating aerospace system operator performance, and as this performance is reflected by system performance. Technologies may take the form of tools, models, operational procedures, instructional systems, prototypes, and 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
- Decision-support tools and methods to improve communication, collaborative, and distributive decision-making
- Data fusion technologies to integrate flight-related information for improved situation awareness and appropriate workload modulation
- Support for crew response planning and selection
- Computational approaches to determine and appropriately modulate crew engagement, workload, and situation awareness
- Human-centered information technologies to improve the performance of less-experienced operators, and pilots from special population groups
- Avionics designers and/or certification specialist tools to improve the application of human-centered principles
- Human-error reliability approaches to analyzing flight deck displays decision aids, and procedures;
- 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
- 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

Proposals should describe technologies, tools, and approaches with high potential to serve NASA program objectives, and to be developed as marketable products.

A1.02 Aviation Safety and Security; Fire, Icing, Propulsion and Secure CNS Aircraft Systems
Lead Center: GRC

NASA is concerned with the prevention of hazardous in-flight conditions and the mitigation of their effects when they do occur. Aircraft fires represent a small number of actual accident causes, but the number of fatalities due to in-flight, post-crash, and on-ground fires is large. One particular emphasis is on early, false-alarm resistant detection of the location, spread, and suppression of in-flight fires in hidden, inaccessible areas of the aircraft. Examples of hidden areas are behind cabin panels, inside ductwork, and so on. Another area of interest is in-tank monitoring of fuel /air flammability factors to provide more efficient active control of fuel tank inerting systems.

A second emphasis for this subtopic is on propulsion system health management, in order to predict, prevent, or accommodate safety-significant malfunctions and damage. Past advances in this area have helped improve the reliability and safety of aircraft propulsion systems; however, propulsion system component failures are still a contributing factor in numerous aircraft accidents and incidents. Advances in technology are sought which help to further reduce the occurrence of and/or mitigate the effects of safety-significant propulsion system malfunctions and damage. Specifically the following are sought: propulsion health management technologies such as instrumentation, sensors, ground and on-wing nondestructive inspection, health monitoring algorithms, and fault accommodating logic, which will predict/prognose, diagnose, prevent, assess, and allow recovery from propulsion system malfunctions, degradation, or damage.

A third emphasis is to increase the level of safety for all aircraft flying in the atmospheric icing environment. To maximize the level of safety, aircraft must be capable of handling all possible icing conditions by either avoiding or tolerating the conditions. Proposals are invited that lead to innovative new approaches or significant improvements in existing technologies for in-flight icing conditions avoidance (icing weather information systems) or tolerance (airframe and engine ice protection systems and design tools). With these emphases in mind, products and technologies that can be made affordable and retrofitable within the current aviation system, as well as for use in the future, are sought:

- Ground and airborne radome technologies for microwave wavelength radar and radiometers that remain clear of liquid water and ice in all weather situations.
- *In situ* icing environment measurement systems that can provide practical, very low-cost validation data for emerging icing weather information systems and atmospheric modeling. Measured information must include location, altitude, cloud liquid water content, temperature, and ideally cloud particle sizing and phase information. Solutions envisioned would use radiosonde-based systems.
- Ice protection and detection technology submittal must provide significant improvements over current systems or address new design needs. Areas of improvement can be considered to be: efficient thermal protection systems, including composite wing or structures applications, ice sensors that provide detection and accretion rate for all possible icing conditions, wide area ice detection, detection that serves both ground and in-flight applications, ice crystal detection probe (for non-research aircraft applications), engine icing probe (that can measure Liquid Water Content and Total Water Content inside engine passages), and de-icing systems that operate at near anti-icing performance. Any submittal must be cost competitive to current technologies.

A fourth emphasis for this subtopic is protection and hardening of the aircraft's communication, navigation, and surveillance (CNS) systems, as well as enabling new aviation security applications through improved air-to-ground data link communications and secure onboard information processing, computing, and air/ground networking. Technology is needed to harden the CNS systems, both onboard and air-to-ground, against abnormalities and deliberate attacks towards also enabling the next-generation airborne, ground- and space-based surveillance systems. Other communications related needs can be found in other NASA SBIR subtopics areas.

The final emphasis for this subtopic is on propulsion damage adaptive controls technologies and systems for new aircraft security applications. This technology is needed to enable a propulsion system to mitigate aircraft damage from hostile attacks.

A1.03 Aviation Security Technologies
Lead Center: LaRC
Participating Center(s): ARC, JPL

The NASA Strategic Plan includes requirements to enable a more secure air transportation system and to create a more secure world by investing in technologies and collaborating with other agencies, industry, and academia. NASA's role in civil aeronautics has always been to develop high-risk, high-payoff technologies to meet critical national aviation challenges.

NASA aims to develop and advance technologies that will reduce the vulnerability of the Air Transportation System (ATS) to threats or hostile acts, and identify and inform users of potential vulnerabilities in a timely fashion. Specific technical focus areas include system-wide security risk assessment and incident precursor identification; enhanced flight procedures and on-board systems to protect critical infrastructures and key assets and enable the safe recovery of a seized aircraft; definition of directed energy threats to the aircraft and on/off-board systems that will provide surveillance and countermeasures of these threats; integrated adaptive control systems to detect and compensate for vehicle damage; hardened and security enhanced aircraft networks and datalinks; remote monitoring of the aircraft environment and systems; new materials for composite fire and explosive resistant fuselage structures; advanced, airborne, *in situ* detection of chemical and biological terror agents; and commercial aircraft fuel tank inerting. Technologies under development are intended for the next-generation ATS; however, issues such as retrofit, certification, system implementation, and cost-benefit must be considered during the technology development process.

NASA seeks highly innovative and commercially viable technologies that will improve aviation security by addressing threats to air vehicles as well as the ATS. Specific areas of focus include: preventing aircraft from being used as a weapon of mass destruction; protection from man-portable air defense systems (ManPADS) and electromagnetic energy (EME) attacks; light-weight, fire and explosive resistant composite materials; explosive resistant fuel systems; ground-based decision support tools needed to monitor airspace security concerns; reporting systems to monitor security violations; secure encrypted datalink systems, intrusion-tolerant communications networks and communications systems to support emerging aviation security applications; tools to support real-time management of security information; and Chem/Bio sensor development. Technologies may take the form of tools, models, techniques, procedures, substantiated guidelines, prototypes, and devices:

- Intelligent Systems monitoring and alerting technologies;
- Secure communications systems to support emerging aviation security applications;
- Onboard and ground surveillance and interception systems for aircraft immunity to electromagnetic interference and electromagnetic pulse intrusions;
- Flight control systems that accommodate vehicle damage relative to changes in aircraft stability, control, and structural load characteristics;
- Material systems, fuselage structural concepts, and fuel systems that are resistant to fire and explosions;
- Fuel system technologies that prevent or minimize in-flight vulnerability of civil transport aircraft due to small arms or man-portable defense systems type projectiles;
- Computational approaches to monitoring crew health, stress level, state of duress, and performance;
- Validation methods and tools for advanced safety/security critical systems;
- Technologies that enable secure communications, navigation, and surveillance on-board the aircraft;
- Technologies and methods to provide accurate information and guidance to enable pilot avoidance of protected airspace, maintain positive identity verification of aircraft operators, determine pilot intent, and deny flight control access to unauthorized persons;
- Decision-support tools and methods to improve communication and collaborative and distributive decision-making; and
- Data fusion technologies for integrating disparate sources of flight-related information.

A1.04 Automated On-Line Health Management and Data Analysis
Lead Center: ARC
Participating Center(s): DFRC

Online health monitoring is a critical technology for improving air transportation safety in the 21st century. Safe, affordable, and more efficient operation of aircraft 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 health monitoring emphasizes algorithms that minimize the time between data acquisition and decision-making.

This subtopic seeks solutions for online aircraft subsystem health monitoring and prognostics. Solutions should exploit multiple computers communicating over standard networks where applicable. Solutions can be designed to monitor a specific subsystem or a number of systems simultaneously. Resulting commercial products might be implemented in a distributed decision-making environment such as onboard diagnostics and management systems, or maintenance and inspection networks of potentially global proportion.

Proposers should discuss who the users of resulting products would be, e.g., research/test/development, manufacturing; maintenance depots, flight crew, Unmanned Aerial Vehicles/Remotely Operated Aircraft (UAV/ROA) aircraft operators, airports, flight operations or mission control, or airlines. Proposers are encouraged to discuss data acquisition, processing, and presentation components in their proposal. Proposals that focus solely on sensor development should not be submitted to this subtopic. Such proposals should be addressed to sensor development subtopics such as the Flight Sensors and Airborne Instruments for Flight Research subtopic.

Examples of desired solutions targeted by this subtopic follow:

- Real-time autonomous sensor validity monitors;
- Flight control system or flight path diagnostics for predicting loss of control;
- Automated testing and diagnostics of mission-critical avionics;
- Structural fatigue, life cycle, static, or dynamic load monitors;
- Methods and tools for remaining life estimation and prognostics for critical aircraft components;
- Automated nondestructive evaluation for faulty structural components;
- Electrical system monitoring and fire prevention;
- Architectures for online monitoring, including architectures that exploit wireless communication technology to reduce costs;
- Model-reference or model-updating schemes based on measured data, which operate autonomously;
- Proactive maintenance concepts for aircraft engines, including engine life-cycle monitors;
- Predicting or detecting any equipment malfunction;
- Middleware or software toolkits to lower the cost of developing online aircraft health monitoring applications; and
- Innovative solutions for harvesting, managing, archiving, and retrieving aircraft health data.

TOPIC: A2 Vehicle Systems

The Vehicle Systems Program (VSP) goal is to provide breakthrough technologies for significantly advanced future air vehicles. The approach is to develop these technologies and demonstrate them in flight to provide evidence of barrier breakthroughs. The benefits of these breakthrough technologies including opening more communities to air transportation, enabling new air transportation models by doubling vehicle speed capacity, eliminating aviation pollution, and enabling new science platforms. VSP will focus on four demonstration projects. The subsonic noise reduction project will start by demonstrating a 50% noise reduction compared to 1997 state of the art. The sonic boom reduction project will begin by demonstrating technology that could enable an acceptable sonic boom level. The high altitude, long endurance project will start by demonstrating a 14-day duration high-altitude aircraft. Finally, the zero emissions aircraft will begin by demonstrating an aircraft powered by hydrogen fuel cells.

A2.01 Noise Breakthrough Turbine-Based Propulsion Technologies
Lead Center: GRC

Future subsonic and supersonic aircraft may be required to achieve reduced noise levels up to 20 effective perceived noise levels (EPNdB) below FAR 36 Stage 3 certification levels without significant impacts to performance. The main emphasis of this subtopic is on high-risk, breakthrough technologies in order to reduce the technical risk associated with the development and deployment of new technologies in future commercial products. Subsonic noise reduction to date has predominantly been achieved via higher-bypass-ratio engines. With current practices, the nacelle diameter limit has physically been reached and engine noise is now comparable to airframe noise on approach. Engine noise reduction concepts proposed for subsonic applications must be compatible with low noise propulsion/airframe integration designs and continuous descent approach, low noise guidance flight procedures. Innovative noise reduction concepts need to be identified that provide economical alternatives to conventional propulsion systems.

Integrated, advanced propulsion systems with intelligent controls technologies will enable supersonic vehicles (up to Mach 2) having acceptable takeoff/landing noise and increased efficiency. Studies suggest that gas turbine engines with increased thrust-to-weight, bypass ratios, and decreased thrust specific fuel consumption are required to support quiet supersonic aircraft. NASA is interested in the development of advanced gas turbine engine concepts and key enabling technologies that can dramatically reduce the landing/take-off noise to an acceptable level, and which have the potential to dramatically improve the sustained cruise performance of a supersonic aircraft. Concepts proposed for supersonic applications must not adversely impact the airframe configurations to reduce sonic boom intensity, especially with regard to the formation of shaped waves and the human response to shaped waves.

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

Subsonic Propulsion System Technologies
- Innovative source identification techniques for fan, jet, combustor, or turbine noise;
- Advanced turbine engine cycles to achieve effective very high-bypass-ratio with smaller diameter engines;
- Innovative technologies for reduction of fan, jet, combustor, or turbine noise; and
- Advanced sound attenuating liners, including active and passive control.

Supersonic Propulsion System Technologies
- Advanced turbine engine cycle concepts to achieve low takeoff/landing noise and high supersonic cruise efficiency, including high pressure, high bypass multiple spool cycles, inter-stage turbine burning, variable cycle engines;
- Advanced propulsion system technologies, including advanced integrated airframe-propulsion control methodologies, adaptive flow control technologies, smart structures for nozzles and inlets, inlet technologies for weight/ performance/ operability/ stability; and
- High temperature materials such as monolithic ceramics and nano materials, evaporatively cooled turbine blades, and counter rotating stages enable more compact engine cores, greater thermal efficiency, and higher thrust to weight ratios.

Proposals must show improvements to the state-of-the art and viable application to aircraft.

A2.02 Fuel Cell Technologies for Aircraft Propulsion and Power
Lead Center: GRC
Participating Center(s): DFRC

Fuel cells offer a promising technology for clean, efficient power generation important to both High Altitude Long Endurance (HALE) remotely piloted aircraft, and future envisioned environmentally friendly commercial transports. Both consumable fuel and regenerative fuel based fuel cells are of interest. The former type is applicable to both HALE and commercial transports, while the latter type is of interest for a solar-electric powered HALE capable of multi-month missions. The consumable fuel based fuel cell will likely use atmospheric air for the cathode gas, while the regenerative systems will likely use pure oxygen stored and regenerated on-board. For both applications, the focus of this subtopic is on hydrogen fuel based systems including liquid for consumable fuel systems and gaseous for regenerative fuel cell systems.

To realize these aircraft applications will require one or even two orders of magnitude improvement in unit power and power density (volume and weight) for the power generation system, and specifically the fuel cell stack, as compared to ground based systems. In addition, the systems are required to operate at altitude, including high altitudes (≥ 60,000 ft) for the HALE applications, and provide service life and reliability significantly greater than ground-based systems. Thus, NASA is seeking "break-through" technologies necessary for aircraft instead of evolutionary improvement to current state-of-the-art.

Technologies of specific interest include:

- Innovative fuel cell power systems demonstrating high specific power and high efficiency using consumed liquid hydrogen fuel with scalability to 100's of kW and capable of high altitude operations;
- PEM stack demonstrating ≥ 2 kW/kg and ≥ 50% efficiency (LHV) with scalability to 100's of kW;
- SOFC stack demonstrating ≥ 1 kW/kg and ≥ 50% efficiency (LHV) with scalability to 100's of kW; and
- Innovative regenerative fuel cell energy storage systems and critical components (e.g., unitized fuel cell and electolyzer stack, PEM or SOFC based systems, etc) demonstrating ≥ 600 watt-hr/kg and high round trip efficiency.

A2.03 Hydrogen Fuel Systems and Components for Aircraft Applications
Lead Center: GRC
Participating Center(s): DFRC, LaRC

Hydrogen is the most likely fuel to enable future zero emissions aircraft and High Altitude Long Endurance Remotely Operated Aircraft (HALE ROA). Due to the increased volume required for hydrogen systems as compared to current hydrocarbon fueled aircraft, key technologies are required to reduce feed system weight while maximizing propellant storage efficiency. To be a viable technology for future aircraft systems, hydrogen feed components most likely will require life cycles approaching 10,000+ with an expectation of 20+ years in service, a significant difference from current state-of-the-art for space flight systems. For HALE ROA systems, vehicle mass must be kept low enough for flights up to altitudes exceeding 60,000 ft. Insulation systems must be lightweight and designed for minimum maintenance. Hydrogen storage and feed systems can be either cryogenic or gaseous depending upon the vehicle configuration. Tank mass fraction requirements (mass of storage system/mass of hydrogen) for liquid hydrogen on the order of 15% are expected to meet mission requirements. Hydrogen tank systems applications will be expected to provide storage for flight vehicles for up to 14 days duration with cryogenic systems and 6 months for aircraft with gaseous hydrogen. System safety is a critical factor in the design and development of any hydrogen system. To ensure public safety it is important that highly-sensitive, low-power-use sensors and instrumentation are developed to identify and diagnose potential problems with the hydrogen systems. Technology focus areas will include storage, distribution, and propellant conditions. Innovations are solicited in the following areas:

Storage and Distribution Components

- Lightweight, low thermal conductivity on-board cryogenic storage tanks, feed lines, valves, and relief devices;
- Lightweight, low thermal conductivity insulation for tanks and feed lines that requires minimal inspection and maintenance;
- Lightweight, low permeable gaseous hydrogen storage tanks and feed lines; and
- Low power, high-sensitivity sensors for hydrogen leak detection and condition monitoring.

Propellant Conditioning Components and Technologies

- Innovative methods to reduce the volume of stored hydrogen while minimizing system weight;
- Technologies for the reformation of hydrocarbon based fuels to hydrogen;
- Advanced technologies to minimize losses during loading and unloading of hydrogen, including autonomous operations, tank transfers, delivery to propulsion system, venting, and/or hydrogen recovery;

- Advanced technologies to minimize hydrogen losses and reduce energy requirements for system pre-chill, delivery to propulsion system, venting and/or hydrogen recovery, and long duration temperature.

Proposals must show improvements to the state-of-the-art and viable application to aircraft.

A2.04 Aircraft Systems Noise Prediction and Reduction
Lead Center: LaRC

Innovative technologies and methods are necessary for the design and development of efficient, environmentally acceptable airplanes, rotorcraft, and advanced aerospace vehicles. In support of the goal of the Quiet Aircraft Technology Project for reduced noise impact on community residents, improvements in noise prediction and control are needed for jet, propeller, rotor, fan, 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 aircraft passengers and crew and on 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;
- Simulation and prediction of aero acoustic noise sources particularly for airframe noise sources and situations with significant interactions between airframe and propulsion systems;
- Concepts for active and passive control of aero acoustic noise sources for conventional and advanced aircraft configurations;
- Innovative active and passive acoustic treatment concepts for engine nacelle liners and concepts for high-intensity acoustic sources, which can be used to characterize engine nacelle liner materials;
- Reduction technologies and prediction methods for rotorcraft and advanced propeller aerodynamic noise;
- Development of synthesis and auditory display technologies for subjective assessments of aircraft community and interior noise;
- Development and application of flight procedures for reducing community noise impact of rotorcraft and subsonic and future supersonic commercial aircraft while maintaining safety, capacity, and fuel efficiency;
- Computational and analytical structural acoustics techniques for aircraft and advanced aerospace vehicle interior noise prediction, particularly for use early in the airframe design process;
- Technologies and techniques for active and passive interior noise control for aircraft and advanced aerospace vehicle structures; and
- Prediction and control of high-amplitude aero acoustic loads on advanced aerospace structures and the resulting dynamic response and fatigue.

A2.05 Electric Drive Components, Power Management and Distribution Technologies
Lead Center: GRC
Participating Center(s): GSFC, JPL, JSC

Future environmentally harmonious aircraft propulsion systems may be driven by electric power. These new systems will likely be fueled by hydrogen stored as a cryogenic liquid. Like all flight systems, these new electric based propulsion concepts will require each component to be extremely lightweight, especially when compared to similar ground-based systems. Future specific power requirements for the entire propulsion system from power supply to electric motor could reach 20-kW/kg. The total electric power supplied for aircraft will be orders of magnitude higher than for existing flight-rated secondary electrical systems. Future high power electric systems present a number of challenges for application to volume and weight limited aircraft. NASA is interested in the development of innovative technologies that demonstrate the feasibility of high power densities (>5kW/kg) for electric power delivery and propulsion. Specific areas of interest include but are not limited to the following:

- High power density electric motors and actuators, including superconducting, cryogenic and non-cryogenic systems;
- Cryogenically cooled lightweight, possibly superconducting, high power transmission lines;
- Cryogenically cooled and non-cryogenic lightweight power conditioning and control technology including technologies for isolation of noise-sensitive avionics power busses from main propulsion power busses;

- Cryogenically cooled and non-cryogenic lightweight high voltage high power density power management components;
- Highly integrated dual function components and systems that have the potential to reduce overall vehicle and subsystem weight (e.g., power conductors that are integrated into the airframe structure, motors directly integrated into the fan/propeller structure);
- Advanced enabling technologies such as nanoelectronics, smart sensors, and actuators;
- Advanced diagnostics, health monitoring and control concepts, smart sensors, electronics and actuators for enabling self-diagnosis and prognosis, and self-reconfiguration capabilities;
- Concepts that integrate distributed sensing with actuation and control logic for micro-level control of parameters (such as propulsion system internal flows, electrical states, etc. that impact performance and environment).

Proposals must show improvements to the state-of-the-art and viable application to aircraft.

A2.06 Smart, Adaptive Aerospace Vehicles With Intelligence
Lead Center: ARC
Participating Center(s): LaRC

This subtopic emphasizes the roles of aerodynamics, aerothermodynamics, adaptive software, vehicle dynamics in nonlinear flight regimes, and advanced instrumentation in research directed towards the identification, development, and validation of enabling technologies that support the design of future, autonomous aerospace vehicle and platform concepts for aviation safety, and security vehicle systems. Some of the vehicle attributes envisioned by this subtopic include: a) "Smart" vehicle attributes-using advanced sensor technologies, flight vehicle systems are "highly aware" of onboard health and performance parameters, as well as the external flow field and potential threat environments; b) "Adaptive" vehicle attributes-flight avionics systems are reconfigurable, structural elements are self-repairing, flight control surfaces and/or effectors respond to changing flight parameters and/or vehicle system performance degradation; and c)"Intelligent" vehicle attributes-vehicle onboard processing and artificial intelligence technologies, interfaced with advanced vehicle structural component and subcomponent designs and appropriate actuating devices, reacts rapidly and effectively to changing performance demands and/or external flight and security threat environments. Future air vehicles with the above attributes will manage complexity, "know" themselves, continuously tune themselves, adapt to unpredictable conditions, prevent and recover from failures, and provide a safe environment.

For atmospheric vehicles and platforms, both military and civil applications are sought, while for aviation applications, emphasis is placed on configurations that enable the discovery of new aviation safety and security concepts. Concepts and corresponding enabling technologies are sought which expand the traditional boundaries of conventional piloted vehicles categories such as General Aviation (GA) or Personal Air Vehicles (PAV), as well as significantly advance the state-of-the-art in remotely operated vehicle classes such as Long-Endurance Sensing Platforms (LESP), Unmanned Aerial Vehicles (UAV) or Unmanned Combat Aerial Vehicles (UCAV) as they can relate to aviation safety and security. Furthermore, for Earth applications, special emphasis is placed on research proposals that attempt to provide solutions for a future state in which revolutionary vehicles operate in a highly integrated airspace including hub and spoke, point-to-point, long-haul, unmanned aircraft, green aircraft, as well as a future state where air vehicle designs reflect a high level of integration in performance, safety and security, airspace capacity, environmental impact and cost factors.

There are a number of specific areas of interest:

- Conceptual flight vehicle/platform designs featuring variable levels of vehicle and airspace requirements integration, and/or smart, intelligent, and adaptive flight vehicle capabilities, as demonstrated by state-of-the-art systems analyses methods to determine enabling technologies and resulting impacts on future system integrated performance, environmental impact, and safety and security issues;
- New algorithms for predicting vehicle loads and response using minimal vehicle state information;
- Novel optimization methodologies to support conceptual design studies for highly-integrated flight vehicle and air space concepts and/or smart, intelligent and adaptive flight vehicle capabilities, which demonstrate

appropriate design variable selection, scaling techniques, suitable cost functions, and improved computational efficiency;

- Physics-based modeling and simulation tools of multiple vehicle classes and corresponding airspace operations aspects to support scenario-based planning and requirements definition of highly integrated vehicle and airspace capacity concepts, including investigations of the potential use of virtual/immersive simulations on future engineering decision making processes; and
- Micro-scale wireless communications, health monitoring, energy harvesting, and power-distribution technologies for large arrays of vehicle-embedded MEMS sensors and actuators.

A2.07 Revolutionary Atmospheric Flight Concepts
Lead Center: DFRC

This subtopic 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. It seeks advanced flight techniques, operations, and experiments that promise significant leaps in vehicle performance, operation, safety, cost, and capability; and may require a demonstration or validation in an actual flight environment to fully characterize or validate it.

The scope of this subtopic is broad and includes advanced flight experiments that accelerate the understanding, research, and development of advanced technologies and unconventional operational concepts. Examples extend to (but are not limited to) such things as inflatable aero-structures (new designs or innovative applications, new manufacturing methods, new materials, new in-flight inflation methods, and new methods for analysis of inflation dynamics), innovative control surface effectors (micro-surfaces, embedded boundary-layer control effectors, and micro-actuators), innovative engine designs for UAV aircraft, alternative engines/motors/concepts, alternative fuels research (hydrocarbon, hydrogen, or regenerative), sonic boom reduction, noise reduction for Conventional Take-off and Landing/Short Take-off and Landing (CTOL/STOL) aircraft and engines, advanced mass transportation concepts, aerodynamic systems optimization for planetary aircraft (Venus, Mars, Io, and/or Titan), flexible system stability derivative identification, innovative approaches to thermal protection that minimize aerodynamic performance degradation, innovative approaches to structures, stability, control, and aerodynamics integration schemes, and innovative approaches to incorporation of UAV operations into commercial airspace. This subtopic is intended to advance and demonstrate revolutionary concepts and is not intended to support evolutionary steps required in normal product development. Proposals should emphasize the need of flight testing a concept or technology as a necessary means of verifying or proving its worth; emphasis should also be given to multidisciplinary integration of advanced flight systems. The benefit of this effort will ultimately be more efficient aerospace vehicles, increased flight safety (particularly during flight research), and an increased understanding of the complex interactions between the vehicle or technology concept and the flight environment.

A2.08 Modeling, Identification, and Simulation for Control of Aerospace Vehicles to Prepare for Flight Test
Lead Center: DFRC

Safer and more efficient design of advanced aerospace vehicles requires advancement in current predictive design and analysis tools. The goal of this subtopic is to develop more efficient software tools for predicting and understanding the response of an airframe under the simultaneous influence 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 dynamical subsystems with an emphasis towards 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, aero elastic maneuver performance, and load control including smart actuation and active aero structural 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, such as Unmanned Aerospace Vehicles/Remotely Operated Aircraft (UAV/ROA), and flight regimes ranging from low-speed High-Altitude Long-Endurance (HALE) to hypersonic and access-to-space aerospace vehicles. Proposals should address one or more of the following:

- Accurate prediction with validation of steady and unsteady pressure, stress, and thermal loads;
- Effective multidisciplinary dynamics analysis algorithms with flight-test correlation capability conducive to validation with test data, such as with finite-element aeroservoelastic computations;
- Time-accurate simulation systems from nonlinear multidisciplinary dynamics models with applications toward flight-testing, such as with reduced-order CFD-based methods;
- Novel and efficient schemes for control-oriented identification of nonlinear aeroservoelastic dynamics from test data with provisions for uncertainty estimation and model correlation;
- Online and autonomous model update schemes for loads, aerodynamic, and aero elastic model identification for stability and performance monitoring and prediction in adaptive control;
- Self-learning control strategies for aero structural vehicles and development of enhanced real-time controls software and hardware for long-term onboard systems operation;
- Integration of modeling, analysis, simulation, and identification techniques for control objectives in a unified, compatible manner; and
- Innovative, high-performance facilities for integrated simulation and graphical interface, or virtual reality systems, for multidisciplinary aerospace systems.

A2.09 Flight Sensors and Airborne Instruments for Flight Research
Lead Center: DFRC

Real-time measurement techniques are needed to acquire aerodynamic, structural, 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 or instrumentation systems for improving the state-of-the-art in aircraft 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, and minimizing the disturbance to the measured parameter from the sensor presence or deriving new information from conventional techniques. This subtopic solicits proposals for improving airborne sensors and instrumentation systems in all flight regimes. These sensors and systems are required to have fast response, low volume, minimal intrusion, and high accuracy and reliability. Innovative concepts are solicited in the areas that follow below.

Vehicle Condition Monitoring
Sensor development in support of vehicle health and performance monitoring includes the monitoring of aerodynamic, structural, propulsion, electrical, pneumatic, hydraulic, navigation, control, and communication subsystems. Proposals that focus solely on health management algorithms and systems integration should be addressed in the Automated Online Health Management and Data Analysis subtopic.

Vehicle Environmental Monitoring
Sensor development in support of vehicle environmental monitoring includes the following:

- Non-intrusive air data parameters (airspeed, air temperature, ambient and stagnation pressures, Mach number, air density, and flow angle);
- Off-surface flow field measurement and/or visualization (laminar, vortical, and separated flow, turbulence) zero to 50 meters from the aircraft;
- Boundary layer flow field, surface pressure distribution, acoustics or skin friction measurements or visualization; and
- Unusually small, light and low-power instrumentation for use on miniature aircraft and high altitude long endurance vehicles.

TOPIC: A3 Airspace Systems

NASA's Airspace Systems (AS) program is investing in development of revolutionary improvements and modernization for the air traffic management (ATM) system. The AS Program will enable new aircraft, new aircraft technologies, and air traffic technology to safely maximize operational efficiency, flexibility, predictability, and access into airspace systems. The major challenges are to accommodate projected growth in air traffic while preserving and enhancing safety; provide all airspace system users more flexibility and efficiency in the use of airports, airspace and aircraft; reduce system delays; enable new modes of operation that support the FAA commitment to "Free Flight" and maintain pace with a continually evolving technical environment, and provide for doorstep to destination transportation developments. AS Program objectives are: improve mobility, capacity, efficiency and access of the airspace system; improve collaboration, predictability and flexibility for the airspace users; enable modeling and simulation of air transportation systems; enable runway-independent aircraft and general aviation operations; and maintain system safety and environmental protection. NASA is working to develop, validate, and transfer advanced concepts, technologies, and procedures through partnership with the Federal Aviation Administration (FAA), other government agencies, and in cooperation with the U.S. aeronautics industry.

A3.01 Next Generation Air-Traffic Management Systems
Lead Center: ARC
Participating Center(s): DFRC

The challenges in Air Traffic Management (ATM) are to create the next generation system and to develop the optimal plan for transitioning to the future system. This system should be one that (1) economically moves people and goods from origin to destination on schedule, (2) operates without fatalities or injuries resulting from system or human errors or terrorist intervention, (3) seamlessly supports the operation of unmanned aerial vehicles (UAVs) or remotely operated aircraft (ROAs), (4) is environmentally compatible, and (5) supports an integrated national transportation system and is harmonized with global transportation. 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.

To meet these challenges, innovative and economically attractive approaches are sought to advance technologies in the following areas:

- Decision support tools (DST) to assist pilots, controllers, and dispatchers in all parts of the airspace (surface, terminal, en route, command center);
- Integration of DST across different airspace domains;
- Next generation simulation and modeling capability-models of uncertainty and complexity, National Airspace System (NAS) operational performance, economic impact;
- Distributed decision making;
- Security of advanced ATM systems;
- System robustness and safety-sensor failure, threat mitigation, health monitoring;
- Weather modeling and improved trajectory estimation for traffic management applications;
- Role of data exchange and data link in collaborative decision-making;
- Modeling of the NAS;
- Distributed complex, real-time simulations-components with different levels of fidelity, human-in-the-loop decision agents;
- Integrated ATM/aircraft systems that reduce noise and emissions;
- Automation concepts for advanced ATM systems and methodologies that address transitioning to more automated systems;
- Application of methodologies from other domains to address ATM research issues;
- Intelligent software architecture;
- Runway-independent (e.g., Vertical Take-off Landing [VTOL], Short Take-off and Landing [STOL], and Vertical/Short Take-off and Landing [V/STOL]) aircraft technologies required to meet national air trans-

portation needs, to satisfy requirements for airline productivity, passenger acceptance, and community friendliness, and autonomous operations;

- Automated, real-time detect, see, and avoid operations;
- Intermodal transportation technologies; and
- Each of the abovementioned technologies and other technologies specifically fostering the operation of unpiloted aircraft within NAS under control of the ATM system, including, but not limited to, innovative control, navigation, and surveillance (CNS) concepts; also considering high altitude, long endurance operations.

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9.1.2 EXPLORATION SYSTEMS

On January 14, 2004, the President directed NASA to embark upon a robust space exploration program that will advance the nation's scientific, security, and economic interests. This is the fundamental goal of the Vision for Space Exploration and, therefore, the primary objective of the Exploration Systems Mission Directorate (ESMD). The Exploration Systems Mission Directorate is a new organization within NASA. It is dedicated to creating a constellation of new capabilities, supporting technologies, and performing foundational research that enables and supports sustained and affordable human and robotic exploration.

In order to support its complex mission, the directorate has been organized into eight divisions: the Office of Research, the Development Programs Office, the Office of Mission Integration, Acquisition and Mission Support, the Contracts Division, the Requirements Division, the Office of Communication, and the Administration Office. Within these offices are numerous subdivisions, which are integral to the objectives of ESMD, including Constellation Systems, Exploration Systems Research and Technology, Prometheus Nuclear Systems and Technology, and Human Systems Research and Technology.

The goal of these subtopics will be to help supplement and enhance the ongoing research of ESMD through the involvement of creative high tech firms eligible for SBIR contracts.

http://www.exploration.nasa.gov/

TOPIC: X1 Communications, Computing, Electronics and Imaging (CCEI)

The goals of this topic are to develop advanced space communications and networking technology; high-performance computers and computing architectures for space systems and data analysis; low-power electronics to enable robotic operations in extreme environments; and imaging sensors for machine vision systems and the characterization of planetary resources. Subtopics of this topic area include:

In-Space Computing and Reconfigurable Electronics. This subtopic includes architectures and components required for space-based computing and avionics systems. Architecture efforts will emphasize modular, fault-tolerant approaches that leverage commercial standards and COTS devices. Component work will focus on capabilities for enhancing general- and special-purpose processing to meet multiple mission goals. Products of particular interest include reconfigurable electronics, fault-tolerant, reconfigurable processor, micro-controllers and storage devices.

Extreme Environments/Low Temperature Electronics. This subtopic includes radiation-tolerant, wide-temperature-range digital, analog, mixed signal, dynamic member and RF electronic components, and integrated modules suitable for operation in the extreme environments of the Moon, Mars and other deep space destinations. Efforts will emphasize supporting electronics for sensors, actuators and communications. The focus of this subtopic is radiation-tolerant, analog, mixed signal, dynamic memory and RF electronic components, and integrated modules suitable for operation in extreme low-temperature space environments.

Sensing and Imaging. This subtopic includes orbital remote sensing for topographical and resource mapping and atmospheric profiling and control-loop sensing for robotic functions such as rendezvous and docking, assembly and construction, and precision landing. Products of particular interest include control-loop sensors for position, velocity and force, rapid detection and readout arrays for 2D and 3D imaging at 1.5 µm and multi-wavelength IR and visible laser arrays.

Surface Networks and Access Links. This subtopic includes communications technologies to support operational activities in space beyond low Earth orbit and on planetary surfaces in which nodes are simultaneously connected to each other, to Earth, and to the CEV via in-space relay orbiters, and via wired and wireless networks providing the bidirectional voice, video and data needed. The focus of this subtopic is on the modular, reconfigurable RF communications and networking technologies needed to support a human presence on remote lunar and planetary surfaces with short-range networks and access links to long-haul systems.

X1.01 In-Space Computing and Reconfigurable Electronics
Lead Center: GSFC
Participating Center(s): JSC, MSFC

The goal for this subtopic is the development of advanced space technology to further high-performance computers and computing architectures and reliable electronic systems that can operate effectively for long periods of time in harsh environments. These systems require management of low power and radiation, and must be reliable, robust and reconfigurable.

The objective for this development goal is to elicit novel architectural concepts and component technologies that have realistic potential and achievable applications and are responsive to the priority areas of this subtopic. Technologies will be selected based on the potential that their final end products are sustainable (affordable, reliable/safe and effective), and will advance solutions to the challenges of reusability, modularity and autonomy. Priority areas are:

Data processing

- General purpose processors (piece part, rather than an entire board) possessing fault tolerance at cell and or die levels, floating point and error correction.

- Technologies that reduce the physical size and power requirements of computing systems: making the data system more adaptable, modular, and cost effective.
- New standard models for analysis of interplanetary radiation and radiation belts, and technologies that enable radiation measurements such as total dose and single event effects in computing systems: enhances capability to design radiation tolerant data systems, monitor systems in flight, and predict errors and contingencies.

Reconfigurable Electronics and Implementations

- Reconfigurable designs and architectures that support fault tolerance and are functionally and physically modular.
- Solutions, designed around generic blocks, for recovery from multipoint failures (as opposed to single fault) component failure, where a system can monitor and identify the failing components, and self-repair or bypass small portions of the electronics. These prioritized generic blocks would enable graceful degradation of higher functions while maintaining the system core functionality.

Data System Support Electronics

- Radiation-hard microcontrollers, phase lock loops (PLL), and high-speed oscillators (greater than 150 MHz, equal duty cycle).
- FPGA: Environmentally tested, reliable, tolerant IO, radiation hardened cell structures, Anti-Fuse or reconfigurable.
- Robust and reliable non-volatile storage devices such as EEPROMs and FLASH memory.

Command and Data Transfer

- Inter-system data transfer communications between spacecraft subsystems based on standard interfaces that address high multi-drop throughput (10 to 100 mbps), self diagnosis, inherent redundancy and low power, and support subsystem data transfer to realize higher autonomy.
- Intra-system data transfer communications within the spacecraft subsystems, between cards within a box, to replace the conventional passive backplanes, e.g., switched fabric backplanes with fault detection and serial interfaces.

X1.02 Extreme Environment Electronics/SEE
Lead Center: JPL
Participating Center(s): GSFC, MSFC

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. All exploration endeavors, including robotic, habitat, and ISRU systems that are expected to reliably operate on the Moon or Mars surface for years will need electronics that are able to survive and operate in a wide temperature range and thermal-cycling environment. The lunar and Martian temperatures are well outside the specification range of military and commercial electronics. While many types of devices, especially Si CMOS transistors, can operate down to low temperatures. There are significant circuit design challenges that need to be addressed, especially in the case of mixed signal and analog circuits.

In addition, thermal cycling present in lunar, and especially Mars, environments introduces reliability concerns associated with mechanical stress and fatigue of the IC package. For example, compounds optimized for Earth-like packaging of electronic systems have glass transition temperatures that are within the cycling range of these environments, and cycling of electronic systems packaged using these materials will likely result in package failures. Hence, the choice of packaging technology and material combination used is extremely critical for these missions.

Proposals are sought in following specific areas:

- Wide temperature (-180°C to +130°C) and low-temperature (-230°C), radiation-tolerant and SEU immune, low power, mixed-signal circuits including analog-to-digital converters, digital-to-analog converters, low-noise pre-amplifiers, voltage and current references, multiplexors, power switches, microcontrollers, and integrated command/control/drive electronics for sensors, actuators, and communications transponders.
- High-density packaging able to survive large numbers of thermal cycles (hundreds) and tolerant of the extreme temperatures of the Moon and Mars, including appropriate selection of packaging materials combinations (substrates, die-attach, encapsulants, etc.) modular system level electronics packaging, including power, command and control, and processing functions, enabling integration of electronics with sensors and actuators elements.
- Wide temperature (-180°C to +130°C) and ultra-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 electronic systems and components.

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 testing at the completion of the Phase 2 contract.

X1.03 Sensing and Imaging
Lead Center: JPL
Participating Center(s): GSFC, LaRC

Sensing and imaging systems can provide a number of capabilities required for anticipated NASA missions including exploration of Mars and the Moon. Capabilities of interest include the following:

- Orbiting sensors to map:
  - Extent and concentration of useful, surface, or subsurface resources to identify promising outpost or science sites and traversable terrains;
  - Surface topography and roughness to identify promising safe landing sites for human, robotic science, and pre-provisioning missions, and to guide pinpoint landing algorithms.
- Robot-mounted sensors for: estimating robot pose and motion; recovering 3D scene structure; identifying hazards or objects of interest; identifying articulation of observed objects, and performing visual serving. Flight ready (radiation and temperature hardened), high cycle rate, and low power systems are generally preferred. Applications include:
  - Autonomous rendezvous and docking;
  - Pinpoint landing;
  - Surface navigation;
  - Surface and on-orbit assembly/construction;
  - Resource mining/processing;
  - Multi-vehicle cooperation.

Specific technologies of interest in addressing these challenges include:

- Rapid frame rate arrays for 1, 1.5 and 2 µm vision (2D and 3D);
- Multi-wavelength laser arrays;
- Flight-ready, high-speed, medium-resolution (640x480) stereo-vision sensors;
- Flight-ready, low-power lighting systems (headlights) to allow imaging during nighttime robotic operations;
- Tightly coupled inertial and vision sensors for pose estimation;
- Ground truthing systems for evaluating performance of ranging systems.

A number of related technologies are of interest but are covered under other subtopics, including:

- High power or high rep-rate lasers (S6.02, S1.04);
- Ultra-high sensitivity detectors and arrays (S4.01);
- Active and passive microwave sensors (S6.04, S6.05).

X1.04 Surface Networks and Access Links
Lead Center: GRC
Participating Center(s): GSFC, JPL, JSC

To develop safe and sustainable exploration capabilities at minimum cost, while maximizing return, an incremental spiral development process will guide a build out of an integrated communication, navigation, networking, computing, informatics, and power architecture that supports all surface and proximity nodes, including humans in spacesuits, robots, rovers, human habitats, satellite relays, and pressurized vehicles.

The architecture will enable operational activities in which both fixed and mobile nodes with vastly differing communications requirements are seamlessly interoperable. Nodes are simultaneously connected to each other, to Earth, and to the CEV via in-space relay orbiters, and via wired and wireless networks that provide the bidirectional voice, video, and data needed. The need to be self-sufficient during exploration requires local control and an unprecedented level of autonomous operation to seamlessly connect the nodes and reduce operations cost. The Moon and Mars environments require SEU and extreme temperature-tolerant equipment tightly constrained by power, mass, and volume. Human presence requires at least one usable bidirectional link to the communications network at all times and high definition video to engage the public interest.

This subtopic focuses on the modular, reconfigurable RF communications and networking technologies needed to support a human presence on remote lunar and planetary surfaces with surface-to-surface and surface-to-orbit (access) communications.

Surface Networks
The complexity of astronaut excursions, habitats, surface manned and unmanned rovers, and landers make surface operations and man-occupation complex and daunting tasks. Exploration of planetary surfaces will require short-range, bidirectional, multi-point links to provide on-demand, autonomous interconnection among surface-based assets. Some of the nodes will be fixed (base stations) and some will be moving (rovers and humans). This will encompass a number of communications and networking technologies for communications in the 2.4 Ghz range, including: integrated low mass, low power (100's of milliwatts) transceivers for very short-range interfaces with sensors and other small devices; power-efficient, miniature, modular transceivers for short-range communications among large (e.g., lander) and medium-sized (e.g., rover) surface assets; reconfigurable directionally selectable, multi-frequency arrays for wide coverage, high-gain links among surface assets; miniaturized modular antenna technology for surface-to-surface communications among mobile and fixed nodes; wireless products integrated with low-power space-rated ASICs and FPGAs; short (~1km) range access point base stations, or wireless router bridges for extending surface network coverage; fixed, long (~50km) range, wireless network terminals for extending high data rate communications over large distances; self-healing ad-hoc network MAC and protocols for intelligent, autonomous link management; and networking technologies to enable autonomous, seamless interconnectivity among all nodes.

Access Links
To interface with orbiting relays, terminals capable of providing seamless connectivity between surface networks and orbiting relays will be positioned on lunar and planetary surfaces and in orbit. Such an access link communications system will include: high rate, efficient, solid state amplifiers capable of very high data rates over 1,000-10,000 km distances with ranging signals embedded; very low-power data rates, and cost inter-spacecraft S-band transceivers/transponders for inexpensive spacecraft; optical transceivers capable of very high data rates over 1,000-10,000 km distances; SEU and solar flare tolerant transponders capable of: programmable wide-carrier frequency ranges from S-band to Ka-band, taking GPS measurements, and handling IP at the digital level; micro software radio

technology for autonomous and intelligent space applications; low mass, volume, power, and cost-stable oscillators to provide accurate time and frequencies for autonomous operations; autonomously reconfigurable receivers capable of automatic link configuration and management; microwave ranging hardware built into communication systems for rendezvous and collision avoidance; and ad hoc long range spacecraft-to-spacecraft network protocols to setup links on demand, such that each node can route data through to another node.

TOPIC: X2 Advanced Materials and Structural Concepts (AMSC)

The goals of this topic are to develop high-performance materials, fabrics, modular vehicle structural concepts, and mechanical components for exploration systems. Major technology drivers include reducing system cost, mass, and launch volume; enabling the construction of space and surface infrastructure from modular elements; extending the performance and lifetime of systems operating in extreme environments; and providing systems with integrated diagnostic and adaptive capabilities. This topic is responsible for basic technology level research, development, and testing through experimental and/or analytical validation of novel materials and structural concepts for a wide range of exploration applications. The three subtopics include Advanced Materials and Mechanisms, Structures and Habitats, and Nanotechnology.

X2.01 Advanced Materials
Lead Center: LaRC
Participating Center(s): GRC, MSFC

Technology areas included in this subtopic are high performance, super lightweight structural materials, space-durable materials, multifunctional materials, and flexible material systems. Materials of interest include ceramics, metals, polymers, and their composites as well as coatings for erosion resistance and environmental protection. Proposals with innovative and revolutionary ideas in the area of advanced materials are sought for explorations applications such as:

- Flexible fabrics and thermal insulation for spacesuits and habitats;
- High strength-to-weight and high temperature composite materials for lightweight vehicle structures and power and propulsion systems;
- Self-healing materials to repair damage to spacesuits, habitats, and wire insulation electronics, sensing, and actuators for monitoring system health and adapting to changing mission conditions;
- Flexible fabrics relevant to mission needs such as inflatable systems for ballutes, habitats, airbags, para-chutes, and suits;
- Innovative approaches to materials systems yielding durable, lightweight, flexible films and fabrics.

X2.02 Structures and Habitats
Lead Center: LaRC
Participating Center(s): DFRC, MSFC, JSC

This subtopic solicits innovative structural concepts, materials, and assembly techniques that support the development of modular space systems. Also needed is a criteria to judge the different concepts in terms of impact on the overall performance and weight. Structural concepts can include inflatable, erectable, deployable, or easily connected modules to create large space structures utilizing membranes, composites, or other material concepts. Modular units can provide reconfigurable structures, such as multiple-energy configurations using cables and linkages, compliant structures or mechanisms that adapt to varying surfaces, or multi-purpose integrated structures, such as load-bearing modular power distribution, thermal management, or radiation protection systems. Additionally, this subtopic includes research related to novel rotating devices, actuators, tribology, and seals. It further includes intelligent structural, electrical, and fluid interfaces to enable the assembly (or 'self-assembly') of modular systems.

Of particular interest are inflatable structures and habitats to minimize launch volume and costs. Large inflatable structures can be folded into compact packages for launch, pressurized for deployment once in space, and rigidized after deployment so that internal pressure is not required to maintain structural stiffness and shape.

New concepts, materials, and methods for in-space structures and habitats to enable humans to safely and effectively live and work in space are needed. Specifically, structures or habitats with integral radiation shielding, impact shielding, thermal management, and integral diagnostics/health monitoring capabilities are of interest as well as high strength-to-weight materials (e.g., foamed materials), structural elements, and beams that can be deployed or fabricated *in situ*. Development of smart and multifunctional modular structures, including the use of embedded sensors and actuators, is encouraged.

Also solicited are assembly technologies such as innovative connectors for joining and/or bonding techniques, module positioning and alignment concepts, component deployment or erection concepts, and component/module inspection and verification techniques. Structures and materials that support reconfigurable modular architectures are also solicited.

Modeling and structural testing techniques and analyses that support the design of modular structural concepts or their assembly are of interest. Two areas are of particular interest: one is controls-structures interaction (CSI) techniques and the second one is hybrid-test and physics based-modeling approaches. Application of advanced controls-structures interaction (CSI) techniques for measuring and controlling structural dynamics and geometry are important. Solutions for incorporation of CSI techniques for controlling such inflatable structures are also highly desirable. On hybrid modeling, ways to integrate test and physics-based models for cases where the physics-based models are not sufficient is also desirable.

X2.03 Nanostructured Materials
Lead Center: ARC
Participating Center(s): LaRC, JSC

The applications of advances in Nanotechnology are anticipated to have a profound impact on NASA's future missions by offering significant advantages in terms of cost affordability and reliability from multifunctional materials. Nanotechnology enables systems performance beyond those expected from conventional materials. While many fundamental findings are reported in the literature, there is a strong need to focus efforts on the demonstration of real benefits provided by nanostructured material systems.

It is especially interesting to meet exploration challenges with the development of high strength-to-weight and multi-functionality possible from the unique combinations of desirable properties of the nano-structred materials. The promise of high strength-to-weight, multi-functional, nano-structured materials has led to intense interest in developing them for near-term applications for human spaceflight and exploration.

Nano-structured materials of interest include, but are not limited to, the utilization of single wall, carbon, nanotube-based composites, ceramic nanofibers, and bio/nano-inspired materials and composites.

Due to the size scale and fundamental physical properties of the structures involved, a successful proposal for applications development should demonstrate a mature understanding of nano-material synthesis and material quality, as well as incorporate the development and use of new characterization methodologies to fully assess the impact of the nano-structured materials upon a given matrix or system.

The specific focus of this subtopic will include, but not be limited to:

- New materials for structures and components offering significant mass reduction and increased strength with improved thermal conductivity, low permeability, low density, and improved damage tolerance through self-repairing mechanisms;

- Application of nano-structured materials to self-healing and self-repair materials and concepts;
- Nano-structured materials offering enhanced radiation protection;
- Development of nano-material systems that are resistant to large thermal fluctuations, radiation, electro-static charging, abrasion, and micrometeoroid debris damage;
- Nano-materials for energy generation, storage, and distribution.

TOPIC: X3 Power Propulsion and Chemical Systems (PPCS)

The goals of this topic are to develop high-efficiency power conversion/generation, energy storage, and power management and distribution systems to provide abundant power for long-duration, sustainable, human and robotic exploration missions as well as systems for the storage and handling of cryogens and other propellants. The subtopics include: Power Generation and Transmission, Energy Storage, and Cryogenic and Thermal Management.

X3.01 Power Generation and Transmission
Lead Center: GRC
Participating Center(s): JPL, MSFC

All innovative technologies for power generation and conversion are highly encouraged under this subtopic. Proposals addressing technologies, including solar photovoltaic conversion, thermo-photovoltaic conversion, thermoelectric conversion, and thermodynamic conversion (heat engines), etc., are encouraged. In addition, research and technology development in topics related to advanced power cabling and power management are also needed.

Significant improvements in photovoltaic systems are required to enable future exploration missions. Dramatic increases in array mass specific power (>1000 W/kg), reductions in stowed volume, increases in operational voltages to 1000V, increases in radiation hardness enabling reliable operation in high-radiation environments, increases in survivability over wide temperature extremes, as exists on a lunar surface, and developments of automated deployment systems for surface power applications. Developments are sought for photovoltaic cells on flexible, ultra-lightweight substrates, array technologies that maintains the high mass specific power of these cells, nanostructures incorporated to enhance the performances of thin-film, organic/inorganic, or single-crystal photo-voltaic cells and thermo-photovoltaic cells. Demonstrations of high efficiency, lightweight, concentrator cell and supporting array techniques, multi-quantum well and multi-quantum dot devices, and advanced multi-band gap devices are also of interest. Advanced photovoltaic areas of emphasis include high-efficiency quantum well technology. Nano-engineered materials are an area of emphasis for all of these applications.

High power solar dynamic power conversion systems, including Brayton and Stirling, support the development of solar-electric propulsion and power systems requiring low overall system specific mass (kg/kW). The objectives for solar dynamic systems, with power output capacities ranging from 100W to >100kW, require demonstrating thermal efficiencies greater than 30% over a range of cycle temperature ratios and heat rejection temperatures. A system specific mass of <200 kg/kWe modularity, and high reliability by fault-tolerant system architectures are desired.

Technological advances are needed for large deployable solar concentrators and secondary concentrators, high temperature heat receivers with thermal energy storage capability, and advanced lightweight heat rejection sub-systems. For Brayton power, advances are needed in ceramic high temperature turbine technology, high efficiency compressors matched to turbine performance, high efficiency alternators, lightweight carbon composite heat exchangers and recuperators.

For Stirling, advances required are: high frequency, low inductance linear alternators, low mass displacer, hot-end materials and structures, efficient cold-end thermal integration with lightweight radiators, high efficiency low mass controllers, and regenerators.

For power management and distribution systems, areas of emphasis include: high reliability, light weight, radiation-hardened power electronic components (semiconductor switches, diodes, capacitors, and transformers); high voltage switching contactors (>100Vdc) tolerant to corona discharge; and high efficiency (>95%) modular DC converters for boost and buck conversion. Concepts for monitoring power system status, fault tolerance, redundancy, and energy management. Advanced power cabling including high voltage, superconductors, carbon nanotube, and cable mbedded with structural elements. Also of importance are, intelligent and modular distribution switchgear and power management that can autonomously reconfigure in response to faults and changing loads.

Research for Wireless Power Transmission (WPT) technology development, to reduce the cost of electrical power and to provide a stepping stone to NASA for delivery of power between objects in space, between space, and surface sites, between ground and space, and between ground and air-platform vehicles. WPT can involve lasers or microwaves along with the associated power interfaces. Microwave and laser transmission techniques have been studied with several promising approaches to safe and efficient WPT identified. These investigations have included microwave phased array transmitters, as well as visible light laser transmission, and associated optics. There is a need to produce "proof-of-concept" validation of critical WPT technologies for both the near-term as well as far-term applications. These investments will be harvested in near-term, beam-safe demonstrations of commercial WPT applications. Proposals are sought that include such activities as the technology elements, architecture, and demonstration programs for wireless transmission of power. Receiving sites (users) include ground-based stations for terrestrial electrical power, orbital sites to provide power for satellites and other platforms, future space elevator systems, and space-based sites for spacecraft and space vehicle propulsion.

X3.02 Energy Storage
Lead Center: GRC
Participating Center(s): JPL, JSC

All exploration missions require advanced primary and rechargeable energy storage devices that are high-density, have long-life capability, and have the ability to function at extreme temperatures. The energy storage requirements vary significantly from a few watt-hours (astronaut equipment) to hundreds of kilowatt-hours (human outposts), depending on the mission. Similarly, power requirements also vary from a few watts (astronaut equipment) to several kilowatts, depending on the mission (human rovers, human outposts, and crew exploration vehicles).

Advanced energy storage devices, such as primary batteries, rechargeable batteries, fuel cells, and flywheels are required to enable future robotic and human exploration missions. Advanced primary batteries are required for applications such as astronaut equipment, communication devices, *in situ* resource utilization systems, sensor networks, etc. Advanced rechargeable batteries are required for solar powered landers and rovers, solar powered human outposts, astronaut equipment, and spacecraft. Primary fuel cells are required for crew exploration vehicles and rovers. Regenerative fuel cells provide an enabling, mass-efficient solution for surface electrical energy storage for future long-duration human exploration of the lunar and Mars surfaces. Flywheels provide an effective solution to meeting peak power requirements when used in hybrid systems with battery or fuel cell systems providing the base power, and offer the capability of integrated power and attitude control.

Energy Storage devices are needed for EVA and EVA accessory applications as well as vehicle and base back-up or peaking power applications. Areas of emphasis include advanced battery materials and cell designs with the potential to achieve the performance and safety advancements required for manned applications. Hybrid systems consisting of fuel cells, batteries, flywheels, and/or ultra capacitors are of interest. Also sought are high energy density fuel cell reactant storage innovations compatible with the performance and safety goals specified herein. Micro and nano-engineered materials are an area of emphasis for all of these applications. Proposals addressing micro-batteries, and integrated power generation and storage are sought.

Primary and rechargeable lithium-based batteries with advanced anode and cathode materials and advanced liquid and polymer electrolytes and solid-state systems are of particular interest. Technology advancements that contribute to the following performance goals are sought: specific energy >180 Wh/kg, calendar life (>15years), and a wide operating temperature range (-60°C to 60°C). Primary batteries with the following performance targets are of interest: low temperature operation capable of delivering >30% of their ambient temperature capacity at temperatures as low as -100°C, specific energy: >400 Wh/kg, long calendar life >15 years, and high rate capability >C/10.

Fuel cell (FC) and regenerative fuel cell (RFC) systems with power capabilities in the range of 100-1000 watts and 2-10kW are of interest. Technological advances are sought that FC/RFC based systems with the following characteristics: specific energies: FC >1500 W/kg, RFC >600 Wh/kg. Efficiencies: FC>70% at 1500 W/kg, RFC >60% at 600 Wh/kg, and lifetimes: FC >10,000 hours, RFC >1500 cycles. Concepts that incorporate passive operation and advanced reactant storage options (example: H_2, O_2) are sought.

Advanced fuel cell development should include proton exchange membrane fuel cells (PEMFC - high and low temperature), regenerative fuel cells (RFC), and solid oxide fuel cells (SOFC). PEMFC areas of emphasis include long-life stacks and systems with emphasis on gravity-independent water management within the stack or elsewhere in the system, passive water separators, and passive reactant recirculation devices. RFC areas of emphasis include long-life, high-efficiency PEMFCs and electrolyzers. SOFC areas of emphasis include the capability to utilize CO/CO_2 and methane fuels for power generation.

Flywheel technology areas of interest are: system configuration concepts for high specific energy (>100Wh/kg for systems >500Whr and >50Wh/kg for systems <500Wh), and advanced vehicle integration, motor, and magnetic bearing control electronics. Flywheel Energy Storage development that addresses rotor concepts using advanced materials incorporating composite nanotubes that enable rotor specific energy >600 Wh/kg, and/or concepts that integrate energy storage, momentum storage, and spacecraft structure are sought.

X3.03 Cryo and Thermal Management
Lead Center: MSFC
Participating Center(s): JSC, GSFC

This subtopic includes technologies for waste heat management, movement, and rejection; technologies including lightweight and/or high-temperature radiators, heat pipes, heat sinks, etc. Also includes cryo-coolers and related low-temperature systems. These technologies will impact space solar power systems, spacesuits and habitation systems, robotics, and surface systems.

Spaceport operations, both on Earth as well as extraterrestrial, are heavily dependent upon a wide range of cryogenic systems, including liquid oxygen, liquid nitrogen, liquid helium, and supercritical breathing air. Each above application has unique performance requirements that need to be met. Sizes of these systems range from the small (<20 for supercritical air and payload cooling) to very large (>3400 m^3 for LOX and LH^2 ground 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 systems, storage and distribution components, refrigeration systems, advanced instrumentation, and advanced operational concepts.

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. Innovative concepts are requested for cryogenic insulation systems, fluid system components, and instrumentation. Although this subtopic solicits unique and innovative concepts in the cryogenic components and instrumentation areas, there is an emphasis at this time for:

- Advanced thermal switches to isolate heat transfer from a de-powered cryocooler;
- Advanced low-gravity submersible pumps designed specifically for moving cryogen heat that enters the tank wall to the heat exchanger coupled to the cryocooler;

- Advanced tank support systems capable of supporting tanks during the launch environment, but decoupling on on-orbit to minimize thermal loads;
- Advanced cryocoolers which are reliable, lightweight, and capable of removing significant heat at liquid hydrogen temperatures;
- Low heat leak cryogenic quick disconnects capable of sealing against the vacuum of space;
- Long-life, low power valves capable of sealing at cryogenic temperatures and being cycled many times without consuming pressurant gas;
- Liquid acquisition devices capable of preventing gas ingestion into engine feed lines in low gravity;
- Methods for cryogenic fluid acquisition and transfer in zero gravity;
- Methods of determining liquid remaining in propellant tanks in low gravity;
- High accuracy differential pressure transducers, which can be read submerged in liquid cryogen;
- On-orbit leak detectors;
- Lightweight, low-power temperature sensors which can be placed internally to the storage tank with a minimum number of feed-throughs;
- New technology valves for cryogenic applications, including LOX, LH^2 and Lhe, that minimize thermal losses and pressure drops. Components include shutoff and flow-control valves. Valves should be adaptable to electromechanical actuation and range in size from ½ to 6 inches;
- Integrated heat exchangers in large-scale storage systems designed to provide for zero boiloff and densification of liquid hydrogen and liquid oxygen;
- Advanced low-temperature materials for cryogenic containment;
- Insulation materials capable of retaining structural integrity while accommodating large operating temperatures ranging from cryogenic to elevated temperature conditions.

Thermal management systems are needed for the rejection of heat to hot environments for daytime operations on the lunar surface, large space radiators to dissipate heat from power and propulsion systems, thermal control for mobile systems, cryogenic propellant storage and handling for in-space refueling, and long-term cryogen storage for propellant depots.

Thermal management concepts include advanced heat sinks, heat pipes, and interface materials with high thermal conductivity that are electrically isolative. Innovative methods of increasing the specific thermal capacitance of the power systems are also sought:

- Qualified heat pumps to reject heat to hot environments;
- Multi-zone thermal control systems for spacesuits and mobile systems;
- Lightweight deployable low temperature radiators for use on the lunar surface;
- Concepts for the thermal management of advanced power system component designs for operation in deep space, lunar, and Martian environments.

TOPIC: X4 Advanced Studies Concepts and Tools (ASCT)

The goal of this topic is to develop ESR&T (Exploration Systems Research and Technology) tools that advance the SOA (State-Of-Art) for: the study of revolutionary exploration system advanced concepts, system technologies, and architectures; the prioritization of mission enabling technologies; systems engineering analysis, which reduces mission risk; systems design and analysis; and the conduct of exploratory research and development for emerging technologies. The projects to be selected are expected to challenge SBIR companies to take on research projects with higher technology development risk and higher potential payoff than they would, otherwise; and, in addition, are judged to be likely to provide new capabilities to meet NASA's strategic goals and objectives for Exploration Systems. Projects must press the state-of-the-art, display a high degree of innovation, and involve significant technical challenges. Projects must be technically feasible, but the proposer should not assume that the lower the technical risk in a project, the greater the probability that it will be funded. Component-related, system-related, and process-related projects are all of interest. Subtopics of this ASCT topic area include: Technology Systems Analysis Tools – this subtopic includes the development of advanced tools to support: advanced concept analysis; systems architecture analysis; emerging systems technology analysis; technology portfolio assessment and forecast analysis; campaign analysis; technology databases; advanced concept development risk and cost modeling; etc. This subtopic encompasses support for technology road map definition. Systems Design and Analysis Tools – this subtopic includes the development of advanced tools for implementing: an advanced modeling and systems simulation environment; integrated analysis for assessing potential system engineering impacts of new technologies; design and analysis databases; system engineering models; engineering discipline analysis; system level risk analysis; probabilistic risk analysis (PRA); reliability, maintainability, and availability analyses; human factor analysis; life cycle cost analysis; and other systems engineering Figures of Merit (FOM) analyses. This ASCT topic is currently focusing on developing advanced tools, which enable the following:

- Study of revolutionary exploration system advanced concepts, technologies, and architectures;
- Exploratory research and technology in the full range of technical fields related to space exploration;
- Integrated modeling and simulation of exploration systems and mission risk.

X4.01 Technology Systems Analysis
Lead Center: GRC
Participating Center(s): JPL

The goal of this subtopic is to develop new tools to ensure that advanced technology investments are guided by appropriate analyses. These analyses are needed in areas involving all of the various element programs within ESR&T. The analyses will support the definition of technology road maps for ESR&T.

The scope of Technology Systems Analysis Tools includes the development of advanced tools to support technology systems analyses, such as: portfolio analysis; campaign analysis; system technology architecture impact analysis; advanced concept analysis; sensitivity analysis; verification and validation analysis; development cost analysis; and the population of advanced technology databases and information systems. The ASCT analyses planned will be performed using low-fidelity/high-level techniques. They will focus on entry level technologies and notional architectures. Higher fidelity assessments will be performed using ESMD (Exploration Systems Mission Directorate) Simulation Based Acquisition (SBA) resources.

This Technology Systems Analysis Tools subtopic is currently focusing on developing advanced tools which enable the following:

- Conducting exploratory research and development of emerging technologies and advanced concepts with high potential payoff;
- Performing architecture, campaign, and technology analyses to identify and inform portfolio development for relevant exploration applications;
- Technology analysis to identify and prioritize mission enabling technologies;
- Architecture, mission, advanced concept, and technology risk analysis;
- Technology databases, roadmaps, and portfolio development;
- Exploration and implementation of different advanced concepts development methodologies and techniques to enable more effective and efficient study development;
- Development of advanced concepts analyses and sensitivity analyses that can incorporate the full range of technical fields related to space exploration;
- Analysis of advanced concepts, advanced technologies, and portfolio analysis;
- Campaign analysis including the synthesis and analysis of many missions, architectures and competing capabilities and technologies against FOMs;
- Technology analysis that identifies SOA and levels of performance metrics associated with cost- and risk-dependent chronologies (technology datasheets);

- Advanced concept and system technology verification and validation;
- Effective techniques for presenting tradeoffs and recommendations to decision-makers.

X4.02 Design and Analysis Tools
Lead Center: GSFC
Participating Center(s): LaRC, ARC

The goal of this subtopic is to maximize the credibility of the integrated systems analysis efforts being performed within ASCT by providing validated systems design, system analysis, and systems engineering tools. This will include the development of tools to produce: a modeling and simulation environment, design and analysis databases, system engineering models, engineering discipline analysis, parametric-based risk analysis, and probabilistic risk analysis (PRA), etc. This effort will closely coordinate with and support the development of the Simulation Based Acquisition (SBA) system in support of Exploration System Mission Directorate (ESMD) program acquisition and analysis.

The scope of System Design and Analysis Tools includes tool development activities in the following areas: advanced systems simulation modeling environment; design and analysis databases and system models; performance and structural sizing; SBA advanced systems engineering tools for mid-technology level simulation and visualization of life cycle cost, risk, reliability, supply chain logistics, maintainability, availability, and other system engineering Figures of Merit.

This subtopic is currently focusing on the following technology areas:

- Systems engineering tools and discipline analysis tools in support of Simulation Based Acquisition. See ESMD-RQ-0025, ESMD-RQ-0026 and SBA Strategy in the Crew Exploration Vehicle Procurement Bidder's library (http://exploration.nasa.gov/acquisition/cev_procurement.html) for additional information.
- Advanced engineering tools that integrate performance, risk, and cost modeling.
- Development of system engineering tools that implement new analytical methodologies and techniques in support of both ESR&T and SBA activities.
- Advanced systems simulation modeling environment that includes database technologies and data collection tools.
- Seamless integration of design tools, modeling tools, simulation tools, and other systems engineering tools via standards-based software interoperability.
- Novel approaches to assessing the performance, cost, or risk of proposed mission architectures.
- Techniques for characterizing and optimizing investments in Modeling and Simulation.
- Methods to extend and reuse models and simulations over the program lifecycle.
- Model-based techniques for optimizing designs in distributed, multi-organization, multi-contract design teams.

TOPIC: X5 Software, Intelligent Systems and Modeling

This SBIR Topic seeks innovative concepts for technologies that will reduce life-cycle mission costs by providing high-confidence design of onboard autonomy, including safe and reliable human autonomy interaction. NASA is preparing for human-robotic exploration of the Moon and Mars. Traditional means of providing system information, such as inspections and preventive maintenance, have limited utility for exploration missions. Other solutions, such as telemetry data, become less useful as communication bandwidth shrinks and communication delays increase. Under these circumstances, increasing the autonomy of the onboard systems provides the best means of managing system operations. Autonomous onboard system technologies involve the use of goal-oriented operations, requiring means for sensing the environment and making intelligent choices with regard to resources, procedures, health and safety, logistics, and configuration. The Software, Intelligent Systems and Modeling (SISM) Element program will develop and test reliable software, autonomous and human-robotic systems, and model-based methods for design, analysis, and operations. SISM is being formulated in collaboration with several ESRT Technology Maturation Program elements (for example, Advanced Space Operations, Lunar and Planetary Surface Operations, and Advanced Space Platforms and Systems), as well as the Human-Systems Integration Program in HSRT. In addition, this Element Program is cognizant of on-going FY04 SBIR tasks in related areas, such as advanced modeling and simulation. To focus the role of this SBIR Topic within the overall scope of SISM, there will be an emphasis on concepts that reduce life-cycle costs by increasing the usability of key classes of advanced design methods and tools. The key classes of methods and tools are defined by the two subtopics, Software Engineering (X5.01) and Human-Autonomy Interaction (X5.02). These kinds of design and test technologies have made great advances during the past ten years, but the usability of the technologies, and therefore their actual impact, has lagged behind their potential impact.

X5.01 Software Engineering
Lead Center: ARC
Participating Center(s): JSC, GSFC

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 for sustaining engineering: achieving affordable reliability over successive spirals of mission software development, maintenance, and upgrades for Crew Exploration Vehicle and Project Constellation. A key requirement is that projects 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 mixed human-robotic teams to accomplish mission objectives. These capabilities will be needed in exploration spirals 2 and 3, including the extended lunar missions. Ensuring that these capabilities are reliable and can be developed and maintained affordably, will be challenging but critical to both the lunar missions and the subsequent Martian missions. 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., simulation-based acquisition for software capabilities; mission planning that incorporates trade-space development of 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:

- 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);
- 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; and

- Technology for verifying and validating autonomy capabilities including intelligent execution systems, model-based diagnosis, and adaptive control.

A requirement for a sustainable and affordable human exploration presence in space is the need for modular, reusable elements and subsystems. Major subsystems (e.g., integrated vehicle health management) will present challenges in terms of software-based reconfigurability needed over a long sequence of missions. Projects can address technology development and maturation that provide for the following and related capabilities:

- Software reuse for mission-critical, real-time applications;
- Architectures that facilitate reconfiguration with upgraded components;
- Affordable verification, validation, and certification of upgraded components and sub-systems within a system (or system-of systems) context;
- Intelligent management of software assets;
- Middleware that enables software platforms to migrate to new hardware platforms (e.g., middleware that enables command and control software to be transparently ported to distributed grid and cluster computer platforms).

X5.02 Human Autonomy Interaction
Lead Center: JSC
Participating Center(s): ARC, GSFC

Autonomous and automated operations will be required for systems fulfilling the Vision for Space Exploration. This subtopic addresses the need for modeling and analysis tools and technologies for design, test, and evaluation of human-autonomy interaction systems. The tools will support analyses of scenarios, tasks, information, and communication. They can validate and build confidence in human-autonomy interfaces and interaction support by identifying and mitigating risks (e.g., workload, situational awareness, and error). The technologies will interoperate with models and tools for design, evaluation, and certification of hardware and software systems, and will support understanding by engineers and planners who are not experts in human-system design or human factors. They will be cost-effective to use and be easily updated and reconfigured to reflect changes in designs and plans.

The human-autonomy modeling and analysis technology will be applied to astronaut crew-autonomy and ground-crew-autonomy interactions in space missions. Autonomous systems can include exploration vehicles and subsystems, science stations, robots, robotic manipulators, rovers, and communications satellites. Autonomous operations can include rendezvous, proximity operations, mating of on-orbit elements, in-space assembly, maintenance, and robotic operations, including inspection, material transport, and sampling. These operations can be nominal, off-nominal, or contingency operations. Autonomy will be essential to ensure safe robot operation in the proximity of critical systems and humans. Autonomous functions can include science traverse and path planning, crew and resource scheduling, procedure execution, and control of subsystems such a power, thermal, propulsion, and communications.

Innovative human-autonomy modeling and analysis technologies are needed to address unique challenges of space missions. These include multi-modal interfaces, asynchronous communication with long delays and long blackouts, unanticipated problems, and rare crew interactions by exception. Human-autonomy interactions can include supervisory control, communication, and coordination in shared planning and operations. They can include interactions to adapt, modify, and maintain systems to respond to emerging requirements and challenges. The interactions can also include dynamic control and adjustment of level of autonomy or supervision, type of coordination, and type of communication.

This subtopic seeks projects that will demonstrate innovative technologies for use by engineering and operations teams for analyzing human-autonomy interactions and risks and for evaluating proposed mitigations of these risks, within the constraints of an affordable and timely mission design and planning process.

TOPIC: X6 Advanced Space Operations (ASO)

This Topic covers a range of key technology options associated with future space exploration systems and architectures that involve a variety of combinations of advanced robotic and human capabilities, ranging from remotely telesupervised robotic systems, through locally-teleoperated systems, to focused human presence (with robotic agent assistance). Technologies that enable in-space assembly, maintenance, and servicing are also included. Key objectives derive from the goals of safe/reliable, affordable, and effective future human and robotic space exploration in support of the U.S. Vision for Space Exploration. These efforts will be closely coordinated with spacecraft subsystem, system, and related R&D within the Advanced Space Platforms and Systems Topic.

X6.01 Intelligent Operations Systems
Lead Center: ARC
Participating Center(s): JSC, MSFC

The goal of this subtopic is to develop intelligent systems and technologies that could dramatically improve the affordability and productivity of long-duration human space operations, while preserving the high degree of safety and flexibility offered by state-of-the-art approaches. The current operations models used for the Space Shuttle and International Space Station, which require large ground teams continuously managing the daily operation of the spacecraft and the activities of the crew, are a major cost driver for these programs. As the human exploration campaign ventures farther into deep space, the communications time delays and longer-duration missions will require greater crew autonomy from Earth-based support. To achieve NASA's exploration goals, technologies are needed that can enable a new paradigm for human space operations.

Intelligent Planning and Execution Systems for Crew Autonomy
Greater autonomy from Earth-based support implies that crewmembers will need to manage their exploration missions holistically. This will be possible only if automation helps the crew to integrate the complex interactions among many spacecraft subsystems efficiently and to manage and prioritize human and automated activities. Intelligent systems will need to be seamlessly integrated with operational procedures so that all the information required to make key decisions is continuously updated and presented to the crew in a rapidly comprehensible fashion. Crew interfaces (e.g., displays, voice recognition, etc.) will need to be intuitive and reliable. Validated, automated systems are needed that help a spacecraft/habitat crew coordinate and prioritize plans and execute nominal/off-nominal procedures in accordance with codified mission rules and objectives. These systems should improve upon capabilities already demonstrated in human space exploration missions (e.g., Space Shuttle and International Space Station).

To evaluate proposed intelligent systems technologies, it is important to identify measurable performance objectives. Such performance measures include: (1) the speed and ease by which astronauts can plan and schedule future activities and understand the consequences of exercising various planning options; (2) the reliability, speed, and ease by which astronauts can maintain comprehensive situational awareness of a complex spacecraft/habitat without cognitive overload; (3) the reliability, speed, and ease by which astronauts can derive (on demand, or in response to detection, of an off-nominal condition) sufficiently detailed knowledge of the spacecraft/habitat, to issue commands that isolate anomalies, perform recovery procedures, and make other safety/mission-critical decisions.

Modular designs that employ open architectures and interface standards are very important to assure cost-effectiveness and flexibility of intelligent operations systems. These architectures should promote extensibility/evolvability and accommodate future system upgrades. Such designs could include standalone tools that capture and manage corporate knowledge about manned spacecraft operations.

Also of interest, though of lesser priority, are innovative technologies that can significantly enhance ground operational efficiency and performance.

Intelligent Modular Training Systems
Intelligent training systems are needed that enable flight crews to operate complex spacecraft safely and effectively, retain proficiency during long-duration missions, adapt easily to an evolving and expanding set of flight systems during the course of the exploration campaign, and achieve flight certification faster and more cost-efficiently than is possible with existing systems. Plug-and-play crew training systems that employ open architectures and interface standards are very important. These architectures should promote extensibility/evolvability and accommodate future system upgrades. The intelligent training systems should enable connectivity with models from various sources, with simulated or flight data (real-time and archived), with students and teachers at multiple locations, and with various platforms including ground-based/desktop environments and in-space, zero-g/partial-g portable or control station systems. When integrated with an operational environment, these systems must demonstrate effectiveness while ensuring that the performance of the vehicle or facility is unaffected.

Focus should be on the following applications:

- Intelligent onboard technologies for human space exploration; and
- Intelligent human space exploration mission control technologies.

Note: Related technologies of interest but covered under other SBIR subtopics include:

- X5.01 Software Engineering;
- X5.02 Human Autonomy Interaction;
- X6.03 Launch Site Technologies (Launch site command and control system technologies); and
- X8.01 Vehicle Health Management Systems.

X6.02 Space Assembly Maintenance and Servicing
Lead Center: GSFC
Participating Center(s): JSC

The goal of this subtopic is to develop technologies that enable reliable and affordable in-space assembly, maintenance, and servicing for human and robotic exploration missions in Earth orbit and beyond. Systems that enhance crew safety and mission reliability by automating these functions (whether robotically, tele-robotically, or with integrated human/robotic teams) are needed. Technologies that enable robust and reliable Earth-orbit assembly of spacecraft components (both modular and non-uniform), and thus alleviate the difficulties of launching larger, pre-integrated payloads, are of particular interest. Long-duration maintenance and servicing systems that are modular and generically applicable to a variety of orbital or transfer exploration spacecraft are also of interest.

Focus should be on the following applications:

- Earth-orbit assembly of large spacecraft systems (e.g. heat shields, propellant stages);
- Autonomous inspection of spacecraft systems using either small free-flying inspection spacecraft or attached, highly-mobile inspection robots; and
- Autonomous removal and replacement of failed spacecraft systems.

Specific technologies of interest in addressing these challenges include:

- Self-contained collision prevention/avoidance systems for robots (free-flying or attached) in close proximity to spacecraft, instruments, astronauts, etc.;
- Dexterous robotic end-effectors/manipulators for robotic assembly and maintenance, including systems that accommodate instability between robotics and target surfaces;
- Robotic non-destructive structural inspection technologies;
- Advanced robotic control systems (e.g., systems that provide active damping of robotic arms to reduce uncommanded motion, high degree-of-freedom (DOF) systems, systems that function in multiple mission en-

vironments, and systems that incorporate intuitive man-machine interfaces and/or virtual reality simulation);

- Robotic tele-operation control systems that accommodate latency and enable "real time" robotic operations;
- Vision systems for both autonomous and tele-robotic operations, including systems that demonstrate: autonomous and rapid object recognition, affordable zoom/focus lens control, robust spatial perception of working environments, ability to operate under various lighting conditions, economical video compression and 3-D mapping techniques, and low power autonomous visual inspection systems;
- Robotically operable structural/precision interface attachment systems;
- Modeling of contact dynamics in zero gravity for capture and manipulation;
- Test beds to validate robotic systems, including 6-DOF simulated weightless testing; and
- Orbital mechanics optimization of libration point rendezvous for assembly and servicing.

Note: Related technologies of interest but covered under other SBIR subtopics include:

- Robot-mounted sensors for on-orbit assembly/construction (X1.03 Sensing and Imaging), and
- Plug-and-play avionics and attachment technologies for autonomous rendezvous and docking (X8.02 Intelligent Modular Systems).

X6.03 Launch Site Technologies
Lead Center: KSC
Participating Center(s): GSFC, MSFC

The purpose of this subtopic is to develop technologies and concepts that will improve launch processing safety through the use of automated systems with limited human contact; make launch operations more cost- and time-efficient through standardization, commonality, and interoperability of launch systems and spaceport infrastructure; and improve the flexibility and adaptability of spaceport infrastructure in order to accommodate multiple vehicle types and diverse missions. 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. Additionally, advanced launch operations technologies and concepts that may significantly improve launch vehicle specific energy or otherwise improve launch performance, affordability, and sustainability for space exploration missions are of interest. Topic areas that will be emphasized for improvements in launch site operations include:

- Propellant handling systems: autonomous propellant loading; automated umbilicals; improved control of cryogenic mass loss; hazardous leak and flame detection; and improved cryogenic cooling, insulation, and sealing technologies;
- Common integrated command and control system technologies for launch site operations: ground integrated health management systems, work control, configuration management, and other support systems;
- Test equipment: universal avionics test equipment and automated and wireless built-in test equipment that reports launch vehicle and/or payload status;
- Launch acoustic modeling and mitigation systems; and
- Payload and launch vehicle systems handling equipment.

Modular designs that employ open architectures and interface standards are very important to assure cost-effectiveness and flexibility of launch site technologies. These architectures should promote extensibility/evolvability and accommodate future system upgrades. Topic areas related to advanced launch operations technologies and concepts include:

- Horizontal launch assist ground systems, including systems that preclude the need for vehicle take-off gear. Specific technology areas of interest include: vehicle acceleration mechanisms, vehicle structural support or

levitation systems, control and stabilization systems, separation mechanisms, runway or track stability and maintenance systems, and energy storage and delivery systems; and
- Other novel launch operations technologies and concepts.

Focus should be on the following applications:

- Earth-based launch site systems for human and robotic space exploration missions.

Note: Related technologies of interest but covered under other SBIR subtopics include:

- X6.01 Intelligent Operations Systems.

TOPIC: X7 High Energy Space Systems (HESS)

This Topic covers a range of key technology options associated with future space exploration systems and architectures that are 'energy rich'—including high power space systems, highly efficient and reliable space propulsion systems, and the storage, management, and transfer of energy/propellants in space. It also addresses high-energy maneuvering including aero-entry, aero-braking, and other aero-assist related R&D. The affordable deployment of systems and logistics beyond low Earth orbit will depend on high-power space transportation. In addition, a broad range of future systems and technologies will be constrained or enabled by the availability (or lack) of significant power at an affordable cost.

X7.01 Chemical Propulsion Systems and Modeling
Lead Center: MSFC
Participating Center(s): DFRC, GRC

The goal of this subtopic is to develop innovative chemical propulsion systems and system concepts as well as modeling tools and capabilities that support chemical propulsion system design and analysis. Applications of interest include earth-to-orbit and in-space transportation, with a particular focus on versatile, multi-use in-space cryogenic engines with exceptionally high reliability, space-based reusability (i.e. capability for many restarts with little to no maintenance), and deep-throttling capability. These are needed for all phases of exploration missions, including trans-lunar injection, decent to the lunar surface, ascent to lunar orbit, and return to Earth. Also of interest are safe and affordable earth-to-orbit systems that enable high overall vehicle payload mass-to-liftoff mass ratios, with improvements in thrust-to-engine weight ratio, trajectory-averaged specific impulse, and overall reliability.

Specific areas of interest for technology advancement and innovations include:

- Propulsion system design concepts that address LOX/LH_2, as well as LOX/CH_4 and other LOX/Hydrocarbon engine and main propulsion systems integration issues;
- Integrated chemical propulsion system concepts that integrate primary propulsion and reaction control system elements;
- Design and analysis tools that significantly enhance the overall systems engineering evaluation of advanced chemical propulsion system concepts. These include tools for sensitivity analysis, quantification of system benefits to changes, propulsion system operability, "bottoms up" weight estimating, cost estimating, and reliability prediction for propulsion systems;
- Manufacturing techniques that allow for significant reduction in the cost and schedule required to fabricate engine and main propulsion system components. These techniques can use current or emerging processes and manufacturing technologies to develop engine and main propulsion system components that will reduce complexity, increase reliability, and that are easier to assemble, install, and test when integrated onto the vehicle;

- Concepts for solid or hybrid rockets that increase mass fraction, decrease the need for thermal insulation, and reduce or eliminate the need for staging; and
- High-performance advanced propellants (as indicated by high specific impulse and high specific impulse density) and non-toxic propellants that can significantly improve safety and cost of propulsion systems operations.

Note: Related technologies of interest but covered under other SBIR subtopics include:

- X7.02 Chemical Propulsion Components
- X8.01 Vehicle Health Management Systems

X7.02 Chemical Propulsion Components
Lead Center: MSFC
Participating Center(s): GRC, JSC

The goal of this subtopic is to develop innovative chemical propulsion component technologies that improve the safety, operability, reliability, and performance of propulsion systems required for human and robotic exploration missions. Components should be applicable to earth-to-orbit or long-duration in-space transportation systems (both primary propulsion and reaction control systems) for a variety of exploration mission phases, including trans-lunar injection, decent to the lunar surface, ascent to lunar orbit, and return to Earth.

System masses will be critical in these far-reaching missions, dictating the use of lightweight components and the use of propellants harvested or manufactured on the surface of the Moon, Mars, or other destinations—an approach known as *in situ* resource utilization (ISRU). Candidate ISRU propellants include hydrogen, oxygen, carbon monoxide, carbon dioxide, methane, various other hydrocarbons, and compounds derived from these materials.

In some scenarios, one propellant may be manufactured *in situ* while its oxidizer or fuel is brought from Earth. Because the use of ISRU propellants represents a departure from the state-of-the-art and from the existing base of engines and technologies, a new suite of propulsion system and component technologies will be required.

These new in-space propulsion systems are expected to encounter conventional challenges such as regulator leakage, valve leakage, valve heating (on pulsing engines), solubility effects (such as combustion instabilities caused by gas bubble evolution in liquid propellants), and propellant acquisition (i.e., extracting gas-free propellant from the tank and delivering it to the engine). In-space chemical propulsion systems that incorporate long-term use of cryogenic propellants such as hydrogen, methane and oxygen present new challenges, including efficient, reliable, and durable propellant cryocooling, storage, acquisition (from tanks), transfer (through feed lines), gauging and flow measurement; however, these particular challenges are addressed by a separate sub-topic, X3.03 Cryo and Thermal Management.

Chemical propulsion component technologies that demonstrate improved capabilities using a variety of propellant combinations are of interest, including:

- Advanced turbopumps with wider throttle range and improved cavitation control, plus specific turbomachinery components such as bearings, turbines, and impellers that demonstrate greater reliability and lifetime;
- Injectors with low thermal mass and long-duration reliability (e.g. for high duty-cycle attitude control thrusters);
- Long-life combustion chambers (e.g., based on use of advanced materials);
- Innovative thruster valve designs that tolerate high thermal loading due to heat soak-back during pulse mode operation;
- Innovative concepts for fast acting valves to enable use of larger thrusters for small impulses (i.e. spacecraft fine pointing);

- Highly-reliable long-duration seals;
- Long-life, high-reliability ignition systems;
- Lightweight, highly reliable gas compressors for pumping gaseous propellant into pressure vessels either in-flight or on a terrestrial surface;
- Novel pressurization approaches that minimize dissolution of pressurant gas in storable propellants (e.g., nitrogen tetroxide, hydrazine, and hydrazine derivatives)
- Novel concepts that increase performance or decrease mass of pressurization systems;
- Development of advanced materials that exhibit high compatibility with gaseous oxygen;
- Propulsion components based on microelectromechanical systems (MEMS) technology;
- Advanced nozzle concepts for in-space propulsion systems;
- Reaction control system thrusters that burn *in situ* and non-toxic propellants;
- Innovative thruster designs that minimize or prevent high heat soak-back during pulse mode operation;
- Highly reliable, lightweight compressors for use in gaseous propellant storage and distribution systems;
- Advanced lightweight multi-use positive expulsion devices for storable propulsion systems; and
- Other innovative chemical propulsion system components that improve system safety, affordability, or effectiveness.

Note: Related technologies of interest but covered under other SBIR subtopics include:

- X3.03 Cryo and Thermal Management
- X7.01 Chemical Propulsion Systems and Modeling
- X8.01 Vehicle Health Management Systems

X7.03 High-Power Electric Propulsion
Lead Center: GRC
Participating Center(s): JPL, JSC

The goal of this subtopic is to develop innovations in high-power (100 kW to MW-class) electric propulsion systems. High-power (high-thrust) electric propulsion may enable dramatic mass and cost savings for lunar and Mars cargo missions, including Earth escape and near-Earth space maneuvers. At very high power levels, electric propulsion may enable piloted exploration missions as well. Improved performance of propulsion systems that are integrated with associated power and thermal management systems and that exhibit minimal adverse spacecraft-thruster interaction effects are of interest. Innovations are sought that increase system efficiency, increase system and/or component life, increase system and/or component durability, reduce system and/or component mass, reduce system complexity, reduce development issues, or provide other definable benefits. Desired specific impulses range from a value of 2000 s for Earth-orbit transfers to over 6000 s for planetary missions. System efficiencies in excess of 50% and system lifetimes of at least 5 years are desired. Specific technologies of interest in addressing these challenges include:

- Long-life, high-current cathodes (100,000 hours);
- Electric propulsion designs employing fuels that are more readily available (whether from Earth or *in situ* space resources) and easy to store/handle;
- Electrode thermal management technologies;
- Innovative plasma neutralization concepts;
- Metal propellant management systems and components;
- Cathodes for metal propellants;
- Low-mass, high-efficiency power electronics for RF and DC discharges;
- Lightweight, low-cost, high-efficiency power processing units;
- Low-voltage, high-temperature wire for electromagnets;
- High-temperature permanent magnets and/or electromagnets;
- Application of advanced materials for electrodes and wiring;

- Highly accurate propellant control devices/schemes;
- Miniature propellant flow meters;
- Lightweight, long-life storage systems for krypton and/or hydrogen;
- Fast-acting, very long-life valves and switches for pulsed inductive thrusters;
- Superconducting magnets;
- Lightweight thrust vector control for high-power thrusters; and
- High fidelity methods of determining the thrust of ion, Hall, and advanced plasma engines without using conventional thrust-stands.

Note: Related technologies of interest but covered under other SBIR subtopics include:

- Low- to medium-power solar electric propulsion for planetary science missions (S8.04 Spacecraft Propulsion).

X7.04 Aeroassist Systems
Lead Center: JSC
Participating Center(s): ARC, DFRC, LaRC

The goal of this subtopic is to develop innovative human-rated aeroassist systems for missions including lunar return to Earth and precursor missions for human Mars exploration. Systems are needed to support the following flight regimes: aerocapture, entry interface to subsonic speeds, and Mach 5 to subsonic speeds. Systems must be capable of controlled flight and be compatible with pinpoint, soft landing systems, which achieve landing accuracies of 10s of meters at touchdown or powered descent initiation. These systems must be compatible with launch vehicles and transit vehicles and capable of safely discarding unneeded and constraining hardware on landing and providing surface access. Technology needs include aeroassist system design, Thermal Protection System (TPS) designs, modeling capabilities, sensor systems, and navigation technologies that support reliable aerocapture or aerobraking of multi-metric-ton-class piloted or cargo spacecraft. In particular, this subtopic seeks innovations in the following areas:

- Innovative aeroassist system designs. This includes low-mass, rigid aeroassist systems based on robust, high-temperature structures and adhesives, modular or deployable/inflatable aeroshells with large surface area, and inflatable ballutes;
- TPS designs for human-rated aeroassist vehicles returning to Earth from the Moon and Mars, and for Mars aerocapture and Entry, Descent and Landing (EDL). Innovative TPS concepts are solicited to reduce current TPS mass fractions by 25% to 50% and to reduce TPS costs;
- Ablative and reusable TPS materials and concepts that significantly enhance performance and reduce mass. This includes development and characterization of single- and multi-use TPS materials, TPS for rigid aeroshells, and flexible TPS materials for deployable aeroshells. Thermo-chemical and mechanical properties data for probabilistic design, spallation characteristics, and accurate simulation tools to predict material behaviors and material compatibility are required. Innovative TPS concepts are solicited to reduce current TPS mass fractions by 25% to 50% and to reduce TPS costs;
- Aerothermodynamic modeling tools with greater accuracy and less uncertainty: (1) Innovative and accurate computer modeling of fluid structure interactions, including flow stability and surface deflections under dynamic conditions for decelerator deployment and inflation; (2) Modeling and simulation of convection/radiation/ablation coupled three-dimensional flow fields, for both optically thick and thin shock layers and highly ionized flows; (3) Accurate prediction of wake heating including radiative heating components; (4) Accurate prediction of single and multiple rocket plume effects (e.g., reaction control system thrusters) on the vehicle aerodynamics and heating;
- Innovative sensor systems which are capable of providing real-time or near real-time updates to atmospheric pressure, temperature, density, and winds to support the guidance systems used on aeroassist vehicles;

- Innovative sensor systems for inflatable aeroassist vehicles capable of providing real time aerosurface temperature, strain, deflection, flight loads and other significant parameters; and
- Lightweight flexible materials that will reduce the mass and increase the strength and thermal characteristics for applications to deployable aeroshells and supersonic deployed decelerators.

Focus should be on aeroassist systems applied to the following mission classes:

- Earth return of piloted spacecraft from the Moon. Return-to-Earth scenarios for human lunar missions include: (1) short-range direct entry and landing; (2) extended-range entry using a skip out of the atmosphere with subsequent EDL to the Earth's surface; and (3) aerocapture into a low-energy Earth orbit followed by EDL. Inertial arrival speeds of approximately 11 km/s (up to 12 km/s for some abort scenarios) with entry masses of at least 5 metric tons are expected for normal lunar return. Acceptable sustained loads for these piloted missions are limited to about 5 gs perpendicular to the human spine in the "eye balls in" direction; and
- Mars precursor missions for human exploration. These include robotic missions designed to deliver pre-deployed cargo or to conduct technology demonstrations in anticipation of follow-on human Mars missions. Candidate human mission scenarios for Mars include human and cargo aerocapture into a Mars orbit followed by EDL to the Mars surface and return to Earth. Mars aerocapture missions are expected to have arrival speeds of 6 to 8 km/s and aerocapture mass on the order of many 10s of metric tons. Return-to-Earth scenarios for human Mars missions are similar to those for lunar missions, except for higher arrival speeds (11.5 - 12.5 km/s, up to 14 km/s for some off-nominal scenarios).

Note: Related technologies of interest but covered under other SBIR subtopics include:

- Inflatable and other innovative structures (X2.02 Structures and Habitats); and
- Aeroassist systems for deep space robotic science missions (S5.01 Low Thrust and Propellantless Propulsion Technologies).

TOPIC: X8 Advanced Space Platforms and Systems

This Topic covers a range of key technology options associated with future space exploration systems and architectures that are resilient, reliable, and reconfigurable through the use of miniaturization, modularization of key functions in novel systems approaches. Platforms technologies that support self-assembly and in-space assembly, as well as in-space maintenance and servicing, are included. These efforts are coordinated with in-space assembly and related R&D within the Advanced Space Operations Topic (e.g., involving extra-vehicular activity (EVA) systems, robotics, etc.).

X8.01 Vehicle Health Management Systems
Lead Center: ARC
Participating Center(s): MSFC, JSC, SSC

In order to meet the automation and autonomy requirements of the Vision for Space Exploration, innovative health management technologies are required throughout the system lifecycle including design, development, test, validation, integration, operation, maintenance, and disposition. Traditional means of supporting vehicle health such as invasive inspections are extremely limited in their utility for exploration missions. Other solutions such as ground-based monitoring of telemetry data become less useful as communication delays or bottlenecks increase. 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.

Another significant concern is in mission operations. Operations models that require large numbers of ground controllers and other mission support staff will be cost prohibitive in the future. Future systems must provide appropriate levels of safety and mission success factors while reducing support staff on the ground. In addition, future space missions will have to maintain a healthy balance and seamless transition between crewed and robotic operations.

Proposals should be responsive to the overall goals and objectives of the Exploration System-of-Systems as defined in Project Constellation requirements. 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 propulsion, structures, thermal protection systems, power, avionics, life support, and communications. Proposals that involve the use of existing NASA health management test beds (power, propulsion, systems integration, life support, diagnostics, networking, etc.) for technology validation are encouraged.

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

- Methods and tools to enable concurrent design of system function and health management 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;
- Health monitoring and management technologies to enable situational awareness of system health, safety, and margins. Solutions may include novel approaches to fault detection and isolation, diagnostics, and mitigation of system degradations and failures. Solutions may also include innovative health management system architectures that are robust to single point failures and are scalable, modular, and expandable without costly redesigns;
- Methods for robust control of critical components, subsystems, and systems and robust execution of critical sequences during flight. Of special interest are robust recovery methods and innovative approaches to functional redundancy for the purpose of enhancing safety, availability, and maintainability;
- System-of-systems health management concepts to provide robust cooperation of multiple Exploration elements, e.g., spacecraft constellations or rendezvous and docking operations;
- Prognostic techniques able to anticipate system degradation and enable further improvements in mission success probability, operational effectiveness, human-machine teaming, and automated recovery of function;
- Real-time data analysis methods for structural sensing, including detection, localization, damage assessment, and automated assessment of thermal protection system integrity;
- Crew-automation interfaces that are capable of reporting quantitative/qualitative sensor readings, assessing system status, explaining current conditions, predicting likely system behaviors, and proposing corrective actions in a manner that does not exceed the capacity of human understanding, especially in high-risk situations requiring rapid human response. Innovative ways for the health management system to convey a wealth of information quickly and effectively are desired; and
- End-to-end health management system architectures that are integrated with and validated on spacecraft subsystems on ground-based (or virtual) test beds.

X8.02 Intelligent Modular Systems
Lead Center: MSFC
Participating Center(s): JSC, GSFC

This subtopic will involve development and demonstration of a range of technologies for reconfigurable, intelligent, modular space subsystems, systems, and systems of systems. Technologies should focus on establishing the validity of new approaches to Earth-Moon human and robotic operations, with a view toward longer-term applications for the inner Solar System (e.g., Mars) exploration missions. Many of these future missions, systems, and capabilities imply the need for the development of large and complex systems and infrastructures in space. But, the size-constraints, mass-capability, and cost of launching large monolithic payloads into space limit the development and realization of these capabilities. If a different design approach using intelligent modular systems rather than monolithic payloads is used, these large space systems become more tractable. Also, intelligent modular systems include low system impact of a single launch vehicle loss, since modular systems are launched on multiple vehicles at multiple times. Replacement of modules over the system lifetime is, in many cases, a more reasonable approach to maintaining a system; and, graceful degradation of the system capability can be more readily managed with modular units. Hardware costs of multiple identical units can be reduced through economies of scale, and modular approaches can accommodate cost-phased programs that develop and fly a “pilot” system, which can initially prove a capability, and then be added to later as demand for capability increases. Technologies of interest include:

Modular Structures (MSFC)
Structural technologies of interest include inflatable, erectable, deployable, or easily connected modules to create large space structures. Assembly technology of interest may include approaches for integrating deployable modular units with larger structures such as habitation modules or propellant tanks, and approaches for assembly of erectable modules that form backbones or support trusses. Attachment technologies such as autonomous rendezvous and docking, innovative connectors and joining, bonding techniques, and module positioning and alignment systems are also of interest.

Adaptable and Reconfigurable Modular Systems (GSFC)
Integrated, reconfigurable modular systems incorporating multiple elements such as solar collection arrays, radiators, power, data, utility lines, science instruments, plug and play avionics, and integrated inspection and verification techniques are solicited, including modular structures using embedded sensors and actuators.

Human-Robotic Modular Systems (JSC)
Multi-functional robotic hardware and software systems are of interest to aide in surface and in-space operations. Robotic surface operations including exploration, assembly, fabrication, construction and transportation operations are of interest as well as similar systems for in-space operations. In addition, techniques are solicited for effective, efficient, and intuitive operation and control of robotic hardware through design and development of advanced human-computer interfaces.

TOPIC: X9 Lunar and Planetary Surface Operations

This Topic covers a range of key technology options associated with future lunar and planetary surface exploration and operations for a range of increasingly-ambitious human and robotic mission options through the development of *in situ* resource utilization technologies, highly-capable surface mobility systems, and various supporting infrastructures. Key objectives are derived from the goals of safe/reliable, affordable and effective future human and robotic lunar and planetary surface exploration in support of the U.S. Vision for Space Exploration.

X9.01 *In Situ* Resource Utilization and Space Manufacturing
Lead Center: JSC
Participating Center(s): MSFC, GRC, KSC

The goals of using resources that are available at the site of exploration and pursuing the philosophy of "living off the land” instead of bringing it all the way from Earth are to achieve a reduction in launch and delivered mass for exploration missions, a reduction in mission risk and cost, enable new missions not possible without *in situ* resource utilization (ISRU), and to expanded the human presence in space. Past studies have shown making propellants and other mission critical consumables (life support and power) *in situ* can significantly reduce mission mass and cost, and also enable new mission concepts (e.g., surface hoppers). Experience with the Mir and International Space Station, and the recent grounding of the Shuttle fleet, have highlighted the need for backup caches or independent life support consumable production capabilities, and a different paradigm for repair of failed hardware from the traditional orbital replacement unit (ORU) spares and replacement approach for future long duration missions. Lastly, for future astronauts to safely stay on the Moon or Mars for extended periods of time, surface construction and utility/infrastructure growth capabilities for items such as radiation protection, power generation, habitation space, and surface mobility will be required or the cost and risk of these missions will be prohibitive. However, before ISRU capabilities are incorporated into mission architectures, Earth and flight demonstrations of critical processes and systems will be required to validate performance goals and increase confidence in mission planners.

Proposals for ISRU are requested in four subtopic areas: *in situ* Resource Extraction and Separation, *in situ* Resource Processing and Refining, Surface Manufacturing, and Surface Construction. Areas of interest for each of these four subtopic areas are defined below. Acceptable proposals can either address a single subtopic or can include concepts that encompass more then one subtopic into an integrated system. ISRU technologies or processes proposed for this subtopic must be shown to be beneficial compared to bringing everything from Earth. Proposals must also demonstrate an understanding of any past work, competing processes, and the current state-of-the-art with respect to the technology or process being proposed. To distinguish work supported under this subtopic from related work not using *in situ* resources, successful proposal must show some understanding of the native resource properties and the environmental conditions involved in their use. Proposals that can support future flight demonstrations of ISRU that are scalable to human mission requirements are encouraged, and point of departure mission information is provided below to help provide size and rate parameters for technologies and processes of interest. Proposals that support lunar ISRU applications or both lunar and Mars ISRU applications may be weighted higher then proposals that solely support Mars ISRU applications.

***In Situ* Resource Extraction and Separation**

In situ Resource Extraction and Separation capabilities include resource characterization, prospecting, excavation, and delivery to resource processing units, and simple extraction and separation of desired resources from the bulk resource (including atmospheres). To be successfully implemented, *in situ* Resource Extraction and Separation proposals must minimize the mass which must be brought from the Earth, including the mass of the required power system and Earth-supplied processing consumables, and produce 100s of times their own mass of extracted resource in their useful lifetimes. These processes may also be required to operate in extreme temperature and abrasive environments, and in micro-g (asteroids, comets, Mars moons, etc.) or partial-g (e.g., Moon and Mars). In addition, the maintenance, human supervision, crew operation, and crew training required for process operation must be minimal and affordable. Specific areas of interest include:

- Technologies, processes, and systems for robotic precursor and early human missions to the Moon in the areas of resource characterization, excavation and extraction of lunar resources (especially in the polar regions), and performing initial resource separation and collection of water, regolith volatiles, or feedstock for Surface Manufacturing, Surface Construction, or *in situ* Resource Processing;
- Technologies, processes, and systems for robotic precursor missions to Mars in the areas of resource characterization, excavation and extraction of Mars resources, and performing initial resource separation and collection of atmospheric gases, regolith water/volatiles, or feedstock for *in situ* Resource Processing; and
- Evaluation of granular physics in low gravity and development of models and its effect on material excavation and handling; and developing dust-insensitive excavation hardware, actuators, and bearings particularly for lunar resource extraction.

***In Situ* Resource Processing and Refining**

The purpose of this subtopic is to identify and experimentally validate single and multi-step *in situ* Resource Processing and Refining units that have the potential for achieving the goals for ISRU stated previously. Such processes may include thermal, chemical, and electrical processing of extracted resources into useful products. *In situ* Processing and Refining includes efficient and economical production of propellants, fuel cell reagents, life support gases and water, manufacturing feedstock (such as silicon, aluminum, iron, and polymers) for use in Surface Manufacturing, and construction feedstock (concrete, wires, trusses, etc.) for use in Surface Construction from resources that have been extracted and separated using processes defined and developed under *in situ* Resource Excavation and Separation. To be successfully implemented, *in situ* Resource Processing and Refining proposals must minimize the mass which must be brought from the Earth, including the mass of the required power system and Earth-supplied processing consumables, and produce 100s to 1000s of times their own mass of product in their useful lifetimes. These processes may also be required to operate in extreme temperature and abrasive environments, and micro-g or partial-gravity. In addition, the maintenance, human supervision, crew operation, and crew training required for process operation must be minimal and affordable. Process evaluation metrics include: mass of product made per hour, final mass of product per mass of processor, Watts per mass of product produced per hour, percentage conversion of resources into product in single pass, and mass of Earth consumables used per mass of *in situ* product made. Specific areas of interest include:

- Technologies, processes, and systems for robotic precursor and early human missions to the Moon in the areas of processing of lunar resources into oxygen, propellants, and feedstock for *in situ* manufacturing or surface construction;
- Technologies, processes, and systems for robotic precursor missions or eventual human missions to Mars, which produce mission critical consumables, such as oxygen, propellants, life support gases, fuel cell reagents, and *in situ* manufacturing feedstock. Robotic and human missions to Mars that consider initial or evolutionary use of ISRU consumables currently assume the use of liquid oxygen and hydrocarbon fuel (methane, propane, methanol, ethanol, or low freezing point mixtures) propellants for propulsion systems and mobile fuel cell power systems; and
- Developing and evaluating seals for high temperature multi-temperature and operation cycle regolith processors, water electrolysis and carbon dioxide electrolysis units; developing and evaluating low gas loss regolith inlet and outlet units (seals, augers, hoppers) for regolith processing; and developing and evaluating 0-g water separation, and separation of nitrogen from carbon dioxide are of particular interest for lunar and Mars resource processing.

Surface Manufacturing w/*In Situ* Materials
The purpose of the Surface Manufacturing element of the ISRU subtopic is to identify and experimentally validate capabilities that include production of sub-element and replacement components, assembly of complex products, and manufacturing support equipment to ensure parts/products manufactured meet required dimensions and specifications. Surface Manufacturing can use either *in situ* or Earth-supplied feedstock, however the long-term goal is to exclusively use *in situ* processed feedstock. Therefore, minimum requirements for process feedstock are advantageous to prevent excessive feedstock processing requirements (i.e., raw aluminum metal vs. specific aluminum alloy characteristics). For *in situ* manufacturing to be beneficial compared to bringing everything from Earth, some or all of the following attributes are required: ability to create wide variety of shapes and sizes, ability to utilize multiple feedstocks (plastic, metal, and ceramics), produce greater than its own mass of product and the mass of potential Earth supplied spares, operate in partial-g environments, and require a minimum of maintenance, human supervision, crew operation, and crew training. Specific areas of interest include:

- Additive Manufacturing Techniques;
- Subtractive Manufacturing Techniques;
- Formative Manufacturing Techniques; and
- Part Assembly/Integration.

Manufacturing Support Processes
Proposals that demonstrate manufacturing flexibility capabilities, such as part size, part complexity, and material feedstock for manufacturing while recognizing the mass, volume, and power limitations of future space habitats and delivery systems are highly encouraged.

Surface Construction w/*In Situ* Materials
The purpose of this subtopic is to identify and experimentally validate surface construction techniques that can be applied on the Moon and Mars for future human exploration missions. Early construction capabilities in the form of site preparation and shielding for lander plume debris, meteorites, and solar/galactic radiation can significantly reduce hardware and crew health concerns for missions exceeding several days and returning to the same site of exploration. Also, the ability to construct hardware bunkers, habitats, and power generation, management, and distribution capabilities is essential for mass efficient infrastructure growth on the Moon and Mars. These processes

may also be required to operate in extreme temperature and abrasive environments, and micro-g or partial-gravity. Specific areas of interest include:

- Construction techniques for robotic precursor and early human missions that support site planning and preparation and the use, manipulation, and placement of raw materials and expected feedstock materials from *in situ* Resource Processing and Refining for lander plume debris, meteorites, and solar/galactic radiation shielding;
- Construction techniques for robotic precursor and early human missions that support bunker and habitat structure construction using and manipulating raw and expected feedstock;
- Construction techniques that can be demonstrated on robotic precursor missions that demonstrate dust mitigation concepts for surface mobility around landing pads, habitats, dust-sensitive instruments, and airlocks; and
- Lunar *in situ* fabrication techniques that can be demonstrated on robotic precursor missions that enable growth in solar power generation, storage, management, and distribution capabilities using raw materials, expected feedstock. Demonstrations can initially assume use of Earth supplied consumables in small amounts.

Point of Departure Mission Information for Proposals
For processing concepts that can be used on robotic precursor missions, payload masses (including rovers) are typically below 300 kilograms (kg). Robotic precursor concepts must demonstrate critical functions and must be scalable to human mission needs. Excavation and separation proposals must show supportability to future resource processing needs.

Excavation, separation, and processing needs for lunar missions depend on the resource of interest, location, and concentration of the resource and the processing technology considered. Mars sample return missions that incorporate *in situ* propellant production require atmospheric carbon dioxide collection and possibly atmospheric or regolith water extraction to support the production of 300 kg to 2000 kg of propellant depending on the size of the sample and whether the mission is a Mars orbit rendezvous or direct Earth return mission. Breathing rates for astronauts are approximately 0.07 kg of oxygen (O_2)/person/hour in habitats and 0.1 kg O_2/person/hour for Extra-Vehicular Activities (EVAs). Early human lunar mission surface durations may vary from 3 to 45 days and can include from 2 to 6 crewmembers. Lunar human landers require approximately 5000 to 8000 kg of propellant for ascent and approximately 15,000 to 25,000 kg for landing and ascent combined. Mars mission surface durations are 30 to 90 days for opposition class missions and 450 to 600 days for conjunction class missions. Mars human ascent vehicles typically require 20,000 to 30,000 kg of propellant. Fuel cell reagent consumption rates depend on the power required for the application, the reagents, and the fuel cell technology used. EVA suits and small rovers can require 500W to 1 KW of power/hour, unpressurized rovers can require 3 to 6 KW of power/hour and pressurized rovers can require 10 KW/hour and above.

X9.02 Surface Mobility/Mechanisms
Lead Center: JPL
Participating Center(s): GRC, JSC

This subtopic seeks innovative mobility and mechanisms technologies for robotic systems, crew vehicles, and cargo systems for robotic lunar and Mars missions.

Precursor Mobility Systems
Precursor mobility systems address development of hardware and software mobility technologies for precursor lunar missions that also support missions to Mars. Topics include enabling technologies for modular robotic systems, alternative mobility systems, and the development of software to autonomously control and integrate mobility technologies. Mechanisms include traditional wheel motor and harmonic drives, distributed mechanical drives, traction drives, tracked drives, and walking mechanisms.

Proposals may also focus on surface systems for autonomous robotic outposts. Emphasis is placed on the ability to test, verify, and validate such system prototypes in representative laboratory and field environments. The applicable technologies and design concepts span the full range of surface mobility including high dexterity robotic scouts, long-range navigation on the lunar surface, and robotic systems for structural construction, inspection and repair.

This year, emphasis is placed on: 1) modular robotic systems and subsystems (mechanical and electrical), 2) assembly and control of modular systems, and 3) alternative mobility systems such as inflatable systems or tracked vehicles, and walking systems.

Crew Mobility Systems
We will also consider highly innovative mobility technology in specific support of crew and cargo vehicles. Proposals addressing this area should focus on space-relevant hardware, mobility options, crew transports over rough terrain, and logistical issues such as ingress/egress and loading/unloading.

TOPIC: X10 Prometheus Technologies

The primary goal of the Prometheus Nuclear Systems and Technology (PNS&T) Theme is to mature technology and develop systems to overcome current limitations of space power and propulsion in support of the Vision for Space Exploration. Developing and demonstrating safe and reliable nuclear fission-based spacecraft power and propulsion systems will enable human and robotic exploration, enhance scientific capabilities, and facilitate unprecedented levels of exploration and scientific return. Potential benefits of space nuclear power include very high total energy and total power capability, and high delta-V nuclear-electric propulsion that can enable a wide range of solar system exploration missions not possible today. To meet the goals of the Vision for Space Exploration, new exploration missions would have requirements exceeding what current power and propulsion systems can provide, particularly for surface and outer planet applications. Prometheus nuclear systems can provide a viable, enabling, alternative for those missions that have no other practical solution. The PNS&T Theme is comprised of two programs – the Nuclear Flight Systems program and the Advanced Systems and Technology program. The Nuclear Flight Systems program is focused on developing the first Prometheus demonstration of nuclear fission power in space, including development of nuclear reactor power, electric propulsion and other associated spacecraft systems. The Advanced Systems and Technology program is focused on conducting research and development of advanced systems and technologies beyond those needed for the first demonstration mission including research for advanced power and propulsion systems, materials development, integrated spacecraft systems, and other capabilities. This advanced technology development will be necessary to support NASA's goal of more distant, more ambitious, and longer duration human and robotic exploration of Mars and other destinations. Five key program research areas include advanced nuclear electric propulsion, advanced fission-based power systems, advanced nuclear propulsion systems, advanced nuclear vehicle and spacecraft systems, and long-range nuclear reactor systems technology development. The five PNS&T subtopics are focused on these Advanced Systems and Technology program areas.

X10.01 Long-Life Validation and Flight Qualification of Nuclear Space Systems Hardware Prior to Flight Use
Lead Center: MSFC
Participating Center(s): GRC

Nuclear space systems are expected to be an integral part of the national Vision for Space Exploration. Nuclear electric power would allow human and robotic exploration to reach beyond the constraints of solar power systems and is expected to be crucial for long-duration habitation and exploration of the Moon and Mars. Nuclear propulsion systems offer the potential for significantly higher specific impulse and/or significantly higher delta-V than chemical engines, reducing the amount of propellant and associated costs needed to perform a given mission. Nuclear thermal propulsion (NTP) systems up to several hundred megawatts and nuclear electric propulsion (NEP) systems from 30 kW to hundreds of kilowatts and more, are being considered for the economical delivery of lunar and Mars cargo, rapid crew transit to Mars, and, in the case of nuclear electric propulsion, robotic exploration of the solar system and beyond. However, the long-duration performance and life testing of these high power nuclear space systems can be very expensive and poses several unique and significant challenges. The intent of this solicitation is to elicit new or significantly improved approaches that accelerate or simplify the long-life validation and flight qualification of high power nuclear space systems hardware.

While the testing of nuclear reactors is clearly beyond the scope of this solicitation, proposals are invited for innovative methods that simplify, accelerate, reduce the cost, or otherwise improve upon current techniques to ground test and validate the life and performance of non-reactor high power space nuclear power and propulsion components, subsystems, and systems. Also invited are proposals that address new and innovative approaches to seamlessly integrate high power space nuclear power and propulsion hardware elements into complete systems of systems, with corresponding methods for flight qualification prior to flight use.

Sample high power space nuclear power and propulsion areas that could benefit from accelerated or simplified performance and life validation include, but are not limited to: electric power conversion systems for in-space or planetary surface power; electric power management and distribution systems; accelerated testing of pulsed or steady-state high power electric thrusters or thruster arrays under appropriate vacuum and thermal conditions; performance and life testing of component materials and structures under simulated NTP hot hydrogen flows; the simulated operation, shut-down, and restart of NTP system components over simulated mission profiles in relevant vacuum, thermal, and radiation test environments; other space nuclear power and propulsion hardware elements that must operate in extreme environments over extended mission durations; and simplified or accelerated techniques for hardware integration and flight qualification of a complete system of systems prior to flight use. Proposed methods should substantially and demonstrably reduce the time and expense to validate the life and performance of space nuclear power and propulsion technologies compared to state of the art techniques.

X10.02 Critical Technologies for In-Space Application of Nuclear Thermal Propulsion
Lead Center: GRC
Participating Center(s): MSFC, SSC

NASA is interested in the development of critical technologies for first in-space applications of solid core nuclear thermal propulsion (NTP) systems for use in a variety of future exploration missions. For short, round trip, human missions to Mars, NTP systems may be enabling. It can potentially also help reduce launch mass or increase payload delivery for cargo and crewed missions to the Moon and other destinations. The first anticipated in-space application of solid core NTP systems could occur in the time frame of 2025 to 2030 and could be based on a high-thrust/high-Isp (~850 – 950s) NTP system that uses a fission reactor with U-235 fuel as its source of thermal energy. During the short primary propulsion maneuvers of a typical conceptual mission, large quantities of thermal power (100s of MWt) would be produced within the NTP system and removed using LH_2 propellant that is pumped through the engine’s reactor core. The superheated hydrogen gas is then exhausted out the engine’s nozzle to generate thrust. Recent NASA studies have shown that small engines (~15-25 klbf), used individually or in clusters, could support a broad range of mission types. Representative ranges of engine performance include: 1) hydrogen exhaust temperatures ~2500-2900 K; 2) propellant flow rates ~7-13 kg/s; 3) chamber pressures ~500 –1500 psi ; and 4) nozzle expansion area ratio ~200:1-500:1.

Proposals are sought to further improve safety, performance, reliability, and life factors as well as reduce projected weight and costs for the first in-space NTP systems, subsystems, and components beyond that in previously achieved ground test systems. Proposals are solicited in the following key technology/concept areas:

- High temperature, radiation tolerant instrumentation and avionics for engine health monitoring. Non-invasive designs for measuring neutron flux (outside of reactor), chamber temperature, operating pressure, and H_2 propellant flow rates over wide range of temperatures are desired;
- Long-life, lightweight, reliable hydrogen turbopump designs and technologies;
- Lightweight, long-life, high heat flux thrust chambers, regenerative-cooled nozzles and radiation–cooled skirt extensions that are compatible with hot hydrogen;

- Radiation tolerant materials compatible with above engine subsystem applications and operating environments;
- High temperature, low-to-moderate burn-up carbon- and ceramic-metallic (cermet)-based nuclear fuels for use in NTR and BNTR engines;
- Improved chemical vapor deposition (CVD)/coating techniques for heritage "Rover/NERVA" type carbon-based fuels that reduce and/or prevent cracking, fuel element erosion via H_2 attack, and release of fission product gases into the engine's H_2 exhaust stream;
- Mass-optimum neutron and gamma radiation shielding materials and designs that minimize exposure/damage to key engine components and subsystems (e.g., LH_2 turbopumps) and provide radiation protection for the crew; and
- Dual-use shielding materials and designs that also provide habitat protection against galactic cosmic rays and solar flares are also encouraged.

Note that any associated NTP simplified test approaches, power systems, and thermal management/heat rejection systems technologies should be submitted to subtopic areas X10.01, X10.03, and X10.04, respectively.

X10.03 Critical Technologies for Space-Based Nuclear Fission Power Systems
Lead Center: GRC
Participating Center(s): JPL, MSFC, JSC

NASA is interested in the development of highly advanced systems, subsystems, and components for use with high-power, fission power systems for a variety of future robotic and manned exploration missions to the Moon, Mars, and beyond. Anticipated electric power levels range from 30 to 100s of kilowatts for the nearer-term and possibly up to multi-megawatts for the far-term. Fission-based systems are anticipated to enable long duration stays of approximately 45 to 90 days over the lunar night and may have *in situ* resource utilization applications. Power levels needs are anticipated to be between 30-50 kWe for these early exploration missions.

Potential Mars-surface human outpost applications for high-power space nuclear power systems could include habitats, resource processing, propellant production/liquefaction/maintenance, and excavating and mining equipment. These potential Mars surface human mission activities could require power in the 100 kWe range. Also, space nuclear power systems could be needed for robotic outposts as a precursor to human Mars surface exploration with 50-500 day stays. Power levels of about 30-50 kWe may be needed to support these initial robotic outposts and other science applications such as: deep drilling, resource production demonstrations, rovers, weather stations, etc.

Potential electric propulsion applications include high power space nuclear power systems for primary electric propulsion, vehicle housekeeping, cryogenic propellant maintenance, orbiting power assets and science payloads. Power levels in the 100-200 kWe range are envisioned for robotic vehicles. Far-term vehicles for human missions may also be needed and could require about 1-2 MWe for high-mass cargo vehicles to the Moon or Mars and the low 10s of MWe for piloted electric propulsion vehicles. Nuclear thermal propulsion systems could also be designed to produce electric power and power levels of about 50 kWe could be needed to meet crew habitat, propellant boil-off, and other spacecraft power requirements.

Proposals are sought in the following specific technologies areas:

- Advanced, high-efficiency, high-temperature high-power conversion >20%, 30-200 kWe for the nearer-term, and up to MWe-unit size for the far-term (with technical issues of scaling to high power unit);
- Electrical power management, control and distribution in the 1000-5000 V range;
- Deployment systems/mechanisms and innovative methodologies for surface mobility systems for remote emplacement of power systems and for use of indigenous shielding materials;
- Material compatibility with local environments;
- Systems/technologies to mitigate lunar and planetary surface environments including dust accumulation, lunar surface temperature extremes, wind, planetary atmospheres (CO_2, corrosive soils, etc.);

- Power system design considerations for long life (>10 years), autonomous control and operation, including sensor technologies; and
- Radiation tolerant systems and materials (including lunar, Mars and in-space environments) for robust, long-life operation.

In addition to reducing overall system mass, volume and cost, increased safety, and reliability are of extreme importance. It is envisioned that these high power space nuclear power system technologies could be used on robotic and human exploration missions and it is to NASA's advantage to develop those technologies that evolve from robotic to human exploration mission requirements with a minimum of redesign. Technologies that enable challenging missions such as, nuclear electric propulsion, planetary surface power, and in-space electric power generation are of particular interest. Technologies that easily and efficiently scale in power output and can be used in a host of applications (high commonality) are desired.

Proposals for thermal management systems and innovative materials computational engineering should be proposed to X10.04 and X10.05, respectively.

X10.04 Heat Rejection Technologies for Nuclear Systems
Lead Center: GRC
Participating Center(s): GSFC, JPL, MSFC

NASA is interested in the development of advanced heat rejection subsystems for use with high-power, fission-based power and propulsion systems for a variety of future robotic and manned exploration missions to the Moon, Mars, and beyond. Anticipated electric power levels for these high-power, space nuclear systems could range from 30 to 100s of kilowatts for the nearer-term and possibly up to multi-megawatts (2-20 MWe) for the far-term. Potential applications include in-space transfer vehicles and planetary orbiters, and surface bases with global site capability on the lunar and Mars surface. The heat rejection sub-systems for any of the possible high power space nuclear power plant choices would need to be matched with the thermodynamic cycles of the power plants in a manner that will maximize space nuclear power system performance while keeping heat rejection subsystem and overall power system specific mass (kg/kW) to a minimum. The levels of heat rejection could be from about 100 kilowatts to many megawatts, and the task could be even more challenging by the long life requirements imposed by deep space missions, the extreme radiation environments possibly encountered, and the unique challenges imposed by surface missions including the effect of an atmosphere, elevated sink temperature, and particle contamination. The radiator operating temperature range can vary greatly depending on the mission, but temperatures as low as 400K and in excess of 1000K are possible.

Typical heat rejection systems usually include a) a heat transport loop carrying heat to radiator surfaces for rejection to space, and b) a space radiator, which accomplishes the final heat rejection to space by thermal radiation. If the cycle working fluid is different from the radiator heat transport fluid, a "heat sink" heat exchanger and a fluid-circulating pump also need to be included in the design.

Proposals are sought in the following critical technologies areas:

- Low areal density heat rejection radiators (<5 kg/m^2);
- Innovative heat transfer approaches between heat transport loop and radiating surfaces;
- Development of light weight, radiation tolerant, thermally stable, high-performance components and pump loop systems including heat pipes and pumps in the low to intermediate temperature ranges (300K to 500K), intermediate temperature ranges (450K to 650K), and intermediate to high temperature ranges (700K to 1000K and higher);
- Pumped loops that take advantage of the abundance of waste heat and transport some of it to the spacecraft and payload components for thermal management. Waste heat source to spacecraft radiator distances will likely be too large for passive technologies, and pumped loops may offer a possible solution. Since rejection of megawatts of waste heat could require large radiating surfaces, loop heat pipes may provide a

lightweight solution to distributing this heat over long distances. Specific areas of interest for this area include:

  - Long term material/working fluid compatibility, lightweight material integration, and working fluid performance for the various temperature ranges; and
  - High temperature, long-life pump technology, single- and two-phase systems, and thermal bus concepts involving multi-evaporators and condensers.

- High temperature, lightweight heat rejection system materials. Such materials may include those to enable lightweight radiators and heat pipes. Work in this area should address harsh radiation environments, launch/landing loads, and long life issues;
- Durable low-absorptivity/high-emissivity and variable emissivity coatings for radiating surfaces;
- Novel and efficient deployment systems/mechanisms for radiators in zero gravity and/or non-zero gravity fields to minimize mass, complexity, and stowed area/volume;
- Systems and technologies to mitigate adverse effects of planetary surface operating environments, such as cosmic and fission process induced radiation, dust accumulation, wind loading, planetary atmospheric effects due to CO_2, and variable sink temperatures;
- Design considerations for heat rejection subsystems should include long service life (>10 years) and autonomous operation;
- Development of advanced, high temperature heat pump technologies based upon conventional vapor compression cycles, absorption/adsorption cycles, and advanced thermoelectric and/or thermo-acoustic technologies;
- Advanced eutectic working fluids capable of extended duration use that would mitigate design issues related to the freezing and subsequent reuse of thermal management coolants; and
- Alternate cooling technologies for the rejection of waste heat from large capacity planetary or surface nuclear power systems. Such systems may include, but are not limited to, deployable cooling towers and/or optimized radiators.

In addition to reducing overall system mass, volume, radiator area, and cost, increased safety and reliability are of prime importance. Technologies are desired that readily scale in heat rejection capability for various power plant outputs, and thus can be used in a range of applications.

X10.05 Computational Material Science Tools for Space Nuclear Design Systems
Lead Center: GRC
Participating Center(s): MSFC

NASA is interested in the development of highly advanced systems, subsystems, and components for use with high-power, fission power and propulsion systems for a variety of future robotic and manned exploration missions, including in-space, lunar-surface, and Mars-surface applications. Advanced high-power space nuclear power and propulsion systems for robotic and human exploration missions involve a range of specialized materials for the reactor, heat transfer system, energy conversion system, propulsion system, and other nuclear vehicle systems. These materials may include carbon-carbon, super alloys, refractory alloys, structural ceramics, ceramic matrix composites, and other high-temperature space nuclear systems materials. Long-term stability greater than 10 years is critical for long-life space nuclear power system applications. Materials would be subjected to fission process radiation while exposed to in-space (plasma, out-gassing, etc.) and/or planetary operating environments.

This subtopic is focused on the development of computational materials science tools to develop and select these specialized space nuclear systems materials. Many considerations go into selection of materials for demanding applications. These include strength, creep resistance, phase stability, oxidation/corrosion resistance, nuclear capture cross-section, and radiation tolerance. In recent years computational materials science has assisted with not only the selection of existing materials with a given set of properties but also with the development of new materials with those properties. These tools include first principles calculations of phase equilibria, computational thermodynamics (the CALPHAD technique), and creep modeling.

Proposals are sought for the specific technologies areas:

- A computational 'toolbox' for material selection with particular emphasis on space nuclear power and propulsion systems requirements;
- Computational tools to address particular issues in mechanical property degradation in space nuclear power and propulsion systems over long times. This includes, but is not limited to, long-term creep modeling;
- Computational tools to predict long-term oxidation/corrosion and flow-induced erosion issues in the high temperature portions of these systems, including the heat transfer system. This includes thermodynamic modeling of heat transfer media attack of alloys;
- Computational tools to predict long term stability of various joining techniques used in these space nuclear systems. This includes diffusion modeling in alloys; and
- Computational tools to predict interaction of the radiation environment. This includes effective capture cross-section for complex materials systems and production of secondary energy and potential impact on components.

It is anticipated that Phase 1 will focus primarily on the new computational tools for material selection and development with some limited experimental verification. Later phases should involve more extensive verification, to the point where these tools could be readily utilized for the design of space nuclear systems.

TOPIC: X11 Human Systems Research and Technology

The crews that leave the Earth for exploration destinations must keep healthy to perform their mission and to return safely back to Earth. The subtopics seek innovative technologies that will enable crew health and performance, and that will assure there will be no unacceptably long-term consequences after returning while supporting healthy and productive sustained human presence. Proposals for technologies that will enable human space exploration are sought in the areas of Radiation Health and Radiation Shielding; Human Health Countermeasures including artificial gravity, exercise, pharmacology and nutrition, cell and tissue-based analog systems, and physiological countermeasures; Exploration Biology, including the science, spaceflight systems, and technologies that support human exploration; Autonomous Medical Care including technologies of prevention, monitoring, diagnosis, and treatment of human medical problems. Research should be conducted to demonstrate technical feasibility during the Phase 1 contract and show a path toward a Phase 2 specific deliverable. The contractor will then, when appropriate, deliver a demonstration unit of the instrumentation for NASA testing before the completion of the Phase 2 contract.

X11.01 Radiation Health
Lead Center: JSC
Participating Center(s): ARC, LaRC, MSFC

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 distinct from terrestrial forms of radiation, being comprised of high-energy protons and heavy ions and their secondaries produced in shielding and tissue. The Radiation Program Element uses the NASA Research Announcement as a primary means of soliciting research to reduce the uncertainties in risk projections; however, there are specific areas where the SBIR technologies can potentially contribute to NASA's overall goal:

Ground-Based Heavy Ion Accelerator Research Support Equipment
NASA utilizes facilities at Brookhaven National Laboratory (BNL) to conduct fundamental radiobiology and shielding experiments. However, the facilities at BNL were not developed with NASA's high number of investigators in mind, thus there are areas where technology developments can improve efficiency and throughput. Technologies of specific interest include, but are not limited to, the following:

- Advanced animal support equipment, sample holders, live imaging of samples on the beam line during heavy ion irradiation, or specimen transport systems that allow remote transport into and out of the target areas, and precise positioning of specimens in the beam line with minimal human interaction in the target areas;
- Environmental control for cell studies while in the beam line and automated fixation capabilities to perfuse small cell and tissue samples directly after exposure to the ion beam;
- Controlled beam line access that provides safe, but rapid and reliable human access to the beam target areas and lockout during specimen exposure; and
- Advanced detector systems to provide rapid assessments of elemental fluence spectra and neutron fluence spectra following heavy ion irradiation of biological or shielding samples.

High Throughput Genomic Analysis Techniques
Following low-dose irradiation of cells by protons and heavy ions, damage is localized to only a very few cells. The ability to separate cells with or without genetic changes in an automated manner is of interest. Current technologies are inefficient in identifying small-scale genetic changes (less than several thousand base-pairs (Mbp)) under these conditions. Technologies of interest are:

- Complementary technologies to the fluorescence *in situ* hybridization (FISH) method used to score large scale (>1 Mbp) genetic changes to chromosomes following low dose irradiation in order to rapidly score small-scale genetic changes (<1 Mbp); and
- Imaging techniques to rapidly identify with high accuracy undamaged cells from a cell population irradiated at low doses.

Radiation Shielding and Fabrication
The NASA Space Radiation Research Program uses the NASA Research Announcement (NRA) as the primary means of soliciting research to conceive and radiation-test new radiation shielding materials concepts. The materials concepts include new and innovative lightweight radiation shielding materials to shield humans in crew exploration vehicles, large space structures such as space stations, orbiters, landers, rovers, habitats, and spacesuits. The materials emphasis is on non-parasitic radiation shielding materials, or multifunctional materials, where one of the functions is the radiation shielding, but also serves as structural and other functional components of flight and/or habitat systems. The specific areas in which SBIR-developed technologies can contribute to NASA’s overall mission requirements for advanced radiation shielding materials technologies are:

- Characterization of the physical, chemical and relevant functional properties and the validation and qualification of such multi-functional radiation shielding materials;
- New and innovative manufacturing techniques for producing 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;
- New and innovative processing methods for producing quality-controlled advanced radiation shielding materials of all forms - resins, fibers, fabrics, composites and fiber-reinforced composite materials;
- New and innovative fabrication techniques for fabricating advanced radiation shielding materials into useful products and structural components; and
- New and innovative commercialization strategies to introduce advanced radiation shielding materials technologies into the marketplace to enable availability of the technologies for use by NASA and the space exploration community.

Reliable Radiation Dosimeters for Manned and Unmanned Spaceflight
Current environment dosimeters have exceeded their designed lifetimes and should be replaced. These include small, active dosimeters to monitor individual astronauts' exposure, Tissue Equivalent Proportional Counters (TEPC), Charged Particle Directional Spectrometer (CPDS) capable of internal and external deployment, and externally deployed electron and neutron detectors. New software needs to be fault tolerant and updated to current operating systems; new hardware and software must be fully documented (schematics, etc.). Areas of interest are:

- 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; and
- Microdosimetry for operational and research applications, including implantable dosimeters for biological studies, that translate particle counts into biologically relevant dose or damage.

X11.02 Human Health Countermeasures
Lead Center: JSC
Participating Center(s): ARC, GRC, MSFC

In order for humans to live and function safely and efficiently in space or in the hypogravity of the Moon (1/6g) or Mars (3/8g), a good understanding of the effects of micro- and hypogravity and other factors associated with the space environment on human physiology and human responses to the space and extra planetary environments is required. A variety of countermeasures must be developed to oppose the deleterious changes that occur in space and upon subsequent exposure to other gravitational fields. 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. Since 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 becomes more important as we march towards human Moon and Mars missions.

Exercise and Related Hardware
Development of an immersive visual display system is required to be interfaced with treadmill exercise devices. This system may not be head-mounted but could be free standing and provide at least a 180° field of view. This visual display would allow visual flow patterns to be displayed to a non-encumbered subject during in-flight or on-surface treadmill exercise. In addition, miniaturized exercise hardware (treadmill or resistance exercise); physiological monitoring devices; and metabolic gas (carbon dioxide and oxygen) analysis systems for use with exercise and miniaturized interactive feedback and entertainment systems.

A tool or toolkit should simulate and visualize the exercise device design and performance. A comprehensive, scaled 3D/virtual human model interface would be valuable to show biomechanical and kinetic effects of the exercise device. Relative physiological data from anthropometry to stress/fatigue to trauma/insult onset should be targeted. If in-flight/on-orbit micro gravitational and planetary surface gravitational forces can be simulated, this could help produce germane simulations with which to implement new designs and products. A time-delay algorithm would be advantageous in helping provide for latency-moderated haptics (force-feedback) and long-distance teleoperative control. This will allow remote teleoperation with force-feedback despite the high latencies involved.

Noninvasive Pharmacotherapy and Monitoring
Development of innovative technologies resulting in noninvasive 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 hypo-gravity environments, which may interfere with their activity by sensitizing or desensitizing the crewmember or interfering in other ways with the desired physiological effect. Micro-encapsulation of drugs, radio contrast agents, crystals, and development of novel drug delivery systems wherein immiscible liquid interactions, electrostatic coating methods, and drug release kinetics from microcapsules or liposomes can be altered under microgravity. 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.

Device for Providing Increased Neuromuscular Activation during Spaceflight
Astronauts returning from spaceflight exhibit post-flight postural and gait instabilities that are a result of neural adaptation to microgravity. A small, lightweight countermeasure device is required to stimulate somatosensory receptors on the plantar surface of the feet during in-flight exercise with the goal of increasing neuromuscular activation and enhancing sensorimotor integration. This system would integrate with in-flight exercise hardware and coupled with visual stimulation systems would allow a more complete sense of immersion to enhance in-flight postural and locomotor training.

Device for Measuring Body Fluid Shift
A body impedance device to measure fluid shifts in four segments of the body associated with a short-radius centrifuge. The device should measure the following parameters, namely, resistance, change in resistance and rate of change of resistance and reactance. The device should withstand g forces (5g) produced by centrifugation and meet safety standards such as subject isolation.

MEMS-Based Human Blood Cell Analyzer
Development of a small, automated and micro- and hypo-gravity capable instrument that will analyze micro liter quantity of human whole blood and provide a complete blood cell count (RBC, WBC, platelet, hemoglobin concentration, hematocrit, WBC differential, and calculated RBC indices) that correlates with traditional ground-based impedance or light-scattering technologies is needed. Likely devices based on MEMS will employ a biocompatible combination of micro fluidics, micromechanics, micro-optics, microelectronics, and data telemetry capabilities in an integrated handheld package with a user-friendly operator interface.

Cell/Tissue Analog Studies
Cell/Tissue analog studies in ground-based, microgravity-analog bioreactors allow us to understand the ill-effects of microgravity and radiation on human tissues—especially, bone, muscle, and cardiac and immune response. Technologies that allow automated biosampling, lyophilization of mammalian cells, miniaturized protein microarray analyzer, tools derived from Bionanotechnology relevant to the understanding are of interest.

X11.03 Autonomous Medical Care
Lead Center: JSC
Participating Center(s): ARC, GRC

Exploration missions require a healthy, well-performing crew supported by a robust infrastructure for the monitoring, diagnosis, and treatment of medical conditions. Since return time to Earth and communications delays during such missions will greatly reduce the effectiveness of Earth-involvement, the crew must be capable of performing the majority of medical activities independently. Therefore, this system of autonomous medical care must provide the capability for patient care as well as measure and assess fitness levels for duty during a mission with little or no real-time support from Earth. The objective of this subtopic is to sponsor applied research leading to the development of such an infrastructure with the associated medical devices and procedures that will mitigate crew health, safety, and performance risks during future flight missions to the Moon and Mars. Medical diagnostic, treatment, and monitoring devices are critical for providing health care and medical intervention during missions, particularly extended-duration spaceflight to the Moon and Mars. Of particular interest are devices with minimized mass, volume, consumables, and power consumption that are capable of multiple functions in both micro-g and sub-g environments. Design enhancements that improve the operation, reliability, flexibility, and maintainability of medical devices in the space environment are also sought. Additional considerations include innovative approaches to human-device interactivity and interface, automation of device functions, improved ease of use, and astronaut comfort.

Device for Body Chemistry Assessment

Development of an integrated, adaptable laboratory analysis system/sensor system for in-flight assessment of body fluids (including blood) and solids is desired. This system would be used to obtain quantitative measurement of dissolved gases, calcium ions, and other electrolytes, proteins, lipids, hormones, carbohydrates, vitamins, minerals and clinical drug levels with minimal or no consumables usage or specimen preparation skill. Likely candidates will be based on MEMS technology and will employ a biocompatible combination of micro fluidics, micromechanics, micro-optics, microelectronics, and data telemetry capabilities in an integrated handheld package with a user-friendly operator interface.

Voice- and Gesture-Actuated Interactive Procedures

Astronauts working in space or on the lunar or Martian surface will require a hands-free, interactive, step-by-step environment for performing flight medical procedures. This system should have the capability to utilize links, prepare textual or graphical indication of progress through a procedure, return to previous steps, page forward/page backward, and automatically annotate verbal input relative to subject response during procedure or treatment. An inventory capability must exist for obtaining and stowing required items (including medications) as well as a mechanism to assess the resulting consumables status after a procedure has been completed. Ground-monitoring capability is also required, at least in the early stages.

Closed Loop Medical Respirator

A closed loop flight and human certified medical respirator with real-time remote monitoring and remote control capability is required. This respirator must incorporate a function to limit the amount of O_2 leaking into the space vehicle or surface habitat. Current O_2 limits range from ~20/21% at sea level with maximum levels of 30% in a 10.2 psi environment. (This upper limit mitigates flammability concerns and is dictated by ambient pressure.) The system should incorporate real-time remote monitoring and control capabilities.

Medical Grade Water Generation

Methods and technologies for in-flight creation of medical grade water from any available water source are required. Because some pharmacological preparations appear to degrade in the space environment, it is highly desirable, from both a consumables perspective as well as from the standpoint of mass, to fly desiccated pharmacological substrates whenever possible and to reconstitute them only when needed. For this reason, medical grade water is required along with a low-g (e.g., 0 g, 1/3 g, and 1/6 g) system to deliver generated water to the substrate and mix as necessary. The general requirements of low mass, user-friendly interface, reliability, and automation are critical to this system. There should be a mechanism included to verify that the water produced meets standard requirements for the medical grade designator.

Diagnostic Imaging Capability

During long duration flights, it will be important to have medical imaging capability available to assist in diagnosis, treatment, and monitoring during and after medical events. This capability is likely to be an ultrasonic, low power, portable device that provides for diagnostic assistance via data processing algorithms. These algorithms would be expected to provide guidance for the crewmember administering the exam as well as identifying probable diagnoses options and possible treatments for each. The system should be flexible enough to provide fracture analysis, bone density levels, and body cavity status.

In-Flight Suction

Long duration missions must have the capability to provide medical suction for patients in the event of injury or serious illness. This system must be capable of providing suction for a variety of body orientations in multiple reduced gravity environments. It should be a stand-alone system that does not require oversight by another crew-member. In the event of malfunction, it should provide an audio alert, a display of the malfunction type, plus a safing algorithm. The contents of the suction system must be easily disposed of safely and without release of contents into the environment.

Biomedical Signal Processing

Assessment of an ill or injured crewmember may sometimes be accomplished in large part by the status of the biomedical signal, or EKG. This will have to be a "smart" system, which analyzes sensor placement, sensor health, signal monitoring, signal normalcy, and signal analysis. It is required that the biomedical signal be capable of monitoring cardiac health and physiological state. The processor must be fail-safe and must annunciate an audible alarm when a malfunction occurs. A display should provide a readout of the anomaly type and the system must safe itself when malfunctions occur. (NOTE: There may be a subset of malfunctions {e.g., loose lead} that will not require a shut-off or self-safing function.) The system must be volumetrically small with minimal mass.

Intelligent Software Modules

Software modules with the capability to review medical data in a SQL compliant database, assign or suggest appropriate SNOMED CT codes, and store the suggested codes in electronic format with discrete elements is highly desirable to avoid having to train hierarchical nomenclature to crewmembers. The hierarchical relationships between SNOMED codes should be maintained and stored in the output.

TOPIC: X12 Life Support and Habitation

Achieving sustained human presence in space and on lunar and Martian sites requires innovative life support and habitation technologies. Proposals are sought that improve life support and habitation systems in the areas of: Advanced Life Support including closed loop, and to a lesser extent, open loop technologies for air revitalization (including lunar dust abatement technologies), water reclamation, solid waste management (including small disposal units for human waste), food management systems (including galley), and biomass production; Extra Vehicular (EVA) technologies including suit assembly, life support systems, power communications and information handling; Contingency Response technologies including fire prevention, detection and suppression, *in situ* fabrication and repair, and *in situ* resource utilization; Advanced Environmental Monitoring and Control including air, water and surface monitoring, external environment monitoring, and life support integrated control.

X12.01 Advanced Life Support: Air and Thermal
Lead Center: JSC
Participating Center(s): ARC, GRC, KSC, MSFC

Advanced life support systems will be essential to enable human planetary missions as outlined in the Vision for Space Exploration. Innovative, efficient, and practical concepts are needed for regenerative air revitalization, ventilation, temperature, and humidity control. Requirements include safe operability in micro- and partial-gravity, ambient and reduced-pressure environments, high reliability, regeneration and minimal use of expendables, ease of maintenance, and low-system volume, mass, and power. Proposals should explicitly describe how their work is expected to improve power, volume, mass, logistics, crew time, safety and reliability, with comparisons to existing state-of-the-art technologies. Information and documentation on advanced life support systems can be found at http://advlifesupport.jsc.nasa.gov.

Air Revitalization
The management of cabin atmosphere in spacecraft and habitats includes concentration, separation, and control techniques for oxygen, carbon dioxide, water vapor, particulates and trace chemical components. This includes processing and recovering resources derived from waste streams and from *in situ* planetary resources. Technologies focused at closing the air loop will have higher priority. Areas of emphasis include:

- Atmosphere revitalization process integration to achieve energy and logistics mass reductions;
- Separation of carbon dioxide from a mixture primarily of nitrogen, oxygen, and water vapor to maintain carbon dioxide concentrations below 0.3% by volume;.
- Recovery of oxygen from carbon dioxide including approaches to deal with by-products of the process;
- Regenerable processes for removing trace chemical components from cabin air and/or gas product streams from other systems (e.g., water reclamation, waste management, etc.);
- Regenerable, re-usable, particulate filters for air;
- Novel approaches to suspended particulate matter removal from cabin and habitat atmospheres, including approaches to isolating cabin and habitat living areas from external dust sources such as Martian or lunar soil; and
- Methods of storage and delivery of atmospheric gases to reduce mass and volume and improve safety.

Advanced Thermal Control Systems
Thermal control is an essential part of any space vehicle, as it provides the necessary thermal environment for the crew and equipment to operate efficiently during the mission. A primary goal is to provide advanced technologies for temperature and humidity control; however, advanced active thermal control also includes technologies in the areas of heat acquisition, transport, and rejection. Areas of emphasis include:

- Liquid-to-liquid heat exchangers that provide two physical barriers preventing inter-path leakage;
- Advanced technologies to control cabin temperature and humidity in microgravity. Condensate that is collected must be able to be recovered and transported to the water recovery system;
- Alternate methods of atmospheric humidity control that do not use liquid-to-air heat exchanger (dependent on the spacecraft active thermal control system) or mechanical refrigeration technology;
- Technologies to inhibit microbial growth on wetted surfaces. Applications include condensate collection surfaces for humidity control and heat exchangers resident in water loops;
- Lightweight, versatile, and efficient heat acquisition devices including flexible cold plates, to provide cooling to electronics, motors, and other types of heat producing equipment that is internal to the cabin;
- Lightweight, controllable, evaporative heat rejection devices that can operate in environments ranging from space, Mars' atmosphere, and Earth's atmosphere;
- Alternative heat transfer fluids that are non-toxic, non-flammable, and have a low freezing temperature;
- Energy storage devices that maintain the integrity of food or science samples. For maintenance of temperatures of -20°C, -40°C, -80°C or -180°C;
- Highly accurate, remotely monitored, *in situ*, non-intrusive thermal instrumentation; and
- Low-energy, low-noise, high-capacity fans or similar devices for moving air.

Component Technologies
Energy efficient, low mass, low noise, low vibration, or vibration isolating, fail-safe, and reliable components for handling gases, fluids, particulates, and solids applicable to spacecraft environmental control and air revitalization, including actuators, fans, pumps, compressors, coolers, tubing, ducts, fittings, heat exchangers, couplings, quick disconnects, and valves that operate under varied levels of gravity, pressure, and vacuum. Mass flow monitoring and control devices that have similar attributes and that are easily calibrated and serviced.

X12.02 EVA Technologies
Lead Center: JSC
Participating Center(s): ARC

Advanced Extravehicular Activity (EVA) systems are necessary for the successful support of future human exploration space missions. Advanced EVA systems include the space suit pressure garment, the portable life support system, tools and equipment, and mobility aids such as rovers. Exploration EVA 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 weight and volume, increased hardware reliability, maintainability, durability, and operating lifetime, 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. Areas in which innovations are solicited include the following:

Environmental Protection

- Radiation protection technologies that protect the suited crewmember from radiation;
- 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 or technologies to exclude or remove dust and withstand abrasion; and prevent dust adhesion; and
- Flexible space suit thermal insulation suitable for use in vacuum and low ambient pressure.

EVA Mobility

- Space suit low profile bearings that maximize rotation necessary for partial gravity mobility requirements and are lightweight.

Life Support System

- 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 crewmember cooling, heat rejection, and removal of expired water vapor and CO_2;
- Fuel cell technology that can provide power to a space suit and other EVA support systems;
- Lightweight convection and freezable radiators for thermal control;
- Innovative garments that provide direct thermal control to crewmember;
- High reliability pumps and fans that provide flow for a space suit but can be stacked to give greater flow for a vehicle;
- CO_2 and humidity control devices that, while minimizing expendables function in a CO_2 environment; and
- Variable conductivity flexible suit garment that can function as a radiator for high metabolic loads and as an insulator during period of low physical activity and low metabolic rates.

Sensors, Communications, Cameras, and Informatics Systems

- Space suit mounted displays for use both inside and outside the space suit—outside mounted displays will be compatible with the space environment;
- CO_2, bio-med (heart rate and blood oxygen level), radiation monitoring, and core temperature sensors with reduced size, lightweight, increased reliability, decreased wiring, and packaging flexibility;
- Visible spectrum camera that provides environment awareness for crewmembers and the public and are integratable into a spacesuit that is lightweight and low power;
- Lightweight sensor systems that detects N_2, CO_2, NH_4, O_2, ammonia, hydrazine partial pressures, including self-powered sensors;
- Lightweight, low power, radio and laser communications with the capability to integrate audio, video, and data on the same data stream to provide reliable communications between the crew and a lander or habitat; and

- Low power, lightweight, radiation hardened, or radiation tolerant informatics computer systems with standard graphics outputs and standard audio inputs and outputs, capable of running commercial operating systems and applications.

Integration
- Robot control by EVA crewmember via voice control or other methods;
- Minimum gas loss airlocks providing quick exit and entry and can accommodate an incapacitated crewmember; and
- Work tools that assist the EVA crewmember during operations in zero gravity and at worksites; specifically, devices that provide temporary attachments, which rigidly restrain equipment to other equipment and the EVA crewmember, and that contain provisions for tethering and storage of loose articles such as tool sockets.

EVA Navigation and Location
- Systems and technologies for providing an EVA crewmember real-time navigation and position information while traversing on foot or a rover; and
- Systems and technologies for managing and locating tools during planetary surface science and maintenance EVA sorties.

X12.03 Contingency Response Technologies
Lead Center: GRC
Participating Center(s): JSC, MSFC

Decades of experience in manned space flight have demonstrated that during any mission, unexpected events will occur. If the crew is adequately equipped to address such contingencies during exploration missions, the chances of successfully completing that mission can be greatly increased. The objective of this subtopic is to develop technologies in the areas of fire prevention, detection, and suppression (FPDS) and *in situ* fabrication and repair (ISFAR) that will support the crew in the event of a fire or if a critical component breaks during a mission, respectively. These technologies may be in the form of devices, models, and/or instruments for use in microgravity and/or for commercial applications on Earth. The top-level requirements for a viable technology include the reduction of system hardware weight and volume and increased hardware reliability, durability, and operating lifetime. Research conducted during the Phase 1 contract should focus on demonstrating the technical feasibility of the FPDS or ISFAR protocol/system and show a path toward a Phase 2-specific deliverable. The contractor will, when appropriate, deliver a demonstration unit of the instrumentation for NASA testing before the completion of the Phase 2 contract.

Fire Prevention, Detection, and Suppression
The objective of the Fire Prevention, Detection, and Suppression (FPDS) subtopic is to develop technologies that, when incorporated into the design philosophy and functional design of exploration vehicles and habitats, will quantitatively reduce the likelihood of a fire and reduce the impact to the mission should a fire occur. The element is composed of four major theme areas including: fire prevention and material flammability, fire signatures and detection, fire suppression and response, and analysis of fire scenarios. Innovations are sought in the following theme areas:

- Quantifying the effects of microgravity, 1/6-g (lunar) and 1/3-g (Martian) on the ignitability of materials and the subsequent flame spread, particularly related to determining relevant low-gravity behavior from normal gravity tests;
- Improving the performance of spacecraft fire safety systems through the development of advanced fire detection and suppression systems and strategies as well as predicting the effects of smoke and precursor generation and transport; and
- Developing techniques for creating and analyzing the effectiveness of fire resistant materials and coatings, including fire prevention techniques, for spacecraft structures, radiation shielding materials, paneling, fabrics (cotton, paper, synthetics), foams, etc.

In Situ Fabrication and Repair

In Situ Fabrication and Repair develops technologies for life support system maintenance and integrated habitat radiation shielding fabrication with a focus on contingency response and maximization of *in situ* resource utilization to reduce launch mass and volume. The manufacture or repair of components during a mission is essential to human exploration and development of space. Fabrication and repair beyond low Earth orbit is required to reduce resource requirements, spare parts inventory, and to enhance mission security. Proposals are sought in the technical themes listed below:

- Application of Free Form Fabrication (FFF) methods to low gravity (3/8 and 1/6 g level) manufacturing of near net shape products and spare parts from *in situ* derived resources or provisional feedstock;
- Processes for extracting *in situ* resources into raw materials and feedstock for use with rapid prototyping technology;
- Extension of fused deposition methods to the use of binderless metal wire feed stock;
- Adaptation of ultrasonic consolidation methods to use narrow ribbon metal feedstock to reduce subsequent machining operations and waste;
- Novel and innovative *in situ* repair methods such as but not limited to: welding, composite repair, and self healing materials;
- Development of highly automated habitat construction methods that incorporates *in situ* materials on surface or primary structure may use *in situ* construction;
- Development of dust mitigation techniques applicable to planetary habitat construction;
- Integration of radiation shielding materials into habitat construction methods; and
- Innovative approaches for recycling of materials for secondary uses.

X12.04 Advanced Environment Monitoring and Control
Lead Center: JPL
Participating Center(s): GRC, JSC

This subtopic addresses monitoring and control technologies, which support the operation of an Advanced Life Support (ALS) system for future long duration space missions. There are two application areas: Acoustics Monitoring and Environmental Controls.

Acoustics Monitoring Section

The objective is a proof-of-concept acoustic sensor system consisting of fixed and crew-worn transducers. At least ten fixed transducers shall be distributed in a habitable volume of at least 2x2x6m. The goal for the fixed microphones is to provide sound pressure level measurements with Type I measurement accuracy over the Octave Band frequency range from 63 Hz through 20 kHz. The system shall be capable of measuring 1/3 Octave Band, Octave Band, and Narrow Band sound pressure levels averaged over a specified interval with user defined data acquisition parameters. The fixed microphones shall also operate as an acoustic dosimeter with Type III accuracy and shall measure and log the maximum, A-weighted, Overall Sound Pressure Level every 30 seconds for at least 24 hours. The system shall also detect Hazard Levels of 85+ dBA and generate an alarm. The crew-worn transducer, clipped to a shirt collar, shall operate as a Type III acoustic dosimeter and shall measure and log the maximum, A-weighted, Overall Sound Pressure Level every 30 seconds for at least 24 hours. The size and mass of the device shall be comparable to COTS dosimeters. All system measurements shall be carried out remotely and the data managed by software. The system shall be demonstrated in a mock-up, and calibrations and comparisons made with appropriate instruments and methods.

Environmental Controls

Advanced Environmental Controls - the development of advanced control system technologies is necessary for the integrated operation of environmental systems for future long-duration human space missions. The interdependence of advanced environmental processing systems requires a non-avionics requirements process that allows design for controllability. This year particular emphasis is placed on the following:

- Control strategies for closed-loop systems - closed loop and biological systems have different constraints and control paradigms than conventional processes. There is a need for new control algorithms, analyses, design methodologies, strategies, and techniques to provide this capability;
- Ontologies for integrated operations - human exploration missions involve hundreds of systems developed by dozens of organizations. To develop software that can integrate across these systems and integrate with operations requires the use of common terminology across multiple disciplines. A common ontology must be developed to enable the integration of control of advanced life support systems; and
- Development and integration of autonomous system and inter-system control with crew and ground operations - there is a need for tools, architectures, and technologies that can support the integration of operations between crew, ground operators, ground applications, and on-board applications.

X12.05 Advanced Life Support: Food Provisioning and Biomass
Lead Center: JSC
Participating Center(s): ARC, GRC, KSC, MSFC

Exploration missions beyond low Earth orbit greatly limit allowable consumables and require development of innovative low maintenance, reconfigurable, reusable, or self-sufficient food production. Advancements are necessary to develop a combination of extended duration shelf life stored foods augmented with fresh foods grown within the spacecraft. Crop systems, in addition to producing fresh vegetables, storage roots, grains and legumes may contribute to air revitalization and utilize wastes from water recovery and waste management systems.

Crop Systems
The production of biomass (in the form of edible food crops) in closed or nearly closed environments is essential for the future of long-term planetary exploration and human settlement in lunar and Mars base applications. These technologies will lead not only to food production but also to the reclamation of water, purification of air, and recovery of inedible plant resources in the comprehensive exploration of interplanetary regions. Areas in which innovations are solicited include:

- Crop lighting, such as LED, solar collectors and innovative technologies. Lighting transmission and distribution systems, luminaries, fiber optics, water jackets, and other heat removal technologies are also areas of interest;
- Water and nutrient management systems such as hydroponics and/or solid substrates for food production and separation of nutrients from waste streams are solicited. In this area, regenerable media for seed germination plant support are also of interest as is separation and recovery of usable minerals from wastewater and solid waste products for use as a source of mineral nutrients. Consideration should be given tor systems operation in microgravity and hypogravity (1/6 g on Moon, 3/8 g on Mars) environments; and
- Other areas of interest: crop mechanization and automation, facility or system sanitation, crop health measurement, flight equipment support, structures and environmental monitoring and control technologies that are specific to crop systems (e.g., ethylene detection and removal, sensors for root zone oxygen and water content, etc.).

Food Provisioning
- Safe, nutritious, acceptable, and varied shelf-stable foods with a shelf life of 3 to 5 years will be required to support the crew during future exploration missions to the Moon or Mars. Shelf-life extension may be attained through food preservation methods and/or packaging. Packaging materials must provide sufficient oxygen and water barrier properties to maintain shelf life. Food packaging technologies are needed that minimize a potentially significant trash management problem by using packaging with less mass and volume and/or by using packaging that is biodegradable, recyclable, or reusable;
- Processing crops or bulk ingredients into edible food ingredients or table-ready products will be necessary to provide a self-sustaining food system for an exploration mission. Equipment that is highly reliable, safe, automated, and minimizes crew time, power, water, mass, and volume will be required. Equipment for

processing raw materials must be suitable for use in hypogravity (e.g., 1/6g on Moon, 3/8g on Mars) and in hermetically sealed habitats;

- Food preparation systems will be required to heat and rehydrate the shelf stable food items and to prepare meals from the processed and re-supplied items. Technologies to support on-orbit crew meal storage, preparation, dining activities, and trash dispensing are being sought;and
- Food quality and safety are essential components in the maintenance of crew health and well being. Efforts should be focused on control of food spoilage and food quality throughout the entire shelf life of the food. Effects of radiation on crop functionality and the stored food system quality are also needed.

X12.06 Habitation Systems
Lead Center: JSC
Participating Center(s): ARC, GRC, KSC, MSFC

Habitation Systems
Habitation systems for future crewed micro-gravity transits, reduced gravity planetary lunar or Martian surfaces, and long duration, deep-space environments are requested. Products can include basic research, system analysis, mockup evaluation, functionality demonstrations/tests, and actual prototype hardware. Exploration missions away from low Earth orbit greatly limit allowable consumables and require development of innovative low maintenance, re-configurable, and reusable systems. Minimal volume configurations (or dual use) during non-use mission phases are highly desirable.

Habitation systems should consider the following broad themes: re-configurable crew volumes for multi-gravity environments (micro and reduced gravity), multi-use work stations, multi-gravity translation strategies, crew radiation exposure mitigation, physically and psychologically ergonomic personal volumes, automated deployment, quiescent operations between missions, multi-purpose stowage systems for food/trash, advanced hygiene systems, and automated housekeeping/self-repairing habitat surfaces, durability, commonality of hardware/systems, and low total life-cycle costs. Specific areas in which advanced habitability system innovations are solicited include:

<u>Wardroom Systems</u>: Erectable or inflatable systems that support crew dinning, conference, external viewing (windows), illumination, and relaxation activities. Includes off-nominal uses (emergency medical or repair) while maintaining hygienic conditions.

<u>Galley Systems</u>: Systems requiring minimal crew preparation (heating, cooling, and rehydration) for food heating and accurate water dispensing. Specific areas include systems that allow individual crew meal flexibility and high-energy efficiency.

<u>Crew Hygiene Systems</u>: Low maintenance/self-cleaning fecal, urine, menstrual, emesis, hand/body wash, and grooming systems. Specific areas include non-foaming separatorsand no-rinse/non-alcohol hygiene products. Toilet systems should consider air, liquid, vacuum, and low-gravity transport methods. Collected waste should be prepared for recovery or long-term stabilization. Integrated hygiene systems should provide, acoustic and odor isolated private crew volumes compatible with multi-gravity interfaces.

<u>Crew Accommodation Systems</u>: Reconfigurable, deployable, or inflatable integrated crew accommodations that provide visual and acoustical isolated crew volumes for sleeping, audiovisual communication/entertainment, personal stowage, quiet ventilation/thermal control, and radiation exposure reduction/safe-haven.

<u>Clothing Systems</u>: Low mass reusable or long usage clothing options that meet flammability, out gassing, and crew comfort requirements. Used clothing cleaning/drying systems with low-water usage and non-toxic detergents/enzymes compatible with biological water reclamation systems or non-water cleaning methods.

Stowage Systems: Interior/exterior stowage systems for partial gravity environments that maximize usable volume and include contents identification and inventory control systems. Long-term external stowage for biological or other wastes on a planetary surface that safe and consistent with planetary protection policies.

X12.07 Advanced Life Support: Water and Waste Processing
Lead Center: JSC
Participating Center(s): ARC, GRC, KSC, MSFC

Regenerative closed-loop life support systems will be essential to enable human planetary exploration as outlined in the Vision for Space Exploration. These future systems must provide additional mass balance closure to further reduce logistics requirements and to promote self-sufficiency. Recovery of useful resources from liquid and solid wastes will be essential. Requirements include safe operability in micro- and partial-gravity, ambient and reduced-pressure environments, high reliability, regeneration and minimal use of expendables, ease of maintenance, and low-system volume, mass and power. Proposals should explicitly describe how the work is expected to improve power, volume, mass, logistics, crew time, safety and/or reliability, giving comparisons to existing state-of-the art technologies. Additional documentation and information can be found at http://advlifesupport.jsc.nasa.gov, including the expected composition of solid wastes and wastewater, which can be found within the "Baseline Values and Assumptions Document".

Water Reclamation
Efficient, direct treatment of wastewater and product water consisting of urine, brines, wash water, humidity condensate, and or product water derived from *in situ* planetary resources, to produce potable and hygiene water supplies. Technologies that contribute to closing the water loop will be given higher priority. Areas of emphasis include:

- Novel methods of process design and integration to minimize trace contaminant carryover from the cabin atmosphere leading to reduced logistics needs;
- Physicochemical methods for primary wastewater treatment to reduce total organic carbon from 1000 mg/L to less than 50 mg/L and/or total dissolved solids from 1000 mg/L to less than 100 mg/L;
- Post-treatment methods to reduce total organic carbon from 100 mg/L to less than 0.25 mg/L in the presence of 50 mg/L bicarbonate ions, 25 mg/L ammonium ions and 25 ppm other inorganic ions;
- Methods for the phase separation of solids, gases, and liquids in a microgravity environment that are insensitive to fouling mechanisms;
- Methods for the recovery of water from brine solutions;
- Methods to eliminate or manage solids precipitation in wastewater lines;
- Disinfection technologies for potable water storage and point-of-use. Residual disinfectants for potable water that is compatible with processing systems including biological treatment; and
- Techniques to minimize or eliminate biofilm and microbial contamination from potable water and water treatment systems, including components such as pipes, tanks, flow meters, check valves, regulators, etc.

Solid Waste Management
Wastes (trash, food packaging, feces, biomass, 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 (Moon, Earth, and Mars), and to recover useful resources. Treatment methods can include both oxidative and non-oxidative approaches. Areas of emphasis include:

- Volume reduction of wet and dry solid wastes;
- Small and compact fecal collection and/or treatment systems;
- Water recovery from wet wastes (including human fecal wastes, food packaging, brines, etc.);
- Stabilization, sterilization, and/or microbial control technologies to minimize or eliminate biological hazards (to the crew, to Mars, to Earth) associated with waste;
- Mineralization of wastes (especially fecal) to ash and simple gaseous compounds (e.g. CO_2, CH_4);

- Containment of solid wastes onboard the spacecraft that incorporates odor abatement technology;
- Containment devices or systems, with low volume and mass, that can maintain isolation of disposed waste on planetary surfaces (such as Mars); and
- Microgravity-compatible technologies for the containment and jettison of solid wastes in space.

Component Technologies
Energy-efficient, low-mass, low-noise, low-vibration or vibration isolating, fail-safe, and reliable components for handling fluids, slurries, biomass, particulates, and solids applicable to spacecraft wastewater treatment and solid waste management, including particle size reduction technologies (0.2 cm to 100 microns), actuators, pumps, conveyors, tubing, ducts, bins, fittings, tanks, couplings, quick disconnects, and valves that operate under varied levels of gravity, pressure, and vacuum.

TOPIC: X13 Human Systems Integration

Long-term presence in space in confined, isolated, and foreign environments may lead to impairments of human performance and behavioral health problems. Proposals are sought in the areas of space human factors engineering such as physical, cognitive, and team performance; behavioral health and performance including psychosocial, neurobehavioral adaptation as well as cognitive task performance, and sleep and Circadian rhythms. The topics include, but are not limited to: design and verification tools that provide predictions of human-system performance; tools that facilitate designing human-system interfaces or environments; tools useful in verifying human-system requirements; psychological factors relevant to crew selection and performance; pre-launch and in-flight crew training systems; self-sufficient operations in case of emergency and without external resources; technology that can assist the mission control operations: design of workflow in vehicle maintenance, preparation checkout, and launch control.

X13.01 Space Human Factors Engineering
Lead Center: JSC
Participating Center(s): ARC

The long-term goal for this subtopic is to enable planning, designing, training, and carrying out human space missions of up to 5 years with crew independence, without re-supply and without real-time communications to Earth. Specifically, this subtopic's focus is the development of innovations in crew equipment; and the development of technologies for assessment, modeling, and enhancement of human performance; and the development of design tools for engineers to incorporate human factors engineering requirements into hardware and software. Proposals are solicited that seek to develop technologies that address these specific needs:

- Monitoring and maintaining human performance non-intrusively. Specifically, minimally invasive and unobtrusive devices and techniques to monitor the behavior and performance (physical, cognitive, perceptual, etc.) of individuals and teams during long-duration space flights or analog missions. Embedded measures to detect significant changes in crew readiness to perform physical or cognitive tasks;
- Predicting human performance: methods and models for predicting effects on physical performance of encumbrances of clothing, space suits, etc. Models for predicting effects of physical environment (e.g., lighting, noise, temperature, contaminants) on human performance. Models to simulate and optimize interactions between humans and equipment/vehicle. Capability to implement time-delay algorithm and functionality into simulation for higher fidelity and effectiveness. Models for predicting effects of cognitive changes on performance;
- Tools to aid in design and evaluation of human-system interfaces for speed, accuracy, and acceptability in a cost-effective and reliable manner: automated analysis of computer-user interfaces for complex display systems to conduct objective review of displays and controls, and to determine compliance with guidelines and standards. Quantitative measures of the effectiveness of user interfaces to be used for task-sensitive evaluations;

- Tools that facilitate the user interface design for human computer interfaces, and for facilitators such as procedures, labels, and instructions. Tools should assist the designer in incorporating contextual information such as the user's task, the user's knowledge, and the system limitations; and
- Tools to build just-in-time system and operational information software to aid human users conducting routine and emergency operations and activities. Such tools might include effective and efficient job aids (e.g., "intelligent" manuals, checklists, and warnings) and support for designing flexible interfaces between users and large information systems. Methods for development of "facilitators" (procedures, labels, etc.) adapted for the development of space vehicle and payload applications.

X13.02 Behavioral Health and Performance
Lead Center: ARC

Behavioral Health and Performance provides the necessary technology, techniques, capabilities, and knowledge that will support mission success, during human exploration flight and return to Earth. This will be accomplished by optimizing the behavioral health and performance of each astronaut and crewmember, and by mitigating psychosocial, neurobehavioral, sensorimotor, cognitive, and sleep chronobiology risks. Behavioral health and performance research contributes to medical standards, guidelines, and requirements and produces design tools and diagnostic measures for the Chief Health and Medical Officer, flight surgeons, and astronauts. The technical areas supported by this program include performance readiness, effective and efficient teamwork for pre-, in-, and post-flight expedition missions, and psychological selection validated criteria, tools, and procedures. Prolonged missions and the associated adaptation and de-conditioning due to microgravity, as well as significant time delays between Earth and the space environment increase the likelihood of serious crew conflict as well as behavioral health and performance decrements. Proposals are solicited that seek to develop core knowledge, predictive models, and enabling technologies that address these specific needs:

- Non-intrusively monitoring and maintaining human performance. Specifically, minimally invasive and unobtrusive devices and techniques to monitor the behavior and performance (physical, cognitive, perceptual, sensorimotor, etc.) of individuals and teams during long-duration space flights or analog missions. Embedded measures to detect significant changes in crew readiness to perform physical or cognitive tasks; and
- Monitoring and maintaining non-intrusively behavioral health. For example, self assessment tools for determining levels of stress, fatigue, conflict, and anxiety of an individual crewmember and training techniques for coping and on-board support tools for behavioral health.

X13.03 Systems Engineering and Requirements
Lead Center: JSC
Participating Center(s): ARC, KSC

The goal of effective Human Systems Integration challenges many areas of technology, including distributed data management and control, sensor interpretation, planning and scheduling, modeling and simulation, and validation and verification of autonomous systems. These various technology areas must eventually be integrated into a system-of-systems. Particular emphasis is placed on the following:

System Engineering Tools
Technologies, tools, and methodologies are needed that assure development activity is congruent with Exploration Mission capability requirements. Decision support tools are needed to help in the visualization of portfolio balance and clear representation of complex systems as well as a capture method for the interactions/interdependencies/interfaces between system elements.

System Simulation Tools
The ability to analyze, synthesize, and develop integrated function-based and simulation-based system architectures in support of Human Systems. Key to this requirement is either the further extension/enhancement of current

available SE tools or acquisition/development of tools that will allow for system level concept development and concept simulation.

System Integration Tools

The ability to enable human system integration for exploration missions is strongly affected by the structure and architecture of the systems used to sustain and protect the crew. There is a need for the development and evaluation of control architectures and strategies for determining relative benefit, risk, and costs of the utilization of candidate system architectures. Tools for capturing state knowledge of the entire portfolio by project, including dependencies, maturity, and relationships to requirements are also needed.

Capability-based requirements methods require tools and methodologies that enable capture of current practice for information integration between ground-based systems, on-board systems, and crew systems; goal analysis; surveys of existing and proposed technologies; mapping of technology to tasks; prototyping; integrated testing and evaluation criteria; and development of experienced personnel.

Integration Test Bed Tools and Applications

Integrated ground tests for human exploration missions will provide a test bed for development of hardware, requirements, hardware acquisition strategies, novel system concepts, and management. Tools are needed that provide techniques for real-time analysis; techniques for planning, scheduling, and conducting complex integrated mission simulations; tools to develop system-level mathematical models of missions; and systems engineering and analysis tools for mission architecture studies.

Human-System Integration for Manufacturing and Launch Site Operations

Human-System Integration of Manufacturing and Launch Site Operations addresses the following functional areas: Manufacturing, Spacecraft Processing, Launch Control, Landing and Recovery, Repair and Refurbishment, and Enabling Operations. Specific areas of interest include intelligent work instruction systems; maintainer/launch controller situational awareness; human/robotic maintainer on-board capability; reduced size ground crew training modules; and predictive labor requirement models.

Research should be conducted to demonstrate technical feasibility during the Phase 1 contract and show a path toward a Phase 2 hardware and software demonstration. The contractor will, when possible, deliver a demonstration unit of the monitoring instrumentation for NASA testing before the completion of the Phase 2 contract.

TOPIC: X14 Space-Based Industry Enabling Technologies

The goal of this topic is to enable the optimization of investments made in technologies for the development of systems to support and maintain space-based industries and for benefiting NASA's exploration mission infrastructures. As stated in the *Report of the President's Commission on Implementation of United States Space Exploration Policy*, "This new space industry will reduce the cycle time for critical technology innovation. It will immeasurably augment NASA's ability to explore the universe." It is anticipated that, in order to go to the Moon and beyond, a sizable in-space commercial infrastructure will be required. NASA will need this commercially driven infrastructure to build upon in order to further exploration that is affordable and sustainable. This topic seeks breakthrough technologies, concepts, and methods that reduce the cost and risks of the expansion of space-based industries. Innovative approaches are needed that identify what the space-based industries might be doing and their needed infrastructures as well as the technologies required to achieve the infrastructures.

X14.01 Space-Based Industries
Lead Center: MSFC

Innovative techno-economic research proposals are sought for space-based industries ideas that identify their purpose, basic required infrastructures, and how they might complement NASA's exploration missions. The Phase 1 work must sufficiently develop one or more industry ideas to show they are sufficiently feasible, both technically and economically, for Phase 2 demonstrations of their viability. The demonstrations may use physical and mathematical modeling and other research techniques. Each industry idea may have infrastructures that include a wide variety of needed innovations that will be common to NASA's exploration goals as well as to space industries that have a wide variety of purposes like tourism, servicing and maintenance of satellites, food production, energy production, fuels and propellants production, entertainment, in-space fabrication, workshops, hotels and habitats, life support systems, vehicles, freight and warehousing, roads, and spaceports. The research should include economic business models, cost feasibility examination, and analyses that can show how innovations that are common to the multiple goals can save money for NASA as well as space industries. The technical innovations may include, but are not limited to: materials, fabrication processes, power and power distribution, communications, waste management, robotic support, and more. It is expected that the technical innovative ideas will go further than the specific exploration topics and subtopics requests made elsewhere in this 2005 solicitation due to the broader scope of applications.

X14.02 Multi-Use Microgravity and Software
Lead Center: JSC

The purpose of this subtopic is to develop technologies, methodologies, and tools that can support the integrated development of the software system-of-systems necessary for exploration missions. Human space flight challenges many areas of software technology, including distributed data management and control, sensor interpretation, planning and scheduling, modeling and simulation, and validation and verification of autonomous systems. This subtopic focuses on the development portion of the mission life cycle and the dependence of the eventual mission solutions on the processes and methods used to define and build vehicles and support operations. The need for such technologies, methodologies, and tools is evidenced by the low success rate of commercial and government systems, where failure occurs at delivery rather than during operation. Management of the development of such large systems is essential to integration.

Software Architecture and Systems Integration
The challenges of human system integration for exploration missions is strongly affected by the structure and architecture of the software systems required to provide control and status pathways to ground support systems and personnel; to support mission planning and operation; to provide crew interfaces for status, control, and operation of the vehicle systems, science, and operations, including communications, planning, task management, interpersonal activity, system configuration management, inventory, food, workflow, resource management, experiments, and vehicle operation and maintenance. Onboard software must integrate, and be interoperable with the ground support systems for planning, logistics, operations, science, medical, and engineering, as well as with subsequent exploration spirals. This requires the development of structures and methods for determining relative benefits, risks, and costs of the utilization of various engineering approaches. Project management tools are needed that can conduct and manage Exploration Mission capability and technology gap analysis; provide technology-to-capability mapping; map technology gaps to research initiatives; and provide decision support.

Systems Engineering Support to Human Systems
There is a need for new tools to support the development of non-avionic control systems throughout the program life cycle. This includes tools for managing prototyping, requirements, design, design knowledge capture, testing, and growth and maintenance across multiple development teams. Particular emphasis is placed on design methods that address the interdependencies between systems. Adapting the Joint Capabilities Integration and Development System (JCIDS) approach to systems engineering requires development of tools and methodologies that enable: surveys of current information integration practices between ground-based systems, on-board systems and crew systems; goal analysis (software task analysis); surveys of existing and proposed technologies; mapping of technol-

ogy to tasks; prototyping to drive out design constraints and detailed requirements; development of testing and evaluation criteria for advanced or untried architectures and technologies and maturation of those technologies into an integrated system of systems; tracking lessons learned, methods, and processes; and development of an experienced personnel base.

Research should be conducted to demonstrate technical feasibility during the Phase 1 contract and show a path toward a Phase 2 demonstration. The contractor will, when possible, deliver a demonstration unit of the hardware and software for NASA testing before the completion of the Phase 2 contract.

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9.1.3 SCIENCE

The National Aeronautics and Space Administration's (NASA) Vision,

To improve life here, to extend life there, and to find life beyond, and its Mission,

To understand and protect our home planet,
To explore the Universe and search for life, and
To inspire the next generation of explorers
... as only NASA can,

allow the science objectives of the NASA Science Mission Directorate to be clearly defined as the orderly pursuit of the Agency's strategic goals and strategic objectives. Responsibility for achieving several of NASA's strategic objectives (*The New Age of Exploration - NASA's Direction for 2005 and Beyond*, available at http://www.nasa.gov) belongs, in whole or in part, to the Science Mission Directorate (SMD), including:

- Undertake robotic and human lunar exploration to further science and to develop and test new approaches, technologies, and systems to enable and support sustained human and robotic exploration of Mars and more distant destinations;
- Conduct robotic exploration of Mars to search for evidence of life, to understand the history of the Solar System, and to prepare for future human exploration;
- Conduct robotic exploration across the Solar System for scientific purposes and to support human exploration – in particular, explore Jupiter's moons, asteroids, and other bodies to search for evidence of life; to understand the history of the Solar System; and to search for resources;
- Conduct advanced telescope searches for Earth-like planets and habitable environments around other stars;
- Explore the universe to understand its origin, structure, evolution, and destiny;
- Conduct a program of research and technology development to advance Earth observation from space, improve scientific understanding, and demonstrate new technologies with the potential to improve future operational systems;
- Explore the Sun-Earth system to understand the Sun and its effects on Earth, the Solar System, and the space environmental conditions that will be experienced by human explorers, and demonstrate technologies that can improve future operational Earth observation systems; and
- 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.

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

http://science.hq.nasa.gov/

TOPIC: S1 Robotic Exploration of the Moon and Mars

NASA is aggressively pursuing the search for resources on the Moon necessary to sustain prolonged human habitation and water and life on Mars using robotic explorers. NASA will augment this program and prepare for the next decade of research missions by investing in key capabilities to enable advanced robotic missions to the Moon and Mars. This suite of technologies will enable NASA to rapidly respond to discoveries this decade and pursue the search for water and life at Mars wherever it may lead. The technologies developed and tested in each mission will help enable even greater achievements in the missions that follow. See URL: http://mars.jpl.nasa.gov/technology/ for additional information on Mars Exploration technologies. Key goals are to 1) conduct robotic expeditions to further science and to test new exploration approaches, technologies, and systems that will enable future human exploration of the Moon and Mars, and 2) conduct sustained, long-term robotic exploration of Mars to understand its history and evolution, to search for evidence of life, and to expand the frontiers of human experience and knowledge.

S1.01 Detection and Reduction of Biological Contamination on Flight Hardware
Lead Center: JPL
Participating Center(s): ARC

As solar system exploration continues, NASA remains committed to the implementation of its planetary protection policy and regulations. A Mars sample return mission is being planned for the next decade. Other missions will seek evidence of life through *in situ* investigations far from Earth. One of the great challenges, therefore, is to develop or find the technologies or system approaches that will make compliance with planetary protection policy routine and affordable. Planetary protection is directed to 1) the control of terrestrial microbial contamination associated with robotic space vehicles intended to land, orbit, flyby, or otherwise be in the vicinity of extraterrestrial solar system bodies, and 2) the control of contamination of the Earth by extraterrestrial solar system material collected and returned by such missions. The implementation of these requirements will ensure that biological safeguards, to maintain extraterrestrial bodies as biological preserves for scientific investigations, are being followed in NASA's space program. Methods for the detection and reduction of biological contamination are also frequently applicable to non-biological particulate and molecular contamination. To fulfill its commitment, NASA seeks technologies and systems approaches that will support mission compliance with planetary protection requirements. Examples of such technologies include:

- Techniques for cleaning of organics to the level of nanograms per square centimeter on complex surfaces (nondestructively and without residues) and for validation of cleanliness at this level or better;
- Nonabrasive cleaning techniques for narrow aperture occluded areas on spacecraft;
- Techniques for *in situ* (i.e., at the exploration site) cleaning and sterilization to prevent cross-contamination between planetary surface samples;
- Nondestructive and highly efficient sampling methods for detection of the remnants of microbial, particles, and molecular contamination on cleaned spacecraft surfaces;
- Methodology for the quantitative detection of viable microbial cells in the interior of non-metallic spacecraft materials;
- Rapid cleaning validation methods with ultra high sensitivity for the major classes of biomolecules: proteins, amino acids, DNA/RNA, lipids, polysaccharides, etc.;
- A device or methodology for controlled measurement of microbial reduction at temperatures from 200-300°C to enable generation of microbial lethality curves. Rapid ramp-up and cool-down rates are critical to minimize the microbial killing that occurs during the ramp periods;
- Device or methodology for direct observation and evaluation of particles and biological contamination on spacecraft parts;
- Device or methodology for quantitative and homogeneous deposition of particles, microbial cells, and biomolecules on material surfaces for cleaning, sampling, and contamination transport studies;

- System design concepts to enable facile and rapid use of cleaning and sterilization technologies during flight hardware assembly;
- System design concepts to maintain the integrity of cleaned and sterilized complex flight systems and/or subsystems; and
- System concepts that would facilitate spacecraft sterilization at the system level just before launch or in flight.

Research should be conducted to demonstrate technical feasibility during Phase 1 and to show a path toward a Phase 2 hardware and software demonstration. The research will, when possible, deliver a demonstration unit or software package for JPL testing before the completion of the Phase 2 contract.

S1.02 Mars *In Situ* Robotics Technology
Lead Center: JPL
Participating Center(s): LaRC

During future exploration of planets, moons, and small solar system bodies (such as comets and asteroids), developments are needed in new innovative robotic technologies for surface operations, subsurface access, and autonomous software for each. Because of limited spacecraft resources, elements must be robust and have low power, volume, mass, computation, telemetry bandwidth, and operational overhead requirements. Successful technologies will have to operate in environments characterized by extremes of temperatures, pressures, gravity, high-gravity landing impacts, vibration, and thermal cycling. In particular, this subtopic seeks technology innovations in the following areas:

Subsurface Access
Research should be conducted to develop complete, lightweight, dry drilling systems with a penetration depth of 10–50 m and have the capability of penetrating both regolith and rocks. The development should focus on significant reduction in mass from the currently available state-of-the-art interplanetary drilling systems as well as the automation required for real-time control and fault diagnosis and recovery. In addition, because of the lack of water in most of the environments of interest, the drilling should be performed without a lubricant between the bit and rock. Of interest also is the development of ice penetrators, designed with explicit consideration of limited computation and power, which use heat to melt their way through the surface.

Rover Technology
Long-range autonomous navigation systems that focus on long distance (greater than 5 km) traverses through natural terrain, using no a priori knowledge of the subject terrain. Inflatable rover technology with a focus on the development of low-mass, highly capable platforms for exploration of extreme terrain through innovations in novel mechanisms and the automation required for real-time control. Concepts for new mobility systems or components, such as innovative wheel or suspension designs. Instrument placement with a focus on improved tools for the design of manipulation systems, to perform contact and noncontact operations such as drilling, grasping, sample acquisition, sample transfer, and contact and noncontact science instrument placement and pointing. Modular robotic joints that are small (0.5 kg), low power, low mass and can be used to build prototype manipulators and/or legs. Quick changeout mechanisms for planetary manipulators that can enable changing of tools or instruments on the end of a manipulator.

Of particular interest is infrastructure for research, including low-cost, mass producible, research-quality rovers and supporting elements. The development of a low-cost, Rocker-Bogie style, six-wheel steerable, robotic research platform that can drive around in rough terrain is desired.

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

S1.03 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:

- Space-qualifiable, efficient (greater than 20% wall plug), lightweight, variable repetition-rate (1–60 MHz), tunable (± 0.1 nm) pulsed 1064-nm transmitter sources (diode-pumped fiber amplifier or bulk crystal laser/amplifier) with greater than 1 kW of peak power per pulse (over the entire pulse-repetition rate), and greater than 10 W of average power, and narrow (<10 pm) spectral width;
- Space-qualifiable, high-peak power (> 1.2 W), average-power (> 300 mW), operating wavelength less than 1000 nm single-mode-fiber pigtailed laser diode transmitters (includes necessary modulator; internal or external driver) with narrow spectral width (< 100 pm) supporting 4-ary pulse-position-modulation for data rates of 0.5 - 1000 Mbps with high wall-plug electrical-efficiency (> 25%);
- Space-qualifiable, reliable (> 3 years at 100 Mega photons per second continuous photon flux), photon counting 1064 nm and/or 1550 nm detectors with the gain greater than 1000, detection efficiency greater than 50%, very low (<0.1 MHz) additive noise, about 0.5 mm in diameter, bandwidth greater than 500 MHz, saturation levels >50Mcounts/s. and non-gated (continuous operation);
- Lightweight, compact, high precision (less than 0.1 micro-radian), high bandwidth (0–2kHz), inertial reference sensors (angle sensors, gyros) for use onboard spacecraft;
- Novel schemes for stray-light control and sunlight mitigation, especially for large (> 5 m) ground-based optical telescopes that must operate when pointed to within a few (about 3) degrees of the Sun;
- Low-cost, lightweight, efficient, r pigtailed laser diode transmitters including compact, high precision (one micro-radian accuracy) star-trackers for spaceflight application that can be integrated with an optical communications terminal;
- Novel techniques and technologies that will enable very low cost, large aperture (>5m equivalent aperture diameter) telescopes for ground or space-borne use;
- High power ground-based, relatively low-cost diode-pumped laser technology capable of reaching 100 kW average power levels in a TEMoo mode, for uplink to spacecraft;
- Artificial laser guide-star and beam compensation techniques capable of removing all significant atmospheric turbulence distortions (tilt and higher-order components) on an uplink laser beam;
- Novel techniques to reduce the development cost and risk of future space-borne optical communications transceivers (e.g. automatic focusing or alignment techniques);
- High BW Intersatellite Links (ISL) in Earth orbit and deep space ISL or possibly satellite to ground communications; and
- Systems and technologies relating to sub-microradian pointing, acquisition, and spacecraft vibration.

Research should be conducted to demonstrate technical feasibility during Phase 1 and 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.

S1.04 Entry, Descent and Landing
Lead Center: JPL
Participating Center(s): LaRC, ARC, JSC

Entry, Descent, and Landing (EDL) systems are an enabling component of future planetary surface and airborne explorations. EDL systems are naturally comprised of a wide variety of tightly integrated subsystems. These subsystems can include, but are not limited to: entry body, thermal protection, avionics for guidance during entry and/or powered descent (including terrain sensors), aerodynamic decelerators including supersonic or subsonic parachutes, and touch-down systems. In addition to these hardware specific subsystems, algorithms for guidance and hazard detection are an integral element of future EDL systems. Innovations are sought that provide benefits in the following general areas: increased payload delivery mass, improved delivery accuracy, and improved hazard detection and avoidance. The intended outcome of these improvements is to develop the capability to land safely within 100m or less of a preselected landing site and to deliver larger payloads for future Mars missions. In particular, this subtopic seeks technology innovations in the following areas:

- Entry body systems and subsystems including lightweight aeroshells and thermal protection;
- Entry guidance algorithms/methods/techniques capable of reducing uncertainty in parachute deployment altitude, for missions employing bank-only control (i.e., no control of angle of attack) during hypersonic entry;
- Aerodynamic decelerator systems including supersonic and subsonic parachutes. Particular areas of interest include approaches that hold promise for delivering increased mass to the surface (e.g., increasing the Mach-Q deployment envelope beyond Viking-heritage capability) and techniques of reducing the cost of testing/validating the performance of new aerodynamic decelerator systems for use at Mars. Also of interest are para-guidance techniques for pinpoint landing;
- Terrain hazard detection approaches that provide real-time three-dimensional terrain mapping capability during parachute descent and powered terminal descent. In addition, compact, low-mass, high accuracy, and high bandwidth GNC sensors such as attitude and velocity sensors are highly desirable; and
- Lightweight, low-cost, hazard-tolerant touchdown system approaches including (but not limited to) airbag, shock struts, and structural crush zones; allowing landings in moderately cratered terrains with surface rock distribution encountered over a wide variety of Martian landing sites.

S1.05 Sample Return Technologies
Lead Center: JPL
Participating Center(s): JSC

The NASA Mars Exploration Program has recently adopted a plan that includes a Mars Sample Return mission. Such a mission would require breaking the chain of contact with Mars: the exterior of the sample container must not be contaminated with unsterilized Mars material. One mission concept involves placing a grapefruit sized sample container in Mars orbit where it can be picked up by an orbiting spacecraft for return to Earth. Tenuous issues of contamination of the sample container exterior with Mars dust must be dealt with as well as contamination-free handling of the return sample in the receiving facility.

Receiving Facility Sample Handling Technologies
The items described briefly below would find eventual utilization in a sample receiving facility whose basic functions are to do physical and chemical characterizations, bio-hazard detection, and life detection, within a series of double-walled containment vessels. The facility would be operated with significant utilization of robotics, operated either *in situ*, or remotely, or both.

- Demonstrate fine-scale manipulations, either *in situ* or remotely, of a strawman 6-axis ultra-clean robot within the confines of a double-walled containment vessel. The robot can be current state-of-art. Demonstrate the use of different end effectors to manipulate small samples for observation. The task may require use and/or modification of current state-of-the-art control software.
- Demonstrate a sample container/carrier, possibly adapted from a container/carrier currently in use by semiconductor and/or pharmaceutical industries; that has the capability to be identified (labeled) and tracked, for use in cataloging, transporting, and tracking samples of various kinds; generally of approximately 100-micron size, and consisting of fines, dust, individual grains, and very small rocks, or gases; following the certification of these samples for release to a facility for long-term curation and distribution;
- Develop double-walled gloves for use within a double-walled containment vessel. Such gloves would perhaps require self-healing and/or warning systems, in case of a breach, and be compatible with ports developed for double-walled containment vessels; and

- Identify specific sterilization methods and techniques for use in sterilization of extraterrestrial samples. Determine the sterilization levels achieved for sample coupons defined and/or provided by a NASA-sponsored science/biosafety working group.

Miniature Leak Detector
Proposals are sought for the development of a miniature, low-mass, low-power leak detection sensor that can be used to indicate a loss of pressure from a container with a volume of 0.5 liter, that has a pressure of 6 torr, as expected on Mars. Areas of interest include:

- A sensor, driver, and the power source designed for placement inside the container that is made of metal. The metal alloy that will be used will be determined at a later time;
- The sensor and its control electronics that provides power, data processing, and communications should not exceed the volume of 5-cm^3;
- The device should be operational at temperatures that are as low as -70°C and as high as room temperature; and
- A miniature battery as power source is acceptable. Preferably, a wireless power transfer mechanism and a rechargeable battery that is designed for placement inside the container, would be preferred.

Sample Containerization and Protection
Proposals are sought for the development of a robust method of sealing a sample that would be acquired from an extraterrestrial surface for possible return to Earth in future NASA missions. Areas of interest include:

- A simple and reliable process of hermetically seaming and sealing a "coffee-cup" size container with a rock or soil sample;
- The process needs to simultaneously perform sterilization of the container sealed area and its external surface while releasing the container into an area that simulates a clean section of a lander;
- This process should "break-the-chain" of contact of an acquired soil or rock sample from the original area that simulates the environment of an extraterrestrial planet;
- The required process needs to simultaneously seal the contained sample while destroying any potential biological materials that may contaminate the external surface of the container;
- The process to sterilize the surface of a grapefruit-sized sample container in Mars orbit (e.g., pyrotechnic paint) requiring minimal power and minimizing effect on the sample container interior;
- The contained sample should be protected from any mechanical, chemical, or thermal damage during or after the activation of the "break-the-chain" process;
- The process needs to be computer simulated and allow a high degree of control of its parameters; and
- Demonstrate probability of success of the feasibility to seal the container while performing sterilization.

Sample Acquisition
Proposals are sought for mechanisms to acquire clean core samples for Mars rocks and regolith including development of low-mass, low-normal-force, 10x1 cm coring tool, low-mass core sampling tool integrated with sample containment, acquire Mars dust samples, and development of six-axis force-torque sensor (ranges about 160 Newtons, 15 N-m) operating in Mars ambient.

TOPIC: S2 Robotic Exploration Throughout the Solar System

NASA's program for Solar System Exploration seeks to answer fundamental questions about the Solar System and life: How do planets form? Why are planets different from one another? Where did the makings of life come from? Did life arise elsewhere in the solar system? What is the future habitability of Earth and other planets? The search for answers to these questions requires that we augment the current remote sensing approach to solar system exploration with a robust program that includes *in situ* measurements at key places in the solar system, and the return of materials from them for later study on the Earth. We envision a rich suite of missions to achieve this including a comet nucleus sample return, a Europa lander, and a rover or balloon-borne experiment on Saturn's moon, Titan, to name a few. These robotic explorers will pursue compelling scientific questions, demonstrate breakthrough technologies, identify space resources, and extend an advanced telepresence that will send stunning imagery back to Earth. Numerous new technologies will be required to enable such ambitious missions. This topic includes investments in technology to enable the delivery and access of scientific instruments to planetary surfaces and atmospheres. This includes landing, flying, roving, and digging, as well as sample acquisition for delivery to instruments. This topic will also address Earth entry vehicles for sample return missions, planetary protection, and contamination control for *in situ* missions. The planetary bodies of interest are the Moon, Mars, Venus, Titan, and the icy satellites of the outer planets.

S2.01 Science Instruments for Conducting Solar System Exploration
Lead Center: JPL
Participating Center(s): ARC

This subtopic supports the development of advanced instruments and instrument technology to enable or enhance scientific investigations on future planetary missions. New measurement concepts, advances in existing instrument concepts, and advances in critical components are all of interest. Proposers are strongly encouraged to relate their proposed technology development to future planetary exploration goals.

Instruments for both remote sensing and *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 remote sensing, on orbital or flyby spacecraft, or for *in situ* measurements, on surface landers and rovers, subsurface penetrators, and airborne platforms. *In situ* instruments cover spatial scales from surface reconnaissance to microscopic investigations. These instruments must be capable of withstanding operation in space and planetary environmental extremes, which include temperature, pressure, radiation, and impact stresses.

Examples of instruments that will meet the goals include, but are not limited to, the following:

- Instrumentation for definitive chemical, mineralogy, and isotopic analysis of surface materials: soils, dusts, rocks, liquids, and ices at all spatial scales, from planetary mapping to microscopic investigation. Examples include advanced techniques in reflectance spectroscopy, wet chemistry, laser-induced breakdown spectrometers, water and ice detectors, novel gas chromatograph and mass spectrometry, and age-dating systems;
- Instrumentation for the assessment of surface terrain and features. Examples include lidar systems and advanced imaging systems;
- Geophysical sensing systems to determine the near-surface and subsurface structure, textures, bulk components, and composition, such as seismic sensors, porosity measurement devices, permeameters, and surface penetrating radars;
- Instruments and components that will rely on, and take advantage of, high power capabilities (up to 100 kW) for measurements of planetary surfaces. The instruments may make direct or indirect use of the power, long duration observations, or extremely high data rates;
- 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;

- Instrumentation for the chemical and isotopic analysis of planetary atmospheres;
- Advanced detectors for solar absorption spectrometry. One example is a detector that is fast and linear, i.e., does not saturate under high photon fluxes;
- Environmental sensing systems, such as meteorological sensors, humidity sensors, wind and particle size distribution sensors, and sounders for atmospheric profiling;
- Particles and fields measurements, such as magnetometers, and electric field monitors; and
- Enabling instrument component and support technologies, such as laser sources, miniaturized pumps, sample inlet systems, valves, integrated bulk sample handling and processing systems, and fluidic technologies for sample preparation.

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

S2.02 Extreme High Temperature/High Pressure Environment
Lead Center: JPL
Participating Center(s): GRC

Proposals are sought for technologies to enable operation and survivability in high-temperature/high-pressure space environments. These technologies service the needs of the future *in situ* exploration of Venus as well as the atmospheric probes for giant planets.

Venus features a dense, CO_2 atmosphere completely covered by clouds with sulfuric acid aerosols, a surface temperature of 486ºC, and a surface pressure of 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 (380°C) and high pressures (>100 bar) is also required for deep atmospheric probes to giant planets.

Technology needs for high-temperature and high-pressure environments include:

- Advanced passive and active thermal control for Venus missions, including lightweight (50 kg/m^3), high strength/stiffness, high buckling stress resistant pressure vessels to protect the electronics and instruments for several hours; new lightweight thermal insulation materials with conductivity less than 0.1 W/mK at 486ºC, thermal storage systems with 300–1000 kJ/kg energy density, thermal switches with a switching ratio of at least 100:1 between "On" and "Off" modes, and high temperature heat pipe systems operating over a temperature range of 25 to 500ºC. Refrigeration systems capable of pumping heat from a 25 to 75ºC source to the Venus sink temperature of 486ºC;
- Science and engineering sensors able to operate at 486ºC and 100 bar, including for example, high temperature imagers, hybrid imaging system that utilizes high temperature fiber optics, seismometers, and pressure sensors;
- High-temperature, low-power, and ultra low-power electronics and electronic packaging technology for sensor and actuator interfaces at 486ºC, including low-noise (10 nV/sqHz) preamplifiers, power amplifiers and transmitters (S-band), temperature stable oscillators, drivers (with 0–100 V digital output for driving piezoelectric, electrostatic, or electromagnetic actuators), and high value (on the order of one to hundreds of micro Farad) capacitors;
- Computer Aided Design (CAD) tools for predicting the performance, reliability, and life cycle for high-temperature electronic systems and components;
- High-temperature primary batteries (200 Whr/kg)) for operation at 380ºC and 486ºC;
- Actuators for sample handling and acquisition systems including high-temperature drills, motors, and actuators able to operate in the 486ºC, 90 atmosphere surface environment of Venus; and

- Anticorrosive coatings to protect optical systems and spacecraft structures from corrosive agents present in the upper levels of Venus' atmosphere (sulfuric acid clouds) or near surface (besides carbon oxide and nitrogen, the atmosphere contains sulfuric acid, hydrochloric acid, and hydrofluoric acid).

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 or software package for JPL testing at the completion of the Phase 2 contract.

S2.03 Nanosensors
Lead Center: JPL
Participating Center(s): ARC

The subtopic seeks to leverage breakthroughs in the emerging fields of nano-technology and biotechnology to develop advanced sensors and actuators with increased sensitivity and small size for solar system exploration. Technologies should provide enhanced capabilities over the current state-of-the-art and be able to operate in an extreme environment. This harsh environment includes steady operation and cycling in the temperature range of -180 degrees Centigrade to 100 degrees Centigrade, and high radiation. Of particular interest are harsh environment-operable nanosystems for single molecule sensing and manipulation, on-chip biomolecular analysis, and semiconductor laser diodes in the 2-5 um wavelength range, and detectors in the greater than 15 um wavelength range.

S2.04 Deep Space Power Systems
Lead Center: GRC
Participating Center(s): GSFC, JPL, JSC

Innovative concepts using advanced technology are solicited in the areas of energy conversion, power electronics, and power system materials. Power levels of interest range from milliwatts to 1 KW. NASA Space Science missions in deep space environments require energy systems with long life capability, high radiation tolerance, reliability, and low overall costs (including operations) which can operate in high and low temperatures and over wide temperature ranges. Advanced technologies are sought in the following areas:

Energy Conversion
All proposed energy conversion technologies must be able to show substantial increases over state-of-the-art in efficiency and specific power (W/kg) and to operate in deep-space environments with high radiation and wide-temperature operations (-200°C to 300°C). Long-life (>14 years), highly reliable advanced energy conversion technologies are sought that keep manufacturability in mind. Advances in photovoltaic technology are sought, including high power solar arrays and ultra lightweight, thin film, and concentrator arrays. Advances in radioisotope thermal to electric power conversion technology (milliwatt/multiwatt and 100W-1KW classes with efficiencies (state-of-the-art) are sought. This includes advances in thermophotovoltaics, thermoelectrics, Brayton, Rankine, and Stirling technologies as well as compact heat exchangers. Innovative control methods are also sought.

Power Electronics
Advanced power electronic materials and devices for deep-space power systems are sought. The materials of interest include soft magnetics, dielectrics, insulation, and semiconductors. Devices of interest include transformers, inductors, electrostatic capacitors, high-power semiconductor switches and diodes, and integrated control and driver circuits. Proposed technologies must improve upon the following characteristics: high temperature operation (>200°C), low-temperature (cryogenic) operation, wide-temperature operation (-125°C to 200°C), and/or high levels of space radiation (>150 krad) resistance.

Electronics Packaging and Materials
Advanced electronics packaging technologies that reduce volume and mass capable of either high temperature, cryogenic, wide temperature operation, and/or space radiation resistance for use in space power systems are of

interest. Advances are sought in power electronics packaging materials, surfaces, and components that are durable for soft X-ray, electron, proton, and ultraviolet radiation and thermal cycling environments.

S2.05 Astrobiology
Lead Center: ARC
Participating Center(s): JPL

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. Biomarkers produced by microbial communities are profoundly affected by internal biogeochemical cycling. The small spatial scales at which these biogeochemical processes operate necessitate measurements made using microsensors. The search for life on other planetary bodies will also require systems capable of moving and deploying instruments across, and through, varied terrain to access biologically important environments.

A second element of Astrobiology is the understanding of the evolutionary development of biological processes leading from single-cell organisms to multi-cell specimens and to complex ecological systems over multiple generations. Understanding of the effects of radiation and gravity on lower organisms, plants, humans, and other animals (as well as elucidation of the basic mechanisms by which these effects occur) will be of direct benefit to the quality of life on Earth. These benefits will occur through applications in medicine, agriculture, industrial biotechnology, environmental management, and other activities dependent on understanding biological processes over multiple generations.

A third component of Astrobiology includes the study of evolution on ecological processes. Astrobiology intersects with NASA Earth Science studies through the highly accelerated rate of change in the biosphere being brought about by human actions. One particular area of study with direct links to Earth Science is microbe–environment interactions.

NASA seeks innovations in the following technology areas:

- For Mars exploration, technologies that would enable to provide a broad survey of areas in the vicinities of a rover or lander to narrow a field of search for biomarkers;
- For Mars exploration, technologies that (using X-ray, neutron, ultrasonic, and other types of tomography) would enable a noninvasive, nondestructive analysis of the subsurface environment and areas inside rocks and ice to depths 10–20 cm with spatial resolutions of 2–10 microns. Such technologies should provide the capability for analysis of structures inside opaque matrices created by endolithic organisms or fossil structures and possible elemental analysis of such structures;
- Technologies that would enable the aseptic acquisition of deep subsurface samples, the detection of aquifers, or enhance the performance of long-distance ground roving, tunneling, or flight vehicles are required;
- For Europa exploration, technologies to enable the penetration of deep ice are required;
- Desirable features for both Mars and Europa exploration include the ability to carry an array of instruments and imaging systems, to provide aseptic operation mode, and to maintain a pristine research environment;
- Low-cost, lightweight systems to assist in the selection and acquisition of the most scientifically interesting samples are also of significant interest;
- High sensitivity, (femtomole or better) high-resolution methods applicable to all biologically relevant classes of compounds for separation of complex mixtures into individual components;
- Advanced miniaturized sample acquisition and handling systems optimized for extreme environment applications;
- 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;

- High spatial resolution (5 angstrom level) electron microscopy techniques to establish details of external morphology, internal structure, elemental composition, and mineralogical composition of potential biogenic structures;
- Innovative software to support studies of the origin and evolution of life. The areas of special interest are (1) biomolecular and cellular simulations, (2) evolutionary and phylogenetic algorithms and interfaces, (3) DNA computation, and (4) image reconstruction and enhancement for remote sensing;
- Technologies capable of measuring a range of volatile compounds at small spatial scales. Improved sensor designs for a wide range of analytes, including oxygen, pH, sulfide, carbon dioxide, hydrogen, and small molecular weight organic acids both on and near surfaces that could serve as habitats for microbes;
- Biotechnology – determining mutation rates and genetic stability in a variety of organisms as well as accurately determining protein regulation changes in microgravity and radiation environments;
- Automated chemical analytical instrumentation for determining gross metabolic characteristics of individual organisms and ecologies as well as chemical composition of environments;
- Spectral and imaging technology with high resolution and low power requirements;
- Habitat support – technologies for supporting miniature closed ecosystems, data collection, and transmission technologies in concert with the automated chemical instrumentation described above;
- Miniature-to-microscopic, high-resolution, field-worthy, smart sensors, or instrumentation for the accurate and unattended monitoring of environmental parameters that include, but are not limited to, solar radiation (190–800 nm at <1 nm resolution), ions and gases of the various oxidation states of carbon and nitrogen (at the nanomolar level for ions in solution and at the femtomolar or better level for gases), in a variety of habitats (e.g., marine, freshwater, acid and alkaline hot springs, and permafrost);
- High-resolution, high-sensitivity (femtomole or better) methods for the isolation and characterization of nucleic acids (DNA and RNA) from a variety of organic and inorganic matrices;
- Mathematical models capable of predicting the combined effects of elevated pCO_2 (change in CO_2 over the eons) and solar UV radiation on carbon sequestration and N_2O emissions from experimental data obtained from field and laboratory studies of C-cycling rates, N-cycling rates, as well as diurnal and seasonal changes in solar UV;
- Microscopic techniques and technologies to study soil cores, microbial communities, pollen samples, etc., in a laboratory environment for the detailed spectroscopic analysis relevant to evolution as a function of climate changes; and
- Robotic systems designed to provide access to environments such as deep-ocean hydrothermal vents.

S2.06 Advanced Flexible Electronics
Lead Center: JPL

Electronically steerable L-band, phased array antennas are needed for missions to the Moon, Mars, Titan, and Venus. L-band provides the capability to detect surface and subsurface topology including ice or features hidden by the surface dust. Flexible, lightweight active arrays enable better packaging efficiency for the antenna and are critical for these missions. Currently, manufacturing reliable passive arrays with required tolerances is challenging and the only method for integration of the electronics is to attach and interconnect the electronic components on the surface. This method is expensive, unreliable, and impractical for large arrays. Technologies enabling large area flexible antennas, including flexible electronics, are needed. State-of-the-art, flexible, printable electronics have low switching frequencies. Innovative new materials or processes will be needed to enable devices that can handle the gigahertz frequencies needed for radar. In addition, large area manufacturing methods are needed to manufacture these passive and active antennas.

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

S2.07 Risk Modeling and Analysis
Lead Center: JPL
Participating Center(s): LaRC

The purpose of this subtopic is to advance the state-of-the-art in risk modeling and analysis, particularly for use in early design (formulation) phases. Of particular interest would be methods for risk characterization and modeling that extend beyond typical technical aspects, including software, programmatic, operations, organization, and management elements. This subtopic includes tools and methods, visualization techniques, and process enhancements. Technical areas to address include:

- Uncertainty modeling including both epistemic and aleatory uncertainties;
- Attribute-driven risk identification;
- Risk reduction modeling that includes both preventative and mitigative activities;
- Methods for aggregation and/or integration of quantitative and qualitative risks;
- Methods for characterization and integration of software, organizational, operations, and other non-physics based risks;
- Integration of risks and risk insights into the trade and formal design processes, including new techniques for risk visualization and new methods for directly trading risk against other design aspects;
- Development of risk model library elements and techniques for selecting, maintaining, and integrating the elements;
- Methods for cost-effective adaptation and utilization of PRA and other probabilistic methods in early design (e.g., conceptual design) which can be integrated directly into the design process (i.e., can be utilized directly by the system designers without additional analyst support); and
- Methods for risk-based margin determination and management.

TOPIC: S3 Astronomical Observatories to Seek Earth-like Extrasolar Planets and Environments

The NASA Science Missions Directorate seeks to conduct advanced telescope searches for Earth-like planets and habitable environments around neighboring stars. This topic will consider technologies necessary to enable future telescopes and observatories collecting all electromagnetic bands, ranging from X-rays to millimeter waves, and also include gravity waves. The subtopics will consider all technologies associated with the collection and combination of any observable signals.

S3.01 Precision Formations for Interferometry
Lead Center: JPL

This subtopic seeks hardware and software technologies necessary to establish, maintain, and operate hyper-precision spacecraft constellations to a level that enables separated spacecraft optical interferometry. Also sought are technologies for analysis, modeling, and visualization of such constellations.

In a constellation for large effective telescope apertures, multiple, collaborative spacecraft in a precision formation collectively form a variable-baseline interferometer. These formations require the capability for autonomous precision alignment and synchronized maneuvers, reconfigurations, and collision avoidance. It is important that, in order to enable precision spacecraft formation keeping from coarse requirements (relative position control of any two spacecraft to less than 1 cm, and relative bearing of 1 arcmin over target range of separations from a few meters to tens of kilometers) to fine requirements (micron relative position control and relative bearing control of 0.1 arcsec), the interferometer payload would still need to provide at least 1–3 orders of magnitude improvement on top of the S/C control requirements. The spacecraft also require onboard capability for optimal path planning and time optimal maneuver design and execution.

Innovations that address the above precision requirements are solicited for distributed constellation systems in the following areas:

- Integrated optical/formation/control simulation tools;
- 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; and
- Six degrees of freedom precision formation test beds.

S3.02 High Contrast Astrophysical Imaging
Lead Center: JPL
Participating Center(s): ARC

This subtopic addresses the unique problem of imaging and spectroscopic characterization of faint astrophysical objects that are located within the obscuring glare of much brighter stellar sources. Examples include, planetary systems beyond our own and the detailed inner structure of galaxies with very bright nuclei. Contrast ratios of one million to one billion over an angular spatial scale of 0.05–1.5 arcsec are typical of these objects. Achieving a very low background against which to detect a planet 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 any starlight cancellation scheme.

This innovative research focuses on advances in coronagraphic instruments, interferometric 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 Origins Program theme will be similar in character to instruments used for present day space astrophysical observations. The performance and observing efficiency of these 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, coronography, 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 ~1 μm;
- 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;
- Fiber optic spatial filter development for visible coronagraph wavelengths;
- 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;
- 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. The most promising DM technology may be sensitive to temperature, so developing a MUX that has very low thermal hot spots, and very uniform temperature performance will improve the control of the mirror surface; and
- High precision wavefront error sensing and control techniques to improve and advance coronagraphic imaging performance.

S3.03 Precision Deployable Lightweight Cryogenic Structures for Large Space Telescopes
Lead Center: JPL
Participating Center(s): MSFC

Planned future NASA Origins Missions and Vision Missions such as the Single Aperture Far-IR (SAFIR) telescope, Life Finder, and Submillimeter Probe of the Evolution of Cosmic Structure (SPECS), require 10–30 m class telescopes that are diffraction limited at wavelengths between the visible and the near IR, and operate at temperatures from 4–300 K. The desired areal density is 3–10 kg/m^2. Wavefront control may be either passive (via a high stiffness system) or active control. Potential architecture implementations must package into an existing launch volume, deploy and be self-aligning to the micron level. The environment is expected to be L2.

This topic solicits proposals to develop enabling component and subsystem technology for these telescopes in the areas of precision deployable structures, i.e., large deployable optics manufacture and test; innovative concepts for packaging integrated actuation systems; metrology systems for direct measurement of the structure; deployment packaging and mechanisms; active control implemented on the structure (downstream corrective and adaptive optics are not included in this topic area); actuator systems for alignment (2 cm stroke actuators, lightweight, submicron dynamic range, nanometer stability); mechanical and inflatable deployable technologies; new thermally-stable materials for deployables; new approaches for achieving packagable structural depth; etc.

The goal for this effort is to mature technologies that can be used to fabricate 20 m class, lightweight, 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 volume and 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.

S3.04 Large-Aperture Lightweight Cryogenic Telescope Components and Systems
Lead Center: MSFC
Participating Center(s): JPL, GSFC

Planned future NASA infrared, far infrared, and submillimeter missions, such as the Single Aperture Far-IR (SAFIR) telescope, Interferometric Terrestrial Planet Finder (TPF-I), Infrared Origin's Probes, Space Infrared Interferometric Telescope (SPIRIT), and Submillimeter Probe of the Evolution of Cosmic Structure (SPECS) require both 10–30 m and 2–4 m class telescopes that are diffraction limited at 5–20 mm and operate at temperatures from 4–10 K. The desired areal density is 3–10 kg/m^2. Wavefront control may be either passive (via a high stiffness system) or active control (via mechanisms and deformable mirrors). Potential architecture implementations include 2 m class segments, 4 m class mirrors, or membrane systems. Component and system testing techniques are a particular challenge for low areal density or cryogenic specific architectures. It is anticipated that active cooling will be required. Potential telescope system architectures require transporting 1 W of heat at 15 K with 5 W/K, while others require 100 mW at 4 K with 1 W/K.

This topic solicits proposals to develop enabling component and sub-system technology for cryogenic telescopes, including but not limited to: large-aperture lightweight cryogenic optic manufacture and test; thermal management, distributed cryogenic cooling and multiple heat lift; structure, deployment, and mechanisms; deployable cryogenic coolant lines; active wavefront control; etc. The goal for this effort is to mature technologies that can be used to fabricate 2–4 m and 10–30 m class lightweight cryogenic flight-qualified telescope primary mirror systems at a cost of less than $300,000 per square meter. Proposals to fabricate demonstration components and subsystems with direct scalability to flight will be given preference.

TOPIC: S4 Exploration of the Universe Beyond Our Solar System

The Universe division of the NASA/GSFC is charged with exploring the universe beyond the solar system – out to its very edges. To do this, requires ever more powerful missions (beyond Chandra, Spitzer, and Hubble) with larger and better optics and detector systems. Future mission may include optics that fold and deploy and can be assembled on orbit, as well as larger arrays of detectors, bolometers, microcalorimeters (superconducting), and room temperature semiconductors. Our missions cover the full range of the electromagnetic spectrum and gravitational waves. Some of our major science goals are to identify dark matter, to understand dark energy, to produce a census of black holes, to image material in the accretion disks around black holes, and to measure gravitational waves from a wide range of sources. In addition, we are exploring new technologies for sub-orbital platforms including long duration balloons, tethered balloons, and airships. We are soliciting ideas and concepts in six areas covering optical systems, UV, visible, IR and sub-mm detectors, X-ray and Gamma-ray detectors, lasers for gravitational wave measurements, and sub-orbital platforms. The subtopics in this area are described in detail in each subtopic section.

S4.01 Infrared and Sub-mm Sensors and Detectors
Lead Center: JPL
Participating Center(s): MSFC

NASA astrophysics missions currently under development, such as Sofia, Herschel, and Planck (http://science.hq.nasa.gov/missions/phase.html) have been enabled by improvements in sensors and detectors. Beyond 2007, expected advances in detectors, readout electronics, and other technologies, particularly those enabling polarimetry and large format imaging arrays for the far IR/submm and spectroscopy with unprecedented sensitivity. These advances may enable future mission concepts such as the Single Aperture Far Infrared (SAFIR) Observatory (http://safir.jpl.nasa.gov/technologies/index.asp), SPICA (http://www.ir.isas.ac.jp/SPICA/), and CMBPOL.

Space science sensor and detector technology innovations are sought in the following areas:

Mid/Infrared, Far Infrared and Submillimeter
Future space-based observatories in the 10-40 micron spectral regime will be passively cooled to about 30 K. They will make use of large, sensitive detector arrays with low-power dissipation array readout electronics. Improvements in sensitivity, stability, array size, and power consumption are sought. In particular, novel doping approaches to extend wavelength response, lower dark current and readout noise, novel energy discrimination approaches, and low noise superconducting electronics are applicable areas. Future space observatories in the 40 micron to 1 mm spectral regime will be cooled to even lower temperatures, frequently <10 K, greatly reducing background noise from the telescope. In order to take advantage of this potentially huge gain in sensitivity, improved far infrared/submillimeter detector arrays are required. The goal is to provide noise equivalent power less than 10-20 W Hz-1/2 over most of the spectral range in a 100x100 pixel detector array with low-power dissipation array readout electronics. The ideal detector element would count individual photons and provide some energy discrimination. For detailed line mapping (e.g., C+ at 158 micron), heterodyne receiver arrays are desirable, operating in the same frequency range near the quantum limit.

Space Very Long Baseline Interferometry (VLBI)
The next generations of VLBI missions in space will demand greatly improved sensitivity over current missions. These new missions will also operate at much higher frequencies (at first to 86 GHz and eventually to 600 GHz). These thrusts will require development of improved space-borne, low-power, ultra-low-noise amplifiers and mixers to serve as primary receiving instruments.

S4.02 Terrestrial and Extra-Terrestrial Balloons and Aerobots
Lead Center: GSFC
Participating Center(s): JPL

Innovations in materials, structures, and systems concepts have enabled buoyant vehicles to play an expanding role in NASA's Science Mission Directorate and Exploration Systems Mission Directorate. A new generation of large, stratospheric balloons, based on advanced balloon envelope technologies, will be able to deliver payloads of several thousand kilograms to above 99.9% of the Earth's absorbing atmosphere and maintain them there for months of continuous observation. NASA is seeking innovative and cost-effective solutions in support of terrestrial balloons in the following areas:

- Innovative concepts for reducing the UV degradation of flight components including balloon membranes, load carrying members, and parachute components;
- Innovative concepts for the measurement of strain in a thin film during flight;
- Innovative sensor concepts for balloon gas or skin temperature measurements;
- Innovative concepts for trajectory control and/or station keeping for effectively maneuvering large terrestrial balloons in either the horizontal latitude or vertical altitude plane or both;
- Innovative low-mass, high-density, and high-efficiency power systems for terrestrial balloons that produce 2 kW or more continuously;
- Innovative power systems that enable long duration, sunlight independent missions for durations of 30 days or more;
- Innovative floatation systems for water recovery of payloads;
- Innovative guided or gliding parachutes systems for use in thin atmospheres;
- Innovative balloon design concepts for long duration missions that can provide any or all of the following: reduced material strength requirements, increased reliability, enhanced performance, reduced manufacturing time, reduced manufacturing cost, or improved mission flexibility; and
- Smaller scale, but similarly designed, balloons and airships will also 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:

Aerobot Surface Sample Acquisition Device
NASA is soliciting concepts and prototypes for surface sample acquisition devices that can be used on aerobots to collect icy material from Titan and Mars. Typical sample volumes range from 1 to 2 cubic centimeters, with preference for a solid ice core as well as possible granular material. Collection depths of 0 to 2 cm are desired. Preferred techniques do not require close proximity of the aerobot balloon skin to the ground to reduce the probability of damaging the vehicle during sample acquisition. Examples include tethered collection devices deployed from modest altitudes (10s to 100s of meters) or short duration "touch and go" sampling from directional and/or altitude controlled aerobots. Proposed devices can be disposable (single use), but if reusable must avoid cross-contamination between samples. All devices must include solid sample transfer functionality to an analysis chamber on the aerobot itself. Concepts will be preferred that feature low mass (few kilograms or less), small volume (~1 liter) and low electrical power consumption drawn from the aerobot (<10 W) devices.

Apex Valve for Montgolfiere Balloons
Solar-heated Montgolfiere balloons are an attractive platform for the exploration of Mars, particularly the polar regions which experience long periods of solar illumination during summer solstice. These balloons can be altitude controlled through selective venting of the heated gas through a valve located at the apex of the balloon. Proposals are sought for concepts and prototypes for this valve to be used on a solar-heated balloon on Mars. Typical specifications include large flow area (10 m^2), low mass (few kilograms), packaged into a small volume for transport to Mars (<0.1 m^3) and consume minimal electrical energy (<5 W).

Aerial Deployment Modeling Tool
Planetary aerobots at Mars, Titan, and Venus will likely be aerially deployed and inflated 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 films 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/m^2.

S4.03 Cryogenic Systems for Sensors and Detectors
Lead Center: GSFC
Participating Center(s): JPL, MSFC

Stored cryogenic systems have long been used to perform cutting edge space science, but at high cost and with a limited lifetime. Improvements in cryogenic system technology 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 coolers for cooling detectors for scientific instruments and sensors on advanced telescopes and observatories as well as lunar and planetary exploration. The coolers should have long life, low vibration, low mass, low cost, and high efficiency. Specific areas of interest include:

- Highly efficient coolers in the range of 4-10 Kelvin as well as at 50 milli-Kelvin and below, and cryogen-free systems which integrate these coolers together;
- Highly reliable, efficient, low-cost Stirling and pulse tube cooler technologies in the 15 Kelvin and 35 Kelvin regions;
- Essentially vibration-free cooling systems such as reverse Brayton cycle cooler technologies;

- Highly efficient magnetic and dilution cooling technologies, particularly at very low temperatures;
- Hybrid cooling systems that make optimal use of radiative coolers; and
- Miniature, MEMS, and solid-state cooler systems.

S4.04 Optics and Optical Telescopes (including X-Ray, UV, Visual, IR)
Lead Center: GSFC
Participating Center(s): JPL, MSFC

With the reorganization of NASA activities into the Exploration Mission Directorate (EMD) and the Space Mission Directorate (SMD), there is a renewed call for novel optical technologies that extend the state-of-the-art across wavelength bands from far-IR to Gamma-ray. Missions to study the Earth and Sun, the other solar system planets and objects, and the origins and fate of the universe are proposed to operate from low Earth orbit to L2 or drift-away trajectories depending on their system of study and environmental requirements.

Among other areas of study, future planet finder missions will require lightweight optical apertures of tens of square meters with sub-nanometer surface figure errors. Infrared versions will require cooling optics to cryogenic temperatures (to 4 K). Telescopes studying the Sun and its environment in the UV and EUV (20-300 nm wavelength) require novel optical coatings and filters, high precision aspheric optics, and high-density uniform and variable line density diffraction gratings. And high-energy X-ray telescopes will study the origins and fate of the universe with <10 arcsec resolution and effective areas of square meters. Many of these missions have apertures so large that they will require multiple spacecraft to fly in formation, either to combine their optical apertures or to perform sparse interferometric observations.

For all missions, low-mass optics and deployment structures are extremely important. Also, wavefront sensing and control systems are sought that may alleviate the stringent mass and stiffness requirements of such large optics. Finally, advanced, low-cost manufacturing, metrology, and modeling techniques will be required to make these missions possible.

The previous year's Optical Technologies (S2.04) and UV and EUV Optics (S1.06) have been merged to form this year's Optics and Optical Telescopes subtopic. All previously relevant areas of research are invited in this new subtopic including:

Optics

- Ultra-smooth (2–3 Angstroms rms) replicated optics that are rigid and lightweight;
- Lightweight, high modulus (e.g., silicon carbide) optics and structures;
- Ultra-stable optics over time periods from minutes to hours;
- Cryogenic optics, structures, and mechanisms for space telescopes and interferometers;
- High-performance, diamond turned optics (including freeform optical surfaces);
- Large, thin, ultra-lightweight grazing incidence optics for X-ray mirrors with angular resolutions less than 5 arcsec. (>100 cm^2, <1 mm thick, and <10 kg/m^2 areal density);
- Wide field-of-view optics using square pore slumped microchannel plates or equivalent;
- Large, ultra-lightweight optical mirrors (<1 kg/m^2 at near-IR through visible), including membrane optics for very large aperture space telescopes and interferometers;
- UV and EUV Imaging mirrors with simultaneously large aperture (1-4 m diameter), low mass (5-20 kg/m^2), accurate figure (~0.01 wave rms or better at 632 nm), and low micro-roughness (<1 nm @ <1 mm period). Figure accuracy must be maintained through launch and on-orbit (including, for mirrors subjected to direct or concentrated solar radiation, the effects of differential heating); and
- Smooth sub-mm scale image slicer and microlens array component technologies to allow fabrication of integral field spectrographs in the UV and visible, for simultaneous spectroscopy of two spatial dimensions and one spectral dimension.

Filters

- Large area, thin blocking filters with high efficiency at low energy X-ray energies (<600 eV);
- Ultraviolet filters with deep blocking (<1 part in 10^5) of longer and shorter wavelengths, including "solar blind" performance; novel near- to far-IR filters with increased bandwidth, stability, and out-of-band blocking performance;
- FUV and EUV coatings (filters) with improved reflectivity (transmission) and selectivity (narrow bands, broad bands, or edges). Technologies include multilayers, transmission gratings, and Fabry-Perot etalons, among others; and
- Improved X-ray and Gamma-ray modulation optics and coded aperture masks (sub-arcsecond resolution at 10 keV to 10 arcsecond resolution at 1 MeV).

Gratings

- Fabrication techniques for ultra-thin-flat silicon (or like material) for grating substrates for X-ray energies <0.5 keV;
- High resolving power diffraction gratings (>4000 lines/mm) at acceptable focal lengths and pixel sizes; and
- Improvements in grating manufacturing technologies, such as high efficiency/low scatter gratings, variable line spacing, improved echelle gratings, active grating surfaces (gratings replicated onto deformable substrates), and gratings ruled onto concave, aspheric surfaces.

Metrology

- Low-cost, high quality, large optics fabrication processes and test methods including active metrology feedback systems during fabrication, and artificial intelligence controlled systems;
- Portable and miniaturized state-of-the-art optical characterization instrumentation and rapid, large-area surface-roughness characterization techniques are needed. Calibrated processes for determination of surface roughness using replicas made from the actual surface. Traceable surface roughness standards suitable for calibrating profilometers over sub-micron to millimeter wavelength ranges are needed; and
- Instruments capable of rapidly determining the approximate surface roughness of an optical surface, allowing modification of process parameters to improve finish, without the need to remove the optics from the polishing machine. Techniques for testing the figure of large, convex, aspheric surfaces to fractional wave tolerances in the visible.

Wavefront Sensing and Control

- Optical systems with high-precision controls, active and/or adaptive mirrors, shape control of deformable telescope mirrors, and image stabilization systems; and
- Advanced, wavefront sensing and control systems including image based wavefront sensors;
- Nanometer to sub-picometer metrology for space telescopes and interferometers.

Optical Design

- Advanced analytical models, simulations, and evaluation techniques, and new integrations of suites of existing software tools allowing a broader and more in-depth evaluation of design alternatives and identification of optimum system parameters including optical, thermal, structural, and dynamic performance of large space telescopes and interferometers.

S4.05 Sensor and Detector Technology for UV, X-Ray, Gamma-Ray and Cosmic-Ray Instruments
Lead Center: GSFC
Participating Center(s): MSFC

The next generation of astrophysics observatories for the infrared, ultraviolet (UV), X-ray, and Gamma-ray bands require order-of-magnitude performance advances in detectors, detector arrays, readout electronics, and other supporting and enabling technologies. Although the relative value of the improvements may differ among the four energy regions, many of the parameters where improvements are needed are present in all four bands. In particular, all bands need improvements in spatial and spectral resolutions in the ability to cover large areas and in the ability to support the readout of the thousands to millions of resultant spatial resolution elements.

Innovative technologies are sought to enhance the scope, efficiency, and resolution of instrument systems at all energies and wavelengths:

- The next generation of gravitational missions will require greatly improved inertial sensors. Such an inertial sensor must provide a carefully fabricated test mass, which has interactions with external forces (i.e., low magnetic susceptibility, high degree of symmetry, low variation in electrostatic surface potential, etc.) below 10–16 of the Earth's gravity, over time scales from several seconds to several hours. The inertial sensor must also provide a housing for containing the proof mass in a suitable environment (i.e., high vacuum, low magnetic and electrostatic potentials, etc.);
- Advanced Charged Couple Device (CCD) detectors, including improvements in UV quantum efficiency and read noise, to increase the limiting sensitivity in long exposures and improved radiation tolerance. Electron-bombarded CCD detectors, including improvements in efficiency, resolution, and global and local count rate capability. In the X-ray, we seek to extend the response to lower energies in some CCDs, and to higher, perhaps up to 50 keV, in others;
- Significant improvements in wide band gap (such as GaN and AlGaN) materials, individual detectors, and arrays for UV applications;
- Improved microchannel plate detectors, including improvements to the plates themselves (smaller pores, greater lifetimes, alternative fabrication technologies, e.g., silicon), as well as improvements to the associated electronic readout systems (spatial resolution, signal-to-noise capability, and dynamic range), and in sealed tube fabrication yield;
- Imaging from low-Earth orbit of air fluorescence, UV light generated by giant airshowers by ultra-high energy (E >1019 eV) cosmic rays require the development of high sensitivity and efficiency detection of 300–400 nm UV photons to measure signals at the few photon (single photo-electron) level. A secondary goal minimizes the sensitivity to photons with a wavelength greater than 400 nm. High electronic gain (~106), low noise, fast time response (<10 ns), minimal dead time (<5% dead time at 10 ns response time), high segmentation with low dead area (<20% nominal, <5% goal), and the ability to tailor pixel size to match that dictated by the imaging optics. Optical designs under consideration dictate a pixel size ranging from approximately 2 x 2 mm^2 to 10 x 10 mm^2. Focal plane mass must be minimized (2 g/cm^2 goal). Individual pixel readout. The entire focal plane detector can be formed from smaller, individual sub-arrays;
- For advanced X-ray calorimetry improvements in several areas are needed, including:
    - Superconducting electronics for cryogenic X-ray detectors such as SQUID-based amplifiers and their multiplexers for low impedance cryogenic sensors and superconducting single-electron transistors and their multiplexers for high impedance cryogenic sensors.
    - Micromachining techniques that enhance the fabrication, energy resolution, or count rate capability of closely-packed arrays of X-ray calorimeters operating in the energy range from 0.1–10 keV; and
    - Surface micromachining techniques for improving integration of X-ray calorimeters with read-out electronics in large-scale arrays.
- Improvements in readout electronics, including low-power ASICs and the associated high-density interconnects and component arrays to interface them to detector arrays;

- Superconducting tunnel junction devices and transition edge sensors for the UV and X-ray regions. For the UV, these offer a promising path to having "three-dimensional" arrays (spatial plus energy). Improvements in energy resolution, pixel count, count rate capability, and long wavelength rejection are of particular interest. We seek techniques for fabrication of close-packed arrays, with any requisite thermal isolation, and sensitive (SQUID or single electron transistor), fast, readout schemes and/or multiplexers;
- Arrays of CZT detectors of thickness 5–10 mm to cover the 10–500 keV range, and hybrid detector systems with a Si CCD over a CZT pixelated detector operating in the 2–150 keV range;
- For improvements to detector systems for solar and night-time UV and EUV (approx. 20–300nm) observing. the following areas are of interest: large format (4 K x 4 K and larger); high quantum efficiency; small pixel size; large well depth; low read noise; fast readout; low power consumption (including readout); intrinsic energy and/or polarization discrimination (3d or 4d detector); active pixel sensors (back-illumination, UV sensitivity); and high-resolution image intensifiers, UV and EUV sensitive, insensitive to moisture;
- Space spectroscopic observations in the UV, visible, and IR requiring long observation times would be much more sensitive with high quantum efficiency (QE) and zero read noise. Techniques are sought which improve the QE of photon counters, or eliminate the read noise of solid-state detectors; and
- X-ray and Gamma-ray imaging with higher sensitivity, dynamic range and angular resolution requires innovations in modulation collimators and detection devices. The energy range of interest is from a few kilo-electron Volts to hundreds of milli-electron Volts for observations of solar flares and cosmic sources. Collimators with size scales down to a few microns and thicknesses commensurate with photon absorption over a significant fraction of this energy range are required. Low-background detectors capable of <~keV energy resolution, with or without spatial resolution, are required to record the modulated photon flux. The ability to measure fluxes over a wide dynamic range. The capability to determine the polarization of the photon flux is also desirable.

S4.06 Technologies for Gravity Wave Detection
Lead Center: GSFC
Participating Center(s): JPL, MSFC

Laser Technologies for Gravitational Wave Detection
NASA is now developing the Laser Interferometer Space Antenna (LISA) mission to search for gravitational waves from astrophysical phenomena such as the Big Bang, mergers of supermassive black holes, and galactic binary inspirals. Detection of gravitational waves would open a new astrophysical window on the universe with great potential for unexpected discoveries. A number of gravitational wave follow-on missions to LISA are also under study.

The disturbance caused by the passage of a gravitational wave is expected to be very small (of order picometers) and will be measured with laser interferometry. The technology areas below deal with technical problems in these measurements. Because the systems will be deployed in space, the technologies to be considered must have credible paths toward space flight qualification. Background information on LISA, along with preliminary technology discussions, can be found in the *Proceedings of the 5th International LISA Symposium, ,* Penn State University, 19-24 JULY 2002, published in the *Classical and Quantum Gravity Journal*, Vol 20, Number 10, 21 May 2003.

Issues of Space Qualification of LISA Laser: the LISA laser must produce >1W CW of 1.06 micron light with fiber coupled output (for example, a combination of a lower-power master oscillator {eg, NPRO} with suitable amplifier). The laser will have the following characteristics:

- 10 year lifetime;
- Power stability <0.1% (10 Hz to 2 MHz); and
- Linewidth <5 kHz (over 1 msec).

This task will involve investigating the issues of space qualification of the system, experimentally studying the relevant problems, and proposing a realistic plan of development of this system. Given the magnitude of the effort to develop a space qualified LISA laser, it is not expected that the outcome of this task will result in a space qualified laser; rather, the outcome should be a sufficient understanding of the important technical issues in space qualification (e.g., diode lifetime, thermal and vibrational robustness, etc.) so that a clear path towards the development of a fully space qualified system can be identified.

LISA Electro-optical Modulator: produce a phase modulator for a 1 W continuous laser beam, providing 10% power modulation depth at frequencies from 1.9 to 2.1 GHz. The modulator should be fiber coupled (input and output), at 1.06 micron wavelength. The modulator must be space qualified.

LISA Telescope Articulator: produce a mechanical actuator that can articulate the LISA telescope over a 5 mm dynamic range with a 0.1 nm resolution. The actuator must be space qualified and have noise <0.01 nm.

TOPIC: S5 Sun-Solar System Connection

The strategic priorities of the Sun-Solar System Connection derive from a stated NASA Strategic Objective, namely: “Explore the Sun-Earth system to understand the Sun and its effects on Earth, the solar system, and the space environmental conditions that will be experienced by human explorers, and demonstrate technologies that can improve future operational systems.” SSSC has identified three science and exploration objectives. The program will provide the knowledge needed to: 1) open the frontier to space environment prediction: understand the fundamental physical processes of the space environment – from the Sun to Earth, to other planets, and beyond to the interstellar medium; 2) understand the nature of our home in space: understand how society, technological systems, and the habitability of planets are affected by the variable space environment; 3) safeguard our outbound journey: maximize the productivity and safety of human and robotic explorers by developing predictive capability for the extreme and dynamic conditions in space.

S5.01 Low Thrust and Propellantless Propulsion Technologies
Lead Center: MSFC
Participating Center(s): GRC, GSFC, JPL, JSC, LaRC

Spacecraft propulsion technology innovations are sought for upcoming deep-space science missions. Propulsion system functions for these missions include primary propulsion, maneuvering, planetary injection, and planetary descent and ascent. Innovations are needed to reduce spacecraft propulsion system mass, volume, and/or cost. Applicable propulsion technologies include advanced chemical, solar sails, aerocapture, and emerging technologies.

Advanced Chemical Propulsion
Innovations in low-thrust chemical propulsion system technologies are being sought for deep-space, scientific, robotic mission applications. Delta Vs for the missions of interest range from 1000 m/sec to 3000 m/sec. Technologies of interest are bipropellant engines with Isp greater than 360 seconds, both pressure-fed and pump-fed, with chamber pressures ranging from 100 to 500 psia. Throttling capability is desired for engines used for planetary ascent, descent, and orbit insertion maneuvers. Passive long-term storage (greater than 5 years) for advanced bipropellant propulsion systems for deep space missions are of interest. Reliable ignition systems are needed for non-hypergolic propellants. Activities in development of lightweight, compact, and low-power propellant management components, such as valves, flow control/regulation, fluid isolation, and lightweight tankage are also solicited. Advanced materials to allow development of systems for use with advanced bipropellants (higher Isp, higher pressure) are also solicited.

Solar Sail Propulsion
Solar sails have been studied for a variety of missions and have the potential to provide cost-effective, propellantless propulsion that enables longer on-station operation, increased scientific payload mass fraction, and access to previously inaccessible orbits (e.g., non-Keplerian, high solar latitudes, etc.).

NASA missions enabled and enhanced by solar sail propulsion include those that can provide: 1) situational awareness for human and robotic exploration in the Earth-Moon system (e. g., Heliostorm, L1 Diamond); 2) comprehensive monitoring of the inner heliosphere (e.g., Solar Sentinels, Solar Polar Imager, Particle Acceleration Solar Observatory); and 3) pathfinder exploration beyond the solar system (Interstellar Probe). The technology required for these missions can further be classified into two categories: 1) near-term (<15 years) for use in orbits that are between 0.9 AU and 0.5 AU with a propulsive area of greater then 1 x 104 m^2; and 2) far-term (>15 years) for use in orbits at <0.25 AU with a propulsive area of greater then 1 x 105 m^2. A solar sail propulsion system includes the sail membrane and support structure, the thrust vector control subsystem, the health and monitoring diagnostic subsystem, and the launch stowage structure. Three parameters that are used as sail performance metrics in mission applications are: sail size, sail durability in its orbital environment, and areal density (ratio of sail system mass to propulsive area of the sail). In addition, important programmatic metrics are cost, benefit, and risk. Innovations are sought that will lower the cost and risk associated with sail system development through advancements in: manufacturing, fabrication, and assembly; durable lightweight materials, structures, and mechanisms; comprehensive simulations of maneuvering, navigation, trajectory control, propulsive performance, and operations; and integrated diagnostic health monitoring.

Tether Technologies

This effort focuses on technologies supporting innovative and advanced concepts for propellantless propulsion based upon space tethers concepts. The categories under Tether Technologies include, but are not limited to: ElectroDynamic (ED) tether propulsion, Momentum eXchange Electrodynamic Reboost (MXER) tethers or its subsystems, Jovian tether mission concepts, Earth orbiting telescope ED tether reboost, and other innovative in space tether technologies. In general, the electrodynamic tether propulsion method exchanges momentum with a planet's rotational angular momentum through electrodynamic interaction with the planetary magnetic field. Momentum exchange tethers or MXER concepts use orbital energy to provide a high thrust to a payload in LEO. Distinctive variations of existing propulsion methods or chief subsystem component improvements are also suitable for submission. Proposals should provide the development plan of specific innovative technologies or techniques supporting the planned research. Identification of the fundamental technology to be developed is also crucial. A clear plan for demonstrating feasibility, noting any test and experiment requirements, is recommended. Key to each idea is an unambiguous knowledge of past research/concepts conducted on related work and specifically how this new proposal differs from, or enhances, the existing tether roadmaps, particularly for robotic mission support.

Aeroassist

Aeroassist is a general term given to various techniques to maneuver a space vehicle within an atmosphere using aerodynamic forces in lieu of propulsive fuel. Aeroassist systems enable shorter interplanetary cruise times, increased payload mass, and reduced mission costs. Subsets of aeroassist are aerocapture and aerogravity assist. Aerocapture relies on the exchange of momentum with an atmosphere to achieve a decelerating thrust leading to orbit capture. This technique permits spacecraft to be launched from Earth at higher velocities, thus providing a shorter overall trip time. At the destination, the velocity is reduced by aerodynamic drag within the atmosphere. Without aerocapture, a substantial propulsion system would be needed on the spacecraft to perform the same reduction of velocity. Aerogravity assist is an extension of the established technique of gravity assist with a planetary body to achieve increases in interplanetary velocities. Aerogravity assist involves using propulsion in conjunction with aerodynamics through a planetary atmosphere to achieve a greater turning angle during planetary fly-by. In particular, this subtopic seeks technology innovations that are in the following areas:

Aerocapture

Thermal Protection Systems: development of advanced thermal protection systems and insulators for planetary aerocapture.

Low Temperature/High Temperature Adhesives Trade Study: aerocapture inflatable decelerators are currently proposed to be manufactured from thin film materials and/or high temperature fabrics, stowed during transport, and inflated prior to atmospheric entry for aerocapture applications at planetary destinations.

- Prior to the aerocapture maneuver, the inflatable decelerator will be stowed for many years (up to 10) in an uncontrolled space environment (-130^{o}C) during transport to outer solar system destinations;
- Before atmospheric entry, the inflatable decelerator will be unstowed and inflated; and
- During the aerocapture maneuver, up to 24 hours after the inflation process, the inflatable decelerator will experience temperatures to 500^{o}C (or higher).

Conduct a thorough study of the adhesives trade space and select and test adhesive candidates that will maintain bond strength during the temperature extremes and long-term space exposure experienced by inflatable decelerators. The product of this study will be a report thoroughly documenting sample preparation, test procedures, and test results of all materials investigated. This report will be disseminated to inflatable decelerator developers.

S5.02 Accommodation and Mitigation of Space Environmental Effects
Lead Center: GSFC
Participating Center(s): GRC, JPL, KSC, MSFC

This subtopic is concerned with improving the capability to accommodate or mitigate the effects of the space environment on spacecraft design and operations. It will achieve its goal by designing and building flight investigations, developing models, collecting data from investigations in space and from ground tests, and analyzing data to improve the models, tools, and/or databases used for spacecraft design and operations. The resulting products will reduce the design margins and uncertainties in the induced environment definition (i.e., the environment in the presence of a spacecraft) and its effects on spacecraft design and operations. The environments to be considered include planetary-trapped radiation, solar proton events, cosmic rays, the plasma environment at planets and in the solar wind, magnetic fields, EUV/VUV, and the interplanetary meteoroid environment.

The investigations selected have the opportunity to be integrated on the Space Environment Testbed (SET) Carrier. The SET Project opportunities for flight will be in orbits other than LEO. Investigations do not need to fly with the SET Carrier if an investigator makes arrangements for other access to space.

Examples of investigations and models that would satisfy those requirements are described below. A more detailed description, with examples of investigation needs, can be found at: http://lws-set.gsfc.nasa.gov/Opportunities.htm.

Areas for which proposals are sought include:

- Characterization of the space environment, both natural and induced, in the vicinity of a spacecraft;
- Definition of the mechanisms for material and materials applications degradation and the performance characterization of materials (such as coatings, optical properties, composites, etc.) in the space environment;
- Accommodation and/or mitigation of charging/discharging effects on spacecraft and spacecraft components;
- Methods for performance improvement of radiation tolerance of microelectronics used in space, including reduction of single event upsets and other single particle-induced soft errors, and elimination of single event latch-ups and other single particle-induced destructive conditions;
- Development of novel methods for increasing crew safety and system performance relative to the effects of the natural space environment; and
- Development of novel methods of increasing ground-based systems performance and reliability by reducing the effects of the natural space environment on those systems (e.g., space environment-induced soft errors in the power grid).

S5.03 Technologies for Particles and Fields Measurements
Lead Center: GSFC

The SEC theme encompasses the Sun with its surrounding heliosphere carrying its photon and particle emissions and the subsequent responses of the Earth and planets. This requires remote and *in situ* sensing of upper atmospheres and ionospheres, magnetospheres and interfaces with the solar wind, the heliosphere, and the Sun. Improving our knowledge and understanding of these requires accurate *in situ* measurements of the composition, flow, and thermodynamic state of space plasmas and their interactions with atmospheres, as well as the physics and chemistry of the upper atmosphere and ionosphere systems. Remote sensing of neutral atoms are required for the physics and chemistry of the Sun, the heliosphere, magnetospheres, and planetary atmospheres and ionospheres. Because instrumentation is severely constrained by spacecraft resources, miniaturization, low power consumption, and autonomy are common technological challenges across this entire category of sensors. Specific technologies are sought in the following categories.

Plasma Remote Sensing (e.g., neutral atom cameras)
This may involve techniques for high-efficiency and robust imaging of energetic neutral atoms covering any part of the energy spectrum from 1 eV to 100 keV, within resource envelopes less than 5 kg and 5W.

- Miniaturized, radiation-tolerant, autonomous electronic systems for the above, within resource envelopes of 1–2 kg and 1–2 W.

***In Situ* Plasma Sensors**

- Improved techniques for imaging of charged particle (electrons and ions) velocity distributions as well as improvements in mass spectrometers in terms of smaller size or higher mass resolution;
- Improved techniques for the regulation of spacecraft floating potential near the local plasma potential with minimal effects on the ambient plasma and field environment;
- Low power, digital, time-of-flight analyzer chips with subnanosecond resolution and multiple channels of parallel processing; and
- Miniaturized, radiation-tolerant, autonomous electronic systems for the above, within resource envelopes of 1–2 kg and 1–2 W.

Fields Sensors

- Improved techniques for measurement of plasma floating potential and DC electric field (and by extension, the plasma drift velocity), especially in the direction parallel to the spin axis of a spinning spacecraft;
- Measurement of the gradient of the electric field in space around a single spacecraft or cluster of spacecraft;
- Improved techniques for the measurement of the gradients (curl) of the magnetic field in space local to a single spacecraft or group of spacecraft;
- Direct measurement of the local electric current density at spatial and time resolutions typical of space plasma structures such as shocks, magnetopauses, and auroral arcs; and
- Miniaturized, radiation-tolerant, and autonomous electronic systems for the above within resource envelopes of 1–2 kg and 1–2 W.

Electromagnetic Radiation Sensors

- Radar sounding and echo imaging of plasma density and field structures from orbiting spacecraft; and
- Miniaturized, radiation-tolerant, and autonomous electronic systems for the above within resource envelopes of 1–2 kg and 1–2 W.

TOPIC: S6 Earth-Sun System Instrument and Sensor Technology

NASA's Earth-Sun Systems (ESS) Division is committed to studying how our global environment is changing. Using the unique perspective available from spaceborne and airborne platforms, NASA is observing, documenting, and assessing large-scale environmental processes with emphasis on atmospheric composition, climate, carbon cycle and ecosystems, the Earth's surface and interior, the water and energy cycles, and weather. A major objective of ESS instrument development programs is to implement science measurement capabilities with small 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. 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 Earth observing instruments and to enable new Earth observations measurements. The following subtopics are concomitant with this objective and are organized by measurement technique.

S6.01 Passive Optics
Lead Center: LaRC
Participating Center(s): ARC, GSFC, MSFC

The following technologies are of interest to NASA in the remote sensing subtopic "passive optics." Passive optical remote sensing generally requires that deployed devices have large apertures and large throughput. NASA is interested primarily in instrument technologies suitable for aircraft or space flight platforms, and these inherently also prefer low mass, low power, fast measurement times, and a high degree of robustness to survive vibrations in flight or at launch. Wavelengths of interest range from ultraviolet through the far infrared. Development of techniques, components and instrument concepts that can be developed for use in actual deployed devices and systems within the next few years is highly encouraged.

Technologies and components that are not clearly suitable for use in high throughput remote sensing instruments are not applicable to this subtopic. Technical and scientific leads at NASA have given careful consideration to the technology areas described below; responses are solicited for these topics.

- Technology leading to visible/NIR narrowband optical filters exhibiting greatly improved degradation properties over existing filters and minimal spectral drift for long-term space-based applications;
- Technology leading to significant improvements in capability of large format (>1 inch diameter), very narrow band (<5 cm^{-1} full-width at half-maximum [FWHM]), polarization insensitive, high-throughput infrared (0.7–15 µm) optical filters;
- Large format (>1 inch diameter), high-transmission, far infrared filters. Technology and techniques leading to filters operating at wave numbers between 500 and 5 cm^{-1} with FWHM less than 2 cm^{-1} are of immediate interest, though technology leading to very high transmission edge filters (long and short pass) is also solicited. The filters must be capable of operating in a vacuum at cryogenic temperatures; and
- High-performance, four-band two-dimensional (2D) arrays (128x128 elements) in the 0.4 – 2.5 µm wavelength range with high quantum efficiencies (60%–80% or higher) in all spectral bands, low noise, and ambient temperature operation.

S6.02 Lidar Remote Sensing
Lead Center: LaRC
Participating Center(s): GSFC

High spatial resolution, high accuracy measurements of atmospheric parameters from ground-based, airborne, and spaceborne platforms, require advances in the state-of-the-art lidar technology with emphasis on compactness, reliability, efficiency, low weight, and high performance. Innovative technologies that can expand current measurement capabilities to airborne, spaceborne, or Unmanned Aerial Vehicle (UAV) platforms are particularly desirable. Development of components that can be used in actual deployed systems within the next few years is highly encouraged. Technologies and components that are not clearly suitable for effective lidar remote sensing or field deployment are not applicable to this subtopic. This subtopic considers components that enable Earth-sun system measurements such as:

- Cloud and aerosols with emphasis on aerosol optical properties;
- Wind profiles using direct-detection lidar, or coherent-detection (heterodyne) lidar, or both;
- Land topography (vegetation, ice, land use); and
- Molecular species (ozone, water vapor, and carbon dioxide).

Innovative component technologies that directly address the measurement needs above will be considered. Dual-use technologies addressing Planetary Exploration are highly desirable (see subtopics X1.03 and S1.04). For the PY05 SBIR, we are soliciting component technologies described below.

1. Pulsed, single frequency, diode-based seed laser MOPA systems are desired due to inherent robustness, efficiency, thermal and alignment stability. If the cost per unit is reasonable, and the size is small, then many of these can be installed on a spacecraft for either parallel operation or as backup units to lengthen the life of the mission. Systems with the following specifications are solicited:
    - Single frequency 1064 nm operation.
    - Small, pinned package(s) that can generate CW powers in the 100's of mW and higher pulse powers yielding at least 10 nJ pulse energies.
    - Gaussian pulsewidths between 100 ps and 5 ns.
    - MOPA design configuration is desired where the pulse production cavity is short and more readily impedance matched for the fast rise times, gain switching, etc.
    - A semiconductor amplifier, or possibly a small cm-scale Yb:fiber amplifier, can be coupled to the oscillator chip’s output, itself contained in a hermetic butterfly or similar package.
    - Repetition rates as low as 100 Hz and as high as 10 kHz is needed, with pulsed lifetimes in the trillion shot regime (10^{12}).
    - Single mode, PM fiber output is needed.
    - Short term drift less than 1 MHz.

2. CW, dual frequency, diode-based seed laser systems are desired for high power solid-state laser cavity feedback and locking at 1064 nm. If two wavelengths are produced, one must be 1064 nm and another single wavelength 5 nm or more offline (in either direction). Systems with the following specifications are solicited:
    - Simultaneous dual frequency operation; 1064 nm and a second wavelength at least 5 nm (either plus or minus) from 1064 nm.
    - Small, pinned package(s) that can generate CW powers in the 100s of mW and higher pulse powers.
    - CW output powers of >10 mW in each wavelength. Individual tunability is not required, but tunability of the 1064 nm output is required.
    - Dual PM, single mode fiber output is desired, but not absolutely required.
    - 5 MHz or less short term drift over 30 sec.

3. 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 2 mJ to 100 mJ, repetition rate 10 Hz to 200 Hz, and pulse duration of approximately 200 nsec.

4. Shared aperture, angle-multiplexed holographic or diffractive optical elements having several fields of view, each with angular resolution of 50 µrad or better for the Nd:YAG or Nd:YLF laser harmonics, and diffraction limited resolution for the Ho:YLF fundamental wavelength. Wide, flat, focal planes with low

off-axis aberrations is of importance to terrain and vegetation mapping lidar applications. Hybrid designs using both 2053 nm or 1064 nm and 355 nm simultaneously are needed for dual wavelength Doppler wind lidar applications. Materials and technologies are needed that can be scaled up to 1 m apertures and larger and space qualified. Designs using lightweight materials, such as composites or membranes and deployable folded architectures, are also desired to decrease system size and weight.

5. Novel, high-power laser diodes capable suitable for pumping Holmium-based solid state lasers:
   - Quasi-CW laser diode arrays operating in 1939 nm or 1906.8 nm wavelengths with pulse duration of at least 1 msec, peak power in 10s watts regime, and duty cycle of greater than 2%;
   - Quasi-CW fiber-coupled laser diode pump arrays operating in 785 nm or 792 nm wavelengths with pulse duration of at least 1 msec, peak power in 100s watts regime, and duty cycle of greater than 2%; and
   - CW fiber-coupled laser diode pump arrays operating in 1939 nm or 1906.8 nm wavelengths.

6. Lightweight, compact lidar telescopes operating at one or more of the primary laser wavelengths in 1.0 to 2.0 micron wavelength region. The general requirements are: optical quality better than 1/6 wave at 632 nm, mass density less than 12 kg/m^2, and aperture diameter from 10 cm to 30 cm. Proof of scalability to 0.5-1.0 m diameter for deployment in space is required.

7. Laser beam steering and scanning technologies (such as dual-wedge, diffractive optical elements, and liquid crystal) operating at 1.5 or 2.05 micron with 2 cm to 25-cm aperture diameter meeting the following requirements:
   - 60 deg. field of regard.
   - 90% optical throughput.
   - 1/4-wave single pass optical quality at 632 nm.

S6.03 Earth *In Situ* Sensors
Lead Center: GSFC
Participating Center(s): ARC

Proposals are sought for the development of *in situ* measurement systems that will enhance the scientific and commercial utility of data products from the Earth Science Enterprise program and that will enable the development of new products of interest to commercial and governmental entities around the world. Technology innovation areas of interest include:

- Autonomous Global Positioning System (GPS)-located platforms (fixed or moving) to measure and transmit to remote terminals upper ocean and lower atmosphere properties including temperature, salinity, momentum, light, precipitation, and biogeochemistry;
- Dynamic stabilization systems for small instruments mounted on moving platforms (e.g., buoys and boats) to maintain vertical and horizontal alignment. Systems capable of maintaining a specified pointing with respect to the Sun are preferred;
- Small, lightweight instruments for measuring clouds, liquid water, or ice content (mass) designed for use on radiosondes, dropsondes, aerosondes, tethered balloons, or kites;
- Wide-band microwave radiometers capable of high-speed characterization of cloud parameters, including liquid and ice phase precipitation, which can operate in harsh environmental conditions (e.g., onboard ships and aircraft);
- Autonomous, GPS-located airborne sensors that remotely sense atmospheric wind profiles in the troposphere and lower stratosphere with high spatial resolution and accuracy;
- Systems for *in situ* measurement of atmospheric electrical parameters including electric and magnetic fields, conductivity, and optical emissions;
- Systems to measure line- and area-averaged rain rate at the surface over lines of at least 100 m and areas of at least 100x100 m;

- Lightweight, low-power systems that integrate the functions of inertial navigation systems and GPS receivers for characterizing and/or controlling the flight path of remotely piloted vehicles;
- Low-cost, stable (to within 1% over several months), portable radiometric calibration devices in the shortwave spectral region (0.3 to 3 μm) for field characterization of radiance instruments such as sun photometers and spectrometers;
- Miniaturized, low-power (12V DC) instruments especially suited for small boat operations that are capable of adequately resolving, at the appropriate accuracy, the complex vertical structure (optical, hydrographic, and biogeochemical) of the coastal ocean (turbid) water column. Sensors that can be easily integrated within a digital (serial) network to measure the apparent and inherent optical properties of seawater are preferred; and
- Aircraft or UAV instruments for *in situ* measurements of physical and optical properties of clouds and aerosols with instantaneous measurement volumes ranging from cubic meters up to a maximum of a cubic kilometer, the purpose being to furnish validation for satellite remote sensing at the spatial scales satellites actually provide.

S6.04 Passive Microwave
Lead Center: GSFC

Proposals are sought for the development of innovative passive microwave technology in support of Earth System Science measurements of the Earth's atmosphere and surface. These microwave radiometry technology innovations are intended for use in the frequency band from about 1 GHz to 1 THz. The key science goal is to increase our understanding of the interacting physical, chemical, and biological processes that form the complex Earth system. Atmospheric measurements of interest include climate and meteorological parameters—including temperature, water vapor, clouds, precipitation, and aerosols; air pollution; and chemical constituents such as ozone, NOX, and carbon monoxide. Earth surface measurements of interest include water, land, and ice surface temperatures, land surface moisture, snow coverage and water content, sea surface salinity and winds, and multi-spectral imaging.

Technology innovations are sought that will provide the needed concepts, components, subsystems, or complete systems that will improve these needed Earth System Science measurements. Technology innovations should address enhanced measurement capabilities such as improved spatial or temporal resolution, improved spectral resolution, or improved calibration accuracies. Technology innovations should provide reduced size, weight, power, improved reliability, and lower cost. The innovations should expand the capabilities of airborne systems (manned and unmanned) as well as next generation spaceborne systems. Highly innovative approaches that open new pathways are also an important element of competitive proposals under this solicitation.

Specific technology innovation areas include:

Electronics Technologies
- Imaging radiometers, receivers, or receiver arrays on a chip;
- Microwave and millimeter-wave frequency sources as an alternative to Gunn diode oscillators. Compact (<10 cm3) self-contained oscillators with output frequency between 40 GHz and 120 GHz, low phase noise <125 dBc/Hz at 10 kHz, high output power (>100 mW), and low power consumption (<10 W);
- Wideband and ultra-wideband sensors with >15dB cross-pole isolation across the bandwidth;
- Low noise (<1000 K) with low conversion loss (< 6 dB), compactly designed (< 8 cm3), heterodyne mixers requiring low local oscillator drive power (<2 mW) with RF input frequency range between 100 GHz and 1 THz;
- Undersampling, multibit, analog-to-digital converters with Multigigahertz RF input bandwidth, low power consumption, and associated digital signal processing logic circuit;
- Low power, lightweight microwave with DC power consumption of less than 2 W;
- Electronic design approaches and subsystems that can be incorporated into microwave radiometers to detect and suppress RFI within or near the reception band of the radiometer, thus insuring higher data quality;

- Innovative new designs for highly stable noise-diode or other electronic devices as additional reference sources for onboard calibration. Of particular interest are variable correlated noise sources for calibrating correlation-type receivers used in interferometric and polarimetric radiometers;
- Monolithic microwave integrated circuit (MMIC), low-noise amplifiers (LNA). Of particular interest are LNAs covering the frequency range of 165 to 193 GHz with low 1/f noise, and having a noise figure of 6.0 dB or better; and
- GPS receiver systems for application as bi-static altimeters and scatterometers.

Antenna Technologies

- Sensor elements with low mutual coupling allowing close spacing within large arrays;
- Large format, millimeter wave, focal plane array modules for large-aperture passive imaging applications; and
- Large aperture, deployable antenna concepts. Such large apertures can be real or synthetic. Of particular interest are highly compact launch configurations.

Calibration Technologies

- New technology calibration reference sources for microwave radiometers that provide greatly improved reference measurement accuracy. Of particular interest are high emissivity (near-black-body) surfaces for use as onboard calibration targets for microwave radiometers—which will significantly reduce the weight of aluminum core target designs, while reliably improving the uniformity and knowledge of the calibration target temperature; and
- New approaches, concepts, and techniques for microwave radiometer system calibration over or within the 1-300 GHz frequency band—which provide end-to-end calibration to better than 0.1K, including corrections for temperature changes and other potential sources of instrumental measurement drift and error.

S6.05 Active Microwave
Lead Center: JPL
Participating Center(s): GSFC

Active microwave sensors have proven to be ideal instruments for many Earth science applications. Examples include global freeze and thaw monitoring, soil moisture mapping, accurate global wind retrieval, and snow inundation mapping, global 3D mapping of rainfall and cloud systems, precise topographic mapping and natural hazard monitoring, global ocean topographic mapping, and glacial ice mapping for climate change studies. For global coverage and the long-term study of Earth's eco-systems, space-based radar is of particular interest to Earth scientists. Radar instruments for Earth science measurements include Synthetic Aperture Radar (SAR), scatterometers, sounders, altimeters, and atmospheric radars. The life-cycle cost of such radar missions has always been driven by the resources—power, mass, size, and data rate—required by the radar instrument, often making radar not cost competitive with other remote sensing instruments. Order-of-magnitude advancement in key sensor components will make the radar instrument more power efficient, much lighter weight, and smaller in stow volume, leading to substantial savings in overall mission life-cycle cost by requiring smaller and less expensive spacecraft buses and launch vehicles. Onboard processing techniques will reduce data rates sufficiently to enable global coverage. High performance, yet affordable, radars will provide data products of better quality and deliver them to the users more frequently and in a timelier manner, with benefits for science as well as the civil and defense communities. Technologies that may lead to advances in instrument design, architectures, hardware, and algorithms are the focused areas of this subtopic. In order to increase the radar remote sensing user community, this subtopic will also consider radar data applications and post-processing techniques.

The frequency and bandwidth of operation are mission driven and defined by the science objectives. For SAR applications, the frequencies of interest include UHF (100 MHz), P-band (400 MHz), L-band (1.25 GHz), X-band (10 GHz), and Ku-band (12 GHz). The required bandwidth varies from a few megahertz to 20 MHz to 300 MHz to achieve the desired resolution; the larger the bandwidth, the higher the resolution. Ocean altimeters and scatterometers typically operate at L-band (1.2 GHz), C-band (5.3 GHz), and Ku-band (12 GHz). Ka-band (35 GHz) interferometers have applications to river discharge. The atmospheric radars operate at very high frequencies (35 GHz and 94 GHz) with only modest bandwidth requirements on the order of a few megahertz.

The emphasis of this subtopic is on core technologies that will significantly reduce mission cost and increase performance and utility of future radar systems. There are specific areas in which advances are needed.

- SAR for surface deformation, topography, soil moisture measurements:
  - Lightweight, electronically steerable, dual-polarized, L-band phased-array antennas.
  - Very large aperture L-band antennas (20 m x 20 m) for Medium Earth Orbit (MEO) or 30m diameter for Geosynchronous SAR applications.
  - Shared aperture, multi-frequency antennas (P/L-band, L/X-band).
  - Lightweight, deployable antenna structures and deployment mechanisms.
  - Rad-hard, high-efficiency, high power, low-cost, lightweight L-band and P-band T/R modules.
  - High-power transmitters (L-band, 50-100 kW).
  - L-band and P-band MMIC single-chip T/R module.
  - Rad-hard, high-power, low-loss RF switches, filters, and phase shifters.
  - Digital true-time delay (TTD) components.
  - Thin-film membrane compatible electronics. This includes: reliable integration of electronics with the membrane, high performance (>1.2 GHz) transistor fabrication on flex material including identifying new materials, process development, and techniques that have the potential to produce large-area passive and active flexible antenna arrays.
  - Advanced transmit and receive module architectures such as optically-fed T/R modules, signal up/down conversion within the module, and novel RF and DC signal distribution techniques.
  - Advanced radar system architectures including flexible, broadband signal generation and direct digital conversion radar systems.
  - Advanced antenna array architectures including scalable, reconfigurable, and autonomous antennas; sparse arrays; and phase correction techniques.
  - Distributed digital beamforming and onboard processing technologies.
- SAR data processing algorithms and data reduction techniques.
- SAR data applications and post-processing techniques.
- Low-frequency SAR for subcanopy and subsurface applications:
  - Lightweight, large-aperture (30 m diameter) reflector and reflectarray antennas.
  - Large, electronically scanning P-band arrays.
  - Shared aperture, dual-polarized, multiple low-frequency (VHF through P-band, 50–500 MHz) antennas with highly shaped beams.
  - Lightweight, low frequency, low-loss antenna feeds (VHF through P-band, 50–500 MHz).
  - High-efficiency T/R modules and transmitters (50–500 MHz, 10 kW).
  - Lightweight, deployable antenna structures and deployment mechanisms.
  - Data applications and post-processing techniques.
- Polarimetric ocean/land scatterometer:
  - Multi-frequency (L/Ku-band) lightweight, deployable reflectors.
  - Large, lightweight, electronically steerable Ku-band reflectarrays.
  - Lightweight L-band and Ku-band antenna feeds.
  - Dual-polarized antennas with high polarization isolation.
  - Lightweight, deployable antenna structures and deployment mechanisms.
  - High efficiency, high power, phase stable L-band and Ku-band transmitters.
  - Low-power, highly integrated radar components.
  - Calibration techniques, data processing algorithms, and data reduction techniques.
  - Data applications and post-processing techniques.
- Wide swath ocean and surface water monitoring altimeters:
  - Shared aperture, multi-frequency (C/Ku-band) antennas.
  - Large, lightweight antenna reflectors and reflectarrays.

- Lightweight C-band and Ku-band antenna feeds.
- Lightweight, deployable antenna structures and deployment mechanisms.
- High-efficiency, high power (1–10 kW) C-band and Ku-band transmitters.
- Real-time onboard radar data processing.
- Calibration techniques, data processing algorithms, and data reduction techniques.

- Ku-band and Ka-band interferometers for snow cover measurement over land (Ku-band), wetland, and river monitoring (Ka-band):
  - Large, stable, lightweight, deployable structures (10–50 m interferometric baseline).
  - Ka-band along and across-track track interferometers with a few centimeters of height accuracy.
  - Ku-band interferometric polarimetric SAR.
  - Phase-stable Ku-band and Ka-band electronically steered arrays and multibeam antennas.
  - Lightweight deployable reflectors (Ku-band and Ka-band).
  - Shared aperture technologies (L/Ku-band).
  - Phase-stable, Ku-band and Ka-band receive electronics.
  - High-efficiency, rad-hard Ku-band and Ka-band T/R modules or >10 kW transmitters.
  - Ku-band and Ka-band antenna feeds.
  - Calibration and metrology for accurate baseline knowledge.
  - Real-time onboard radar data processing.
  - Data applications and post-processing techniques.
- Atmospheric radar:
  - Low sidelobe, electronically steerable, millimeter wave, phased-array antennas and feed networks.
  - Low sidelobe, multi-frequency, multi-beam, shared aperture millimeter wave antennas (Ka-band and W-band).
  - Large (~300 wavelength), lightweight, low sidelobe, millimeter wave (Ka-band and W-band) antenna reflectors and reflectarrays.
  - Lightweight deployable antenna structures and deployment mechanisms.
  - High power (10 kW) Ka-band and W-band transmitters.
  - High-power (>1 kW, duty cycle >5%), wide bandwidth (>10%) Ka-band amplifiers.
  - High-efficiency, low-cost, lightweight Ka-band and W-band transmit/receive modules.
  - Advanced transmit/receive module concepts such as optically-fed T/R modules.
  - Onboard (real-time) pulse compression and image processing hardware and/or software.
  - Advanced data processing techniques for real-time rain cell tracking, and rapid 3D rain mapping.
  - Lightweight, low-cost, Ku/Ka band radar system for ground-based rain measurements.
  - Light weight, wideband (>200 MHz), low-sidelobe (<30 db) flat plate or phased array antennas with off-axis tilted beams (<40 degrees) at X through Ka bands.
  - Low-power, high-speed, multi-channel single board digital receivers.
  - High-power, high-duty cycle solid state power amplifier from X through W-band.

S6.06 Passive Infrared - Sub Millimeter
Lead Center: JPL

Many NASA future Earth science remote sensing programs and missions require microwave to submillimeter wavelength antennas, transmitters, and receivers operating in the 1-cm to 100-µm wavelength range (or a frequency range of 30 GHz to 3 THz). General requirements for these instruments include large-aperture (possibly deployable) antenna systems with RMS surface accuracy of <1/50th wavelength (or better); the ability to scan or image many beamwidths (array receivers); small low-power monolithic microwave integrated circuit (MMIC) radiometers; and high-throughput, low power, backend correlators, and spectrometers. The focus is on technology for passive radiometer systems that are spectrally flexible, lighter, smaller, and use less power than present receivers. These systems must be of durable design for use on aircraft platforms and at remote and autonomous observatory sites; they must also be suitable for space applications with lifetimes of 5 years or more. Earth remote sensing receivers typically operate at LN2 (or higher) temperatures and require moderate noise performance. Advances in cooler technology will enable the use of technology that is presently used in astrophysics receivers, which are usually cooled to a few Kelvin for better sensitivity, requiring near-quantum noise-limited performance.

For these systems, advancement is needed in primarily three areas: 1) the development of frequency-stabilized, low phase noise, tunable, fundamental local oscillator sources covering frequencies between 160 GHz and 3 THz; 2) the development of submillimeter-wave mixers in the 300–3000 GHz spectral region with improved sensitivity, stability, and IF bandwidth capability; and 3) the development of higher-frequency and higher-output-power MMIC circuits.

Specific innovations or demonstrations are required in the following areas:

- Heterodyne receiver system integration at the circuit and/or chip level is needed to extend MMIC capability into the submillimeter regime. MMIC amplifier development for both power amplifiers and low noise amplifiers at frequencies up to several hundred GHz is solicited. Integration of a local oscillator multiplier chain, mixer, and intermediate frequency amplifier is one example. There is also a specific need to demonstrate array radiometer systems using MMIC radiometers from 60 GHz to approximately 500 GHz;
- Solid-state, phase-lockable, local-oscillator sources with flight-qualifiable design approaches are needed with >10 mW output power at 200 GHz and >100 µW at 1 THz; source line widths should be <100 kHz. Because heterodyne mixers are relatively broadband, a major limitation of existing local oscillator sources is narrow tuning range, which requires many devices for the broad spectral coverage. For example, a single local-oscillator source that could tune from 1–2 THz with flat output power in excess of 10 µW would find immediate use. These local oscillator sources should be compact and have direct current power requirements <20 W;
- Stable local-oscillator sources are needed for heterodyne receiver system laboratory testing and development;
- Multi-channel spectrometers that analyze intermediate frequency signal bandwidths as large as 10 GHz with a frequency resolution of <1 MHz, which are small, lightweight, and low direct current power (<5 mW per channel) while maintaining high stability;
- Compact and reliable millimeter and submillimeter imaging instrumentation that produces images simultaneously in multiple spectral bands;
- Schottky mixers with high sensitivity at T = 100 K and above;
- Low noise superconducting HEB mixers and SIS mixers;
- Receivers using planar diode or alternative reliable local oscillator technologies in the 300–3000 GHz spectrum;
- Lightweight and compact radiometer calibration references covering 100–800 GHz frequency range;
- Lightweight, field portable, compact radiometer calibration references covering frequencies up to 200 GHz. The reference must be temperature stable to within 1 K with a minimum of three temperature settings between 250 and 350 K;
- Low-cost, special purpose, ground-based receivers to detect signals radiated from active satellites that are in orbit for estimating rain rate, water vapor, and cloud liquid water; and
- Calibrated radiometer systems that can achieve accuracy and stability of 0.1 K.

S6.07 Thermal Control for Instruments
Lead Center: GSFC
Participating Center(s): JPL, MSFC

Future instruments for NASA's Science Mission Directorate will require increasingly sophisticated thermal control technology. Innovative proposals for thermal control technologies are sought in the following areas:

- Instrument Optical alignment needs, lasers, and detectors that require tight temperature control, often to better than +/- 1°C. Some new missions, such as LISA and TPF, require methods of temperature measurement and control to micro-Kelvin levels.

- Heat flux levels from lasers and other high power devices are increasing with some projected to go as high as 100 W/cm^2. They will require thermal technologies such as spray and jet impingement cooling. Also, high conductivity, vacuum compatible interface materials will be needed to minimize thermal losses across make/break interfaces.
- Future missions will utilize large, distributed structures such as mirrors and detector arrays at both ambient and cryogenic temperatures. These missions will require creative techniques to integrate thermal control functions and minimize weight. Some anticipated technology needs include: advanced thermoelectric coolers capable of providing cooling at ambient and cryogenic temperatures, high conductivity structural materials to minimize temperature gradients and provide high efficiency lightweight radiators, and advanced thermal control coatings such as variable emittance surfaces and coatings with a high emissivity at ambient and cryogenic temperatures.
- The push for miniaturization also drives the need for new thermal technologies towards the MEMS level. Miniaturized heat transport devices, especially those suitable for cooling small sensors, devices, and electronics, include miniaturized mechanical pumps, Loop Heat Pipes (LHPs), and Capillary Pumped Loops (CPLs) which allow multiple heat load sources and multiple sinks.
- The drive towards robotic missions and reconfigurable spacecraft presents engineering challenges for science instruments, which must become more self-sufficient. Some of the technology needs are:
  - Advanced analytical techniques for thermal modeling focusing on techniques that can be easily integrated into existing codes, emphasizing inclusion of LHPs, CPLs, and mechanically pumped system models;
  - Single and two-phase mechanically pumped fluid loop systems, which accommodate multiple heat sources and sinks, and long life, lightweight pumps for these systems; and
  - Efficient, lightweight vapor compression systems for cooling up to 2 KW.

TOPIC: S7 Earth-Sun System Data Applications

The Science Mission Directorate strives to understand the Sun, heliosphere, and the Earth's system of land, oceans, geology, and atmosphere and the complex interactions of all these systems as a single, connected, end-to-end system. The Directorate's mission is to reap the benefits of Earth and Sun exploration for society by providing accurate, objective scientific data and analysis to help policy makers, businesses, and citizens achieve economic security and to promote environmental stewardship. In this topic, the Directorate wants innovative companies to propose technology and techniques to assist the Directorate in achieving a portion of the mission in the shortest timeframe that is practical. The topic goal is to accelerate the deployment of Sun-Earth science data and understanding into operational decision support tools used by managers concerned with stewardship of the Earth's resources. This goal addresses the development of innovative technology solutions that simplify the processing, analysis, interpretation, and visualization of science data that will allow the routine use of Earth science results in automated decision support tools already in use by a broad user community. Management decision support tools of interest are used daily in management of land/biota, air, water, and emergency issues.

S7.01 Geospatial Data Analysis Processing and Visualization Technologies
Lead Center: SSC
Participating Center(s): GSFC

Proposals are sought for the development of advanced technologies in support of scientific, commercial, and educational applications of Earth Science and other remote sensing data. Focus areas are to provide tools for processing, analysis, interpretation, and visualization of remotely sensed data sets. Earth Science data needs to be benchmarked for practical use of NASA-sponsored observations from remote sensing systems and predictions from scientific research and modeling. Specific interest exists in the development of technologies contributing to decision support systems, and model development and operation. For more information on decision support models under evaluation, please visit http://science.hq.nasa.gov/strategy/index.html. Areas of specific interest include the following:

- Unique, innovative data reduction, rapid analysis, and data exploitation methodologies and algorithms of information from remotely sensed data sets, e.g., automated feature extraction, data mining, etc.;
- Algorithms and approaches to enable the efficient production of data products from active imaging systems, e.g., multipoint data resampling, digital elevation model creation, etc.;
- Data merge and fusion software for efficient production and real-time delivery of digital products of ESE Mission and other remote sensing data sets, e.g., weather observation and land use and land cover data sets;
- Innovative approaches for incorporation of GPS data into *in situ* data collection operations with dynamic links to spatial databases including environmental models;
- Image enhancement algorithms for improving spatial, spectral, and geometric image attributes;
- Innovative approaches for the querying and assimilation of application-specific datasets from disparate and distributed databases from government, academic, and commercial sources into a common framework for data analysis;
- Innovative approaches for querying of application-specific data sets from disparate, distributed databases in government, academic, and commercial data warehouses into a common framework for data analysis; and
- Innovative visualization technologies contributing to the analysis of data through the display and visualization of some or all of the above data types including providing the linkages and user interface between the cartographic model and attribute database.

S7.02 Innovative Tools and Techniques Supporting the Practical Uses of Earth Science Observations
Lead Center: SSC
Participating Center(s): MSFC

Technical innovations and unique approaches are solicited for the development of new technologies and technical methods that make Earth science observations both useful and easy to use by practitioners. This subtopic seeks proposals that support the development of operational decision support tools that produce information for management or policy decision makers. Proposed applications must use NASA Earth Observations (see http://science.hq.nasa.gov/). Other remote sensing data and geospatial technologies may also be employed in the solution.

This subtopic focuses on the systems engineering aspect of application development rather than fundamental research. Offerors are, therefore, expected to have the documented proof-of-concept project in hand. Topics of current interest to the Applied Science Directorate may be found at http://www.asd.ssc.nasa.gov/apps.aspx. Innovation in processing techniques, include, but are not limited to, automated feature extraction, data fusion, and parallel and distributed computing which are desired for the purpose of facilitating the use of Earth science data by the nonspecialist. Ease of use, fault tolerance, and statistical rigor and robustness are required for confidence in the product by the nonspecialist end user.

Promotion of interoperability is also a goal of the subtopic, so Federal data standards, communication standards, Open Geographic Information Systems (GIS) standards, and industry-standard tools and techniques will be strongly favored over proprietary 'black-box' solutions. Endorsement by the end user of both system requirements and the proposed solution concept is desirable. While the proposed application system may be specific to a particular end user or market, techniques and tools that have broad potential applicability will be favored. An objective assessment of market value or benefit/cost will help reviewers assess the relative potential of proposed projects.

S7.03 Wireless Technologies for Spatial Data, Input, Manipulation and Distribution
Lead Center: SSC

Technical innovation is solicited for the development of wireless technologies for field personnel and robotic platforms to send and receive digital and analog data from sensors such as photography cameras, spectrometers, infrared and thermal scanners, and other sensor systems to collection hubs. The intent of this new innovation is to rapidly, in real time, ingest data sequentially from a variety of input sensors, provide initial field verification of data, and distribute the data to various nodes and servers at collection, processing, and decision hub sites. Data distribution should utilize state-of-the-art wireless, satellite, land carriers, and local area communication networks. The technology's operating system should be compatible with commonly available systems. The operating system should not be proprietary to the offeror. The innovation should include biometric capability for password protection and relational tracking of data to the field personnel inputting the data and/or sensors and platforms sending information. The innovation should contain technologies that recognize multiple personnel and other sources (robotics) so that several personnel and platforms can use the same unit in the field. Biometric identification can be fingerprint, retina scans, facial, or other methods. The innovation should include geospatial technologies to use digital imagery and have Global Positioning System (GPS) location capabilities. The innovation should be able to display, with sufficient size and resolution, the rendering of vector and raster data and other sensor data for easy understanding. The field capability of the innovation must be fully integrated end to end with computing capabilities that range from mobile computers to servers at distant locations. Field personnel and robotic platforms providing information and support to science investigations, resource managers, and community planners will use the innovative wireless technology. First responders to natural, human-made disasters and emergencies will also be users of this innovation.

TOPIC: S8 Science Spacecraft Systems Technology

NASA has combined the Earth and Space Sciences into a new mission directorate called the Science Mission Directorate. 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 instrument development programs is to implement science measurement capabilities with small or more affordable spacecraft so development programs can meet multiple mission needs and, therefore, make the best use of limited resources. NASA is fostering innovations that support implementation of the Earth Science (ES) and Space Science (SS) integrated international undertaking to study the Earth and space systems. The Science Mission Directorate Programs define the platforms as the host systems for science instruments. That is, they provide the infrastructure for an instrument or suite of instruments. Traditionally, the term 'platform' would be synonymous with 'spacecraft,' and it certainly does include spacecraft. However, 'platform' is intended to be much broader in application than spacecraft and is intended to include non-traditional hosts for sensors and instruments such as airborne platforms (piloted and unpiloted aircraft, balloons, drop sondes, and sounding rockets). These application examples are given to illustrate the wide diversity of possibilities for acquiring Earth and space science data consistent with the future vision of the Science Mission Directorate and indicate types of platforms for which technology development is required.

S8.01 Guidance, Navigation and Control
Lead Center: GSFC
Participating Center(s): JPL

Future science architectures will include observation and sensing platforms of varying type, size and complexity in a number of mission-operational regimes, trajectories and orbits. Advanced Guidance Navigation and Control (GN&C) technology is required for these platforms to address high performance and reliability requirements while simultaneously satisfying low power, mass, volume and affordability constraints. In particular, there are many technology gaps in challenging orbital environments, including highly elliptical Earth orbits, libration point orbits, and lunar and planetary orbits.

A vigorous effort is needed to develop guidance, navigation and control methodologies, algorithms, and sensor-actuator technologies to enable revolutionary science missions. Of particular interest are highly innovative GN&C technology proposals directed towards enabling scientific investigators to exploit new vantage points, develop new sensing strategies, and implement new system-level observational concepts that promote agility, adaptability, evolvability, scalability, and affordability. Novel approaches for the autonomous control of distributed spacecraft and/or the management of large fleets of heterogeneous and/or homogeneous assets are desired. Specific areas of research include:

GN&C System Technologies
Innovative GN&C solutions are sought for scientific instrument and laser communication system pointing, tracking, and stabilization. Proposals that exploit and combine recent advances in, spacecraft attitude determination and control, advanced electro-mechanical packaging, MEMS technology, and ultra-low power microelectronics are encouraged. Of particular interest is technology to provide alternative solutions to challenging GN&C problems such as spacecraft relative range and attitude determination while in close formation and/or during rendezvous/proximity operations.

GN&C Sensors and Actuators
Advanced technology sensors and actuators are sought such as Sun sensors, Earth sensors, star/celestial object trackers, fine guidance sensors, gyroscopes, accelerometers, inertial measurement units, navigation devices, magnetometers, reaction/momentum wheels, control-moment gyros, magnetic torquers, tethers, attitude control thrusters, etc. These devices should have enhanced capabilities and performance as well as reduced cost, mass, power, volume, and reduced complexity for all platform GN&C system elements.

Of particular interest are technologies that will provide a sensing or actuation function, having performance (e.g., dynamic range, stability, accuracy, noise, sensitivity, bandwidth, control authority, etc.) consistent with the state-of-the-art, with significantly reduced mass, power, volume, and cost. Technologies having the potential for significantly increased performance without additional mass, power, volume, and cost are also of interest. These resource reduction and/or performance improvement factors should be quantified in the proposal and show a minimum factor of 2 with a goal of 10 or greater. Highly autonomous and robust GN&C devices with multifunctional capabilities are of particular interest.

Innovations in Global Positioning System (GPS) receiver hardware and algorithms that use GPS code and carrier signals to provide spacecraft navigation, attitude, and time. Of particular interest are GPS-based navigation techniques that may employ Wide Area Augmentation System (WAAS) corrections.

Novel approaches to autonomous sensing and navigation of multiple distributed space platforms. Of particular interest are specialized sensors and measurement systems for formation sensing and relative navigation functions.

S8.02 Command and Data Handling
Lead Center: GSFC

The goal for this subtopic is the development of advanced space technology and concepts to further high-performance science image and data processing. The instrument electronics must operate reliably and effectively for long periods of time in harsh environments. These systems require management of data and products, low power, and radiation.

The objective for this development goal is to elicit novel concepts, architectures, and component technologies that have realistic and achievable potential for flight applications and are responsive to the priority areas of this subtopic. Technologies will be selected based on the potential that their final end products are sustainable (affordable, reliable/safe, and effective) and will advance solutions to the challenges of reusability, modularity, and autonomy.

Priority areas are: reconfigurable/modular implementations; onboard science (data and image) processing and management; and low-power, radiation-resistant electronics. Additional information about the solicited technologies follows:

Onboard Processing

- Hardware technologies and architectures that support instrument science (data and image) processing and that are reconfigurable in flight and modular;
- Hardware-based algorithms for onboard data and image processing of raw science into multiple custom data products. The intent is to minimize onboard bandwidth constraints;
- Autonomous capability of hardware and algorithm management without ground intervention;
- Low-power electronics: in order to provide higher capabilities on smaller and/or less expensive instruments and decrease subsequent thermal load; and
- Radiation resistant electronics (hardware or application).

S8.03 Long Range and Near Earth RF Communications
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, 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 (32 GHz and 38 GHz);
- High-efficiency (>70 %) Solid-Sate Power Amplifiers (SSPAs), of both medium output power (10-50 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 (32 GHz and 38 GHz);
- Traveling Wave Tube Amplifiers (TWTAs), SSPAs, modulators, and MMICs for 26 GHz Ka-band (lunar comm);
- TWTAs operating at millimeter wave frequencies 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 S-, X-, Ka-, and V-band (60 GHz). Of particular interest is Ka-band from 25.5-27 GHz and 31.5-34 GHz.

Research should be conducted to demonstrate technical feasibility during Phase 1 and 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.

S8.04 Spacecraft Propulsion
Lead Center: GRC
Participating Center(s): GSFC, JPL, JSC, MSFC

Innovations in propulsion technologies are needed to support the Science Mission Directorate (SMD) goals of better understanding the Earth-Sun system, exploring our solar system, and investigating the nature of the universe beyond our solar system. Planetary spacecraft need ever-increasing propulsive performance and flexibility for ambitious missions requiring high-duty cycles and years of operation. Satellites and satellite constellations have high-precision propulsion requirements, usually in volume- and power-limited envelopes. Propulsion systems must avoid contamination of instruments from thruster plumes. This subtopic seeks innovations in propulsion technologies to increase the capabilities of SMD spacecraft. Specifically, technology innovations are sought in the areas of solar electric propulsion, monopropellant technology, and miniature/precision propulsion.

Solar Electric Propulsion
Technology advancements are needed to improve the capability of low- to medium-power electric propulsion systems, including ion, Hall, and advanced plasma thrusters. Areas where innovations are sought include power

processing, long-life, high-efficiency cathodes and neutralizers, electrodeless plasma production, low-erosion materials for ion optics and Hall discharge chambers, high-temperature magnetic circuits, and next-generation thrusters. Innovations sought include, but are not limited to, those that improve performance, increase lifetime, reduce mass, and decrease cost. Improvements are also sought for propellant management system components including storage, distribution, and flow control to support solar electric propulsion applications.

Monopropellant Technology
Advancements are sought for propulsion systems using advanced monopropellants. Spacecraft using high-performance (Isp >275 s), high-density (>1 g/cc) monopropellant formulations will need high-durability catalyst materials or, alternatively, non-catalytic ignition technology for power-limited spacecraft. Critical component materials (e.g., tank bladders, valve seats, and filters) that are compatible with advanced monopropellants need to be developed. Performance and density improvements are sought for applications with very low propulsion requirements.

Miniature/Precision Propulsion
Propulsion technologies for miniature (less than 10 kg) spacecraft and for high-precision (impulse bit <100 milliNewton-second) stationkeeping and attitude control are sought. Propulsion concepts leveraging micro-electromechanical system (MEMS) fabrication techniques are welcomed including those using more robust substrate materials than silicon. Innovations in miniature electrostatic and electromagnetic propulsion devices are sought.

S8.05 Energy Conversion and Storage for Space Applications
Lead Center: GRC
Participating Center(s): GSFC, JPL

Earth science observation missions will employ spacecraft, balloons, sounding rockets, surface assets, aircraft, and marine craft. Advanced power technologies are required for each of these platforms that address issues of size, mass, capacity, reliability, and operational costs. A vigorous effort is needed to develop energy conversion technologies that will enable the revolutionary Earth science missions. Exploiting innovative technological opportunities, developing power systems for adverse environments, and implementing system-wide techniques that promote scalability, adaptability, flexibility, and affordability are characteristics of the technological challenges to be faced and are representative of the type of developments required beyond the state-of-the-art.

The energy conversion technologies solicited include photovoltaics and thermophotovoltaic as well as related technologies such as array, concentrator, and thermal technologies. Specific areas of interest include:

- Photovoltaic cell and array technologies with significant improvements in efficiency, mass specific power, stowed volume, cost, radiation resistance, and wide operating conditions are solicited. Photovoltaic cell technologies for wide temperature operation and radiation environments are solicited;
- Potential array technologies of interest include rigid and deployable arrays, concentrators (rigid or inflatable, primary or secondary), ultra-lightweight arrays for lightweight, flexible, thin-film photovoltaic cells, and electrostatically clean spacecraft solar arrays;
- Proposals are sought addressing structural and microbatteries and rechargeable lithium-based batteries with advanced anode and cathode materials and advanced liquid and polymer electrolytes;
- Primary fuel cell systems that can function in high altitude platforms are solicited. These include primary H_2:Air systems that operate at low air pressure and H_2:O_2 systems;
- Future micro-spacecraft require distributed power sources that integrate energy conversion and storage into a hybrid structure with microelectronics devices/instruments; and
- Thermal technology areas include heat rejection, composite materials, heat pipes, pumped loop systems, packaging and deployment, including integration with the power conversion technology. Highly integrated systems are sought that combine elements of the above subsystems to show system level benefits.

S8.06 Platform Power Management and Distribution
Lead Center: GRC
Participating Center(s): GSFC, JPL

NASA science missions employ Earth orbit and planetary spacecraft, along with terrestrial balloons, surface assets, aircraft, and marine craft as observation platforms. Advanced electrical power technologies are required for the electrical components and systems on these platforms to address the issues of size, mass, efficiency, capacity, durability, and reliability. Advancements are sought in power electronic devices, components, and packaging,

Power Electronic Materials and Components
Advanced magnetic, dielectric, and semiconductor materials, devices, and circuits are of interest. Proposals must address improvements in energy density, speed, efficiency, or wide temperature operation (-125°C to 200°C) with a high number of thermal cycles. Candidate devices and applications include transformers, inductors, semiconductor switches and diodes, electrostatic capacitors, current sensors, and cables.

Power Conversion, Motor Drive, Protection, and Distribution
Technologies that provide significant improvements in mass, size, power quality, reliability, or efficiency in electrical power conversion, motor drives, and protective switchgear components are of interest. Candidate applications include solar array regulators, battery charge and discharge regulators, power conversion, power distribution, fault protection, high-speed motors/generators, magnetic bearing drivers, and integrated flywheel energy storage and attitude control electronics.

Electrical Packaging
Thermal control technologies are sought that are integral to electrical devices with high heat flux capability and advanced electronic packaging technologies which reduce volume and mass or combine electromagnetic shielding with thermal control.

TOPIC: S9 Advanced Modeling, Simulation, and Analysis for Science

Modeling and simulation are being used more pervasively and more effectively throughout the space program for both engineering and science pursuits. 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.

S9.01 Automation and Planning
Lead Center: ARC
Participating Center(s): GSFC

The Automation and Planning subtopic solicits proposals that allow either spacecraft or ground systems to robustly perform complex tasks given high-level goals with minimal human direction. Areas of interest include all aspects of data collection, processing analysis, and decision making. NASA wants to go from specifying “how” something is done to specifying “what” is needed and letting the system figure what data and resources best meet the high-level goals under a set of constraints (e.g., cost, time, etc.).

Technology innovations include, but are not limited to: 1) automation and autonomous systems that support high-level command abstraction; 2) efficient and effective techniques for assembling and processing large volumes of data (commonly available on the Internet) into useful information; 3) intelligent searches of large, distributed data archives, and data discovery through searches of heterogeneous data sets and architecture; and 4) automation of routine, labor intensive tasks 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; The Automation and Planning subtopic solicits proposals that allow either spacecraft or ground systems to robustly perform complex tasks given high-level goals with minimal human direction. Areas of interest include all aspects of data collection, processing analysis and decision making. NASA wants to from specifying "how" something is done to specifying "what" is needed and letting the system figure what data and resources best meet this high level goals under a set of constraints (e.g. cost, time and etc)

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- Search agents that support applications involving the use of NASA data;
- Methods that support the robust production of data products 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;
- Autonomous data logging devices (software, or hardware and software) supporting a variety of weather and climate sensors, capable of ground-based operation in a wide variety of environmental conditions; such systems would probably be solar powered with accurate time stamping;
- Planning and scheduling methods related to Earth Science Mission objectives;
- System and subsystem health and maintenance, both space- and ground-based;
- Distributed decision making, using multiple agents, and/or mixed autonomous systems;
- Automated software testing;
- Verification and validation of automated systems;
- Automatic software generation and processing algorithms; and
- Control of Field Programmable Gate-Arrays (FPGA) to provide real-time products.

Problems address must be relevant to Earth and Solar Sciences including space weather.

S9.02 Distributed Information Systems and Numerical Simulation
Lead Center: ARC
Participating Center(s): GSFC

This subtopic seeks advances in tools, techniques, and technologies for distributed information systems and large-scale numerical simulation. The goal of this work is to create an autonomous information and computing environment that enables NASA scientists to work naturally with distributed teams and resources to dramatically reduce total time-to-solution (i.e., time to discovery, understanding, or prediction), vastly increase the feasible scale and complexity of analysis and data assimilation, and greatly accelerate model advancement cycles. Areas of interest follow below.

Distributed Information Systems

- Core services (autonomous software systems) for automated, scalable, and reliable management of distributed, dynamic, and heterogeneous computing, data, and instrument resources. Services of interest include those for authentication and security, resource and service discovery, resource scheduling, event monitoring, uniform access to compute and data resources, and efficient and reliable data transfer;

- Services for management of distributed, heterogeneous information, including replica management, intuitive interfaces, and instantiation on demand or “virtualized data.” These services would be used, for example, to access and manipulate NASA’s wealth of geospatial and remote sensing data;
- Science portals for cross-disciplinary discovery, understanding, and prediction, encapsulating services for single sign-on access, semantic resource and service discovery, workflow composition and management, remote collaboration, and results analysis and visualization; and
- Tools for rapidly porting and hosting science applications in a distributed environment. These applications should be written for an integrated, or workstation, environment using standard programming languages or tools such as Matlab, Interactive Data Language (IDL), or Mathematica.

Large-Scale Numerical Simulation

- Tools for automating large-scale modeling, simulation, and analysis, including those for managing computational ensembles, performing model-optimization studies, interactive computational steering, and maintaining progress in long-running computations in spite of unreliable computing, data, and network resources;
- Tools for computer system performance modeling, prediction, and optimization for real applications;
- Techniques and tools for application parallelization and performance analysis;
- Tools for effective load balancing, and high reliability, availability, and serviceability (RAS) in commodity clusters and other large-scale computing systems; and
- Novel supercomputing approaches using FPGAs, graphics processors, and other novel architectures and technologies.

S9.03 Data Management and Visualization
Lead Center: GSFC

This subtopic focuses on supporting science analysis through innovative approaches to managing and visualizing large collections of science data. These data sets are extremely large and 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 such as goggles or helmets; and
- 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; and
- Novel tools for data viewing, real-time data browsing, 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

- Metadata catalog environments to locate very large and diverse science data sets that are distributed over large geographic areas; and
- 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.

Distributed Data Access

- Dynamically configurable, high-speed access to data stored in Storage Area Networks (SAN) distributed over wide area environments; and
- Technologies for sharing data over newly developed, high-speed, wide area networks such as the National Lambda Rail (NLR).

S9.04 On-Board Science for Decisions and Actions
Lead Center: ARC

Current sensors are stove-piped systems, which can collect more data than is possible to transmit to the ground. Intelligence in the sensor or platform can prioritize or summarize the data and send down high priority or synoptic science data. In the future, a sensor-web capability will demand this remote onboard autonomy and intelligence about the kind and content of data being collected to support rapid decision making and tasking. This subtopic is interested in developing new methods to autonomously understand ES data in support of making rapid decisions and taking actions under three themes:

Onboard Satellite Data Processing and Intelligent Sensor Control
Software technologies that support the configuration of sensors, satellites, and sensor webs of space-based resources. Examples include capabilities that allow the reconfiguration or re-targeting of sensors in response to user demand or in significant events seen in other sensors. Included are software that supports the reasoning and modeling of such capabilities for demonstration and mission simulation. Also included in this category is onboard analysis of sensor data that could run on reconfigurable computing environments as well as technologies that support or enable the generation of data products for direct distribution to users.

Onboard Satellite Data Organization, Analysis, and Storage
Software technologies that support the storage, handling, analysis, and interpretation of data. Examples include innovations in the enhancement, classification, or feature extraction processes. Also included are data mining, intelligent agent applications for tracking data, distributed heterogeneous frameworks (including open system interfaces and protocols), and data and/or metadata structures to support autonomous data handling, as well as compaction (lossless) or compression of data for storage and transmission.

Simulation and Analysis of Sensor Webs
Software that allows for the simulation of a sensor web of varying platform types producing a variety of data streams. These platforms could be in various orbits (L1, L2, NEO, LEO, etc.) and suborbital (UAV) that are automatically assigned different temporal and spatial coverages. Data streams would be assigned to these platforms and the system computes how the sensor web would cover of events (e.g., volcanic eruption, fires, and crop monitoring) at user designated, particular, geospatial locations (or areas).

9.1.4 SPACE OPERATIONS

In the early days of NASA, the demonstration of human space flight was a national priority motivated by the need to prove American technological preeminence. This demonstration led to some of the most spectacular achievements in human history, and during the past 4 decades, NASA has systematically developed the capability to live and work in space. NASA's role also included space and Earth science, which over time has grown to be a large portion of the Agency's role. Aeronautics research has continued from the days of NACA, the predecessor of NASA.

In January 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 four objectives; the fifth objective was added later:

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 draws its purpose from NASA's Vision and Mission. The NASA vision is "to improve life here, to extend life to there, and to find life beyond". Derived from this vision, the NASA mission is "to understand and protect our home planet, to explore the universe and search for life, and to inspire the next generation of explorers . . . as only NASA can."

In support of the NASA vision and mission, the Space Operations Mission Directorate will marshal its efforts around a key transformation to enable the President's vision. The role of the directorate will continue to involve operational capabilities for the Agency and synergistically guide the development of certain operational systems such as communication systems. The Space Operations Mission Directorate provides the foundation for NASA's space programs—space travel for human and robotic missions, in-space laboratories, and the means to return data to Earth. We provide space access for our customers with a high standard of safety, reliability, and affordability. The focus of the Space Operations Mission Directorate SBIR activity is to provide affordable communications, and space access services are required to enable and support the goals laid out by the President.

http://www.hq.nasa.gov/osf/

TOPIC: O1 Space Communications

NASA communications capabilities are based on the premise that communications shall be an enabler 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 long range optical communications (under the Science Mission Directorate), near earth and intersatellite optical communications, RF communications technologies including antennas, surface networks, reprogrammable/reconfigurable communications systems, advanced antenna technology and transmit array concepts, and communications in support of launch services are very important to the future of the exploration and science activities of NASA. Communications that enable the range safety data from sensitive instruments is imperative. The subtopics below address these technologies and support the goals of the Agency.

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 application scenarios. Coding efficiency from 50% to 87% will be combined with digital modulation from 2bits/symbol/Hz up to yield-optimal solutions. In compression, tunable technique from over 10:1 compression ratio to lossless is desired. Proposals are sought in the following specific areas:

Compression

- Software for transcoding of compressed bit streams from CCSDS Image Data Compression recommendation to commercial JPEG2k bit stream;and
- Demonstration in either PC-based or workstation-based systems with minimal loss of quality during the transcoding process.

Coding and Coded Modulation

- A design for a set of coded modulations operating at bandwidth efficiencies from 0.5 bits/symbol/Hz to 3+ bits/symbol/Hz, in steps of approximately 0.5 bits/symbol/Hz. Each point design shall require a bit signal-to-noise ratio not higher than 1 dB above the unconstrained-input, 2-dimensional capacity of the additive white Gaussian noise (AWGN) channel. The preferred input block frame length is 4K to 16K bits.
- 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 encoder/decoder complexity consistent with implementations at data rates up to 1 Gbps. The new design, when compared with current CCSDS Reed-Solomon (255,223) coder at BER of 10e-5, should have over 2dB Eb/No gain. The preferred code block frame length is from 4K to 16K bits.
- High-speed implementation of the coded modulation suite with processing throughput close to 300 Mbits/sec and demonstration in test bed. The test bed shall include functions of encoding, modulation, demodulation, and decoding. The ability for the test bed to incorporate channel impairments, an over-the-air RF component, and software re-configurability, are desirable.
- RF receivers with symbol synchronizer providing soft-decision output over 8 bits/sample, as input to Maximum Likelihood Detector to provide metrics for decoding Trellis-coded-Modulation.

O1.02 Precision Navigation and Tracking
Lead Center: JPL
Participating Center(s): GSFC

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, including all development spirals of systems of systems supporting Projects Constellation, Prometheus, 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 timeframe of the later spirals of Projects Constellation and Prometheus, 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 of 1.5 e-15 at 1e3 to 1e4 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, lunar and planetary approach and orbit, ascent and descent from lunar and planetary surfaces, including precision landing, lunar and planetary surface operations, automated rendezvous and docking, and formation flying spacecraft forming synthetic apertures for science imaging and interferometry. 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. 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 techniques. These solutions often take several days of CPU 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 prob-

lems 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 H_20, 60 GHz O_2) 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 x 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; and
- 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-quiescent operations, such as robotic servicing and formation flying.

O1.03 Communication for Space-Based Range
Lead Center: GSFC
Participating Center(s): DFRC, KSC, MSFC

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, 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: (a) low power consumption, (b) low mass/volume, (c) compliance with range safety standards, (d) flexible tracking loop programmability, (e) programmable output formats, and (f) 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 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 the outputs of 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 assent stages of flight are required to provide unbroken communications throughout the launch phase. These may enable use of the NASA TDRSS; or commercial communications satellites. 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.

O1.04 Antenna Technology
Lead Center: GRC
Participating Center(s): GSFC, JPL, JSC, MSFC

NASA seeks advanced antenna systems for use in spacecraft and planetary surface vehicles used in science, exploration systems, and space operations missions. Future manned missions to the Moon and Mars will have stringent communication requirements. Highly robust communication networks will be established in the vicinity of the planet to support long-term human interplanetary mission. Such networks will 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 Moon and the Earth. Great demands will be placed upon these communication systems to assure crew safety, robustness in harsh environments, and high reliability for long-duration manned missions.

Areas of interest include lightweight deployable antenna systems, high-gain antenna architectures, multi-frequency and dual polarized antennas, self-orienting systems, reconfigurable antennas, and novel concepts such as antennas that can adapt to failed components without compromising performance and operability (e.g., smart antennas). NASA seeks to develop a lightweight, scanning, phased array antenna system that enables assured communication links for human interplanetary exploration.

Large inflatable membrane antennas to significantly reduce stowage volume, provide high deployment reliability, and significantly reduced mass (i.e. <1kg/square meter) to provide a communication link from the Moon/Mars surface to a relay satellite 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 makeup gas is not required. In particular, 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 a wrinkle-free surface—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.

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. Recent antenna research and development has shown that it is possible to design and build aperture antennas with smaller than the minimum effective aperture sizes of dipoles. This new class of antennas can provide higher antenna gains (>2.5 dBi) than a dipole antenna in much smaller aperture sizes (<< 0.13 lambda square). Because of its size and higher gain, these antennas can be used reliably in astronauts and robotics communications equipment in the UHF, VHF, and S- frequency bands for spiral 3 lunar or Mars exploration missions. This topic is interested in novel antenna concepts that address the aforementioned requirements.

The architecture for lunar exploration is expected to involve a layered communications and navigation network. This network may include lunar vicinity relay satellites at L1 and L2 Lagrange points as well as lunar polar orbiting satellites. The lunar proximity network must be able to access dedicated assets, such as Malapert Station, and eventually include human assets, such as crewed rovers, as relay nodes. Consequently, there is interest in antenna technologies that enable low-cost but reliable, reconfigurable, and agile antennas at frequencies up to 38 GHz. Another component technology that shows high interest in the area of Earth and planet science is thin-membrane, mountable T/R modules, phase shifters, beam former, control circuitry, etc. for future deployable/inflatable, large-aperture, phased array application. This topic seeks novel smart 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 errors induced by thermal gradients, gravitational and other forces, and manufacturing processes. 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; 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, UAVs, and expendable platforms. The balloon vehicles primarily communicate with TDRS and can tolerate a wide range of mechanical dimensions.

Finally, 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.

O1.05 Antenna Array Transmission Techniques
Lead Center: JPL
Participating Center(s): GRC

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 band (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 open questions 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, an-

other key component is a cryogenic refrigerator for the 15-25K range.) Also, low-cost transmitters (including medium-power (of the order of 100s of Watts) amplifiers are key;
- 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; and
- Techniques for integrating a very low-noise, cryogenically-cooled receiver with medium power (1W to 200W) transmitter. If transmitting and receiving are combined on the same antenna, the performance of each should be compromised as little as possible while maintaining low cost and high reliability.

Research should be conducted to demonstrate technical feasibility during Phase 1 and 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.

O1.06 Reconfigurable/Reprogrammable Communication Systems
Lead Center: GRC
Participating Center(s): GSFC, JPL, JSC, MSFC

NASA seeks novel approaches in reconfigurable, reprogrammable communication systems to enable the vision of Space, Exploration, Science, and Aeronautical Systems. Exploration of Martian and lunar environments 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 (e.g. 1’s to 10’s Mbps at UHF and S-band frequency bands up to 10’s to 1000’s Mbps at X, and Ka-band frequency bands.) 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 solicitation seeks advancements in reconfigurable transceivers and associated component technologies. The goal of the subtopic is to provide flexible, reconfigurable communications capability while minimizing on-board resources and cost. Topics of interest include the development of software-defined radios or radio subsystems that demonstrate reconfigurability, flexibility, reduced power consumption of digital signal processing systems, increased performance and bandwidth, reduced software qualification cost, and error detection and mitigation technologies. Complex reconfigurable systems will provide multiple channel and multiple and simultaneous waveforms. Areas of interest to develop and/or demonstrate are as follows:

- Advancements in bandwidth capacity, reduced resource consumption, or adherence to standard and open hardware and software interfaces. Techniques should include fault tolerant, reliable software execution, re-programmable digital signal processing devices;
- Reconfigurable software and firmware that provide access control, authentication, and data integrity checks of the reconfiguration process including partial reconfiguration, which allows simultaneous operation and upload of new waveforms or functions;

- Operator or automated reconfiguration, or waveform load detection failure, and the ability to provide access back to a known, reliable operational state. An automated restore capability ensures the system can revert to a baseline configuration, thereby avoiding permanent communications loss due to an errant reconfiguration process or logic upset;
- Dynamic or distributed on-board processing architectures to provide reconfigurability and processing capacity. For example, demonstrate technologies to enable a common processing system capacity for communications, science, and health monitoring;
- Adaptive modulation and waveform recognition techniques are desired to enable transceivers to exchange waveforms with other assets automatically or through ground control;
- Low overhead, low complexity hardware and software architectures to enable hardware or software component or design reuse (e.g., software portability) to demonstrate cost or time savings. Emphasis is on the application of open standard architectures to facilitate interoperability among different vendors and to minimize the operational impact of upgrading hardware and software components;
- Software tools or tool chain methodologies that enable both design and software modeling and code reuse, and advancements in optimized code generation for digital signal processing systems;
- 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 continues to increase, and size decreases, the susceptibility of the electronics to single event effects also increases. Novel approaches are sought to mitigate single event effects in reconfigurable logic caused by charged particles, thereby improving reliability. New methods may show advancements in reduced cost, power consumption, or complexity compared to traditional approaches (i.e., voting schemes and constant updates {e.g., scrubbing}).
- Techniques and implementations to provide a core 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 capability (e.g., "gold" waveform code) is automatically executed to provide access control and restore operation;
- Innovative solutions to software-defined radio implementations that reduce power consumption and mass. Solutions should enable future hardware scalability among different mission classes (e.g., low-rate, deep space to moderate or high-rate near planetary, or relay spacecraft) and should promote modularity and common, open interfaces; and
- In component technology, advancements in analog-to-digital converters or digital-to-analog converters to increase sampling and resolution capabilities; novel techniques to increase memory densities; and advancements in processing and reconfigurable logic technology, each reducing power consumption and improving performance in harsh environments.

O1.07 Extravehicular (EVA) Radios
Lead Center: JSC
Participating Center(s): GRC

Human exploration of the Martian environment demands radio technology that tolerates extreme conditions. The harsh environment of the Martian atmosphere contains not only increased radiation, which is damaging to semiconductors, but also dust and ionic storms, which are disruptive to communications. Frequency agility will be necessary during periods of disruption due to these storms. Small volume and low mass are always sought for any space mission; they are critical for systems embedded in EVA spacesuits, which seek to enhance the astronaut's mobility on the planet's surface.

The focus of this activity is to develop radio methodologies that ensure increased reliability and fault-tolerance in the processor electronics and performance of EVA radios for human interplanetary missions. Exploring unknown worlds with unforeseeable threats is understandably stressful for the most intrepid astronaut. By providing a system that is even less likely to fail and easier to use, this can be mitigated. In a human exploration mission, loss of communications is not merely inconvenient; it can be deadly.

The radio systems design must reflect the very special human factors requirements imposed by the mission and the protective spacesuit. While these latter provide a pressurized atmosphere, temperature control, protection from micrometeroids, communications, and a myriad of other functions essential to the survival of an astronaut, the best designs add bulk and inhibit natural movements. EVA radio systems must be designed to be easily operable in any circumstance.

This solicitation seeks to develop an EVA radio that notionally consists of limited front-end complexity hardware combined with a signal processing back end while minimizing traditional radio analog system components in order to maintain waveform flexibility and reconfigurability. The communication bands of interest are the space allocations from UHF to Ka; the precise band used will be dictated by bandwidth needs and the specific application. The radio should support multiple bandwidths of data transmission to support telemetry, voice, and video, and should have automatic adaptive techniques to handle changing propagation and interference. The radio should have an upper mass limit of 300g, a peak transmission power of 5W, and a receive mode which consumes no more than 10 mW.

Additionally, this radio must be configurable for many applications, with a goal of reducing radio inventory management. Ka-band is the most appropriate for high data rate video links, while UHF bands can be used for low-rate telemetry and voice applications. Operational scenarios will dictate the exact requirements, but it is envisioned that EVA radios will need to transmit both audio and video to surface rovers, landers, and habitats. An EVA-Ka proximity link will be needed to track the rover should it travel outside the astronaut's field of view. Astronauts will need to communicate with each other while performing maintenance or service tasks either on the ground or in orbit, so an EVA-to-EVA video link will be needed. It is possible that the EVA radio will need the capability to relay communications through a satellite to maintain constant contact with landers, habitats, or astronauts that are obscured or whose signals are otherwise blocked.

Ideally, one radio type will be suitable for many applications, without extensive configuration efforts, through the use of automatic self-configuration or adaptation to the application environment. It is intended that the dual goals of flexibility and survivability can be met with a modular architecture and operational paradigm. New and innovative solutions are sought that provide provable performance and survivability improvements.

The radio should underscore design of both hardware and software for failure tolerance and slow and soft degradation upon component or gate failure. Operation should be maintained following any single point failure in a discrete component or logic gate, even if in diminished capacity. Handling multiple failures with degradation is preferred. Methods that address space hardening of critical components are envisioned. Designs should also consider fallback schemes where the goal is to maintain communications even at the cost of quality, bandwidth, or functionality

Phase 1: The Phase 1 proposal should address the technical challenges posed by the design considerations enumerated above. During the Phase 1 effort, the EVA radio requirements definition, the initial design, and the method of testing the EVA radio will be developed. Because testing needs to include both ground testing and space testing, the proposal should address both of these elements as well as the proposed migration path between the two. Deliverables should include a prototype simulation of the design demonstrating the EVA radio's ability to reconfigure between bands/applications and a hardware prototype demonstrating some degree of fault survivability or reconfiguration.

Phase 2: During Phase 2, prototype integrated hardware and software comprising the EVA radio will be developed, finalized, and tested based on the designs developed in Phase 1. Design changes will be finalized in this phase as a result of testing according to the guidelines developed in Phase 1.

Phase 3: EVA radios suitable for early lunar missions will be fabricated, tested, and demonstrated according to the testing guidelines developed in Phase 1 and the prototypes fabricated in Phase 2.

Commercialization: Fire, police, and other civil and law enforcement agencies would benefit from radios that could be reconfigured on-the-fly to interoperate with each other. Currently, police and fire officials must usually be routed through a central hub and precious time is lost in the attempt to communicate between agencies. Major disasters have shown a need for a universal communication system that is adaptable.

O1.08 Transformational Communications Technology
Lead Center: GRC
Participating Center(s): JSC

NASA seeks revolutionary, highly innovative, "transformational" communications and navigational technologies to potentially enable breakthrough performance improvements for science, exploration systems, and space operations mission applications. Research focuses on (but is not limited to) the following areas:

- Use of quantum entanglement or 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. Methods or techniques that demonstrate extremely novel means of effectively packaging, storing, encrypting (e.g., quantum key distribution), and/or transferring information or knowledge in space-to-space or space-to-ground links;
- 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.) for nano-spacecraft applications;
- RF Micro Electro-Mechanical Systems (MEMS) devices. MEMS devices have low spatial volume, are lightweight, and have low-power consumption, making them attractive to operate as high Q components and perform frequency selectivity (i.e., 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. At present, most high rejection diplexers for space-based radios are quite large. 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; and
- Other areas of investigation to consider 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. Development of RF MEMS circuitry that applies and demonstrates significant advantages that proliferate the implementation of next-generation lightweight communications systems.

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 states that the US maintain a 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. Paramount to obtaining these capabilities is the development of the technologies identified in the following subtopics.

O2.01 Automated Optical Tracking and Identification of 3D Tumbling Objects
Lead Center: KSC
Participating Center(s): GSFC

Automated Optical Tracking
Develop a fully automated optical tracking system using data from multiple tracking stations located in and around the spaceport to provide accurate real-time trajectory and range data on space-lift vehicles for as long as possible following launch. The necessary optical tracking algorithms will be developed and modeled, with an emphasis on a robust automated tracking capability in the presence of smoke, clouds, or haze. The camera locations may be either land or sea based, or mounted on aerial vehicles, or some combination of all three. The initial investigation will determine the maximum downrange tracking distance, the tracking errors as a function of downrange distance, the processing speed, and the means for transmitting analyzed data to the command center.

Tracking and Identification of 3D Tumbling Objects
Develop techniques to track and construct 3-dimensional views of tumbling objects in the atmosphere or space using digital optical tracking images for a variety of missions. These views will be used to determine the objects' approximate geometric sizes and shapes. The potential application is to help track and identify debris quickly after an accident or flight anomaly. The data will be provided by sequential digital images from one or more tracking cameras, ideally operating autonomously. The goal is to track and identify between 50 to 100 objects with typical cross-sections varying from tens of square meters down to one square meter or less within several minutes after an accident. The initial investigation will determine the minimum size that can be imaged using current technology, the probability of correctly estimating an object's size and shape, the processing speed, and the means for transmitting analyzed data to the command center.

O2.02 Space Transportation Test Requirements and Instrumentation
Lead Center: SSC
Participating Center(s): GRC, MSFC

Ground testing of propulsion systems is a critical requirement to enable NASA's New Vision for Exploration announced by President Bush. 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 Systems, and Lunar Surface Access Modules propulsion systems. The ability to quickly and efficiently perform system certification greatly impacts all space programs. While hydrocarbon engines have not been officially selected as the next generation of launch vehicle propulsion systems, it is widely agreed that a return to hydrocarbon propellants is necessary to achieve the heavy lift capability required by these programs.

Engine Plume Sensors and Modeling
Engine plume *in situ* remote measurements during ground testing can provide information on the engine health and the engine performance as well as concentrations of environmentally sensitive species without disturbing the engine testing. In particular, since hydrocarbon fueled rocket engine plumes contain carbon soot because of fuel-rich combustion, soot measurements and modeling are very important. Rocket plume sensors must be able to detect gas species, temperature, and velocity for hydrocarbons (kerosene), and hybrid fuels.

Innovative sensors are required for measuring flow rate, temperature, pressure, rocket engine plume constituents, and effluent gas detection. Sensors must not physically intrude into the measurement space. High accuracy (0.2%), low-millisecond to sub-millisecond response time is required. Temperature sensors must be able to measure both cryogenic and high temperature fluids under high pressure (up to 15,000 psi) and high flow rate conditions (82 ft/sec). Response time must be on the order of a few milliseconds to sub-milliseconds.

Innovative methods in phenomenology, modeling, sensors, and instrumentation for the prediction, characterization, and measurement of rocket engine combustion instability are of interest. Sensor systems should have bandwidth capabilities in excess of 100 kHz. Emphasis is on development of optical-based sensor systems that will be non-intrusive in the test article hardware or exhaust plume.

Sensors must support integration with Integrated Systems Health Management (ISHM) technologies.

Engine Acoustic Energy Prediction and Sensing
The high levels of acoustic energy generated by rocket engines can be destructive to both launch vehicles and ground test/launch facilities. Current acoustic energy prediction methods can only provide a rough order of magnitude estimate of the amount of acoustic energy that a rocket engine will generate. Consequently, facilities and vehicles may be unnecessarily over designed to withstand the higher predictions, adding unnecessary weight and complexity.

New and innovative acoustic measurement techniques and sensors are necessary to accurately measure and predict the rocket plume acoustic environment. Current methods of predicting far-field and near-field acoustic levels produced by rocket engines rely on empirical models and require numerous physical measurements. New and innovative acoustic prediction methods are required that can accurately predict the acoustic levels a priori or using fewer measurements. New, innovative techniques based on energy density measurements rather than pressure measurements show promise as replacements for the older models.

Computational and Modeling Tools and Methods
The wide range of pressures, flow rates, and temperatures associated with rocket propulsion systems result in complex dynamics. It is not realistic to physically test each component and the component-to-component interaction in all states before designing a system. Consequently, systems must be tuned after fabrication, requiring extensive testing and often component redesign. Tools and methods are necessary that will allow the use of computational methods to accurately model and predict system performance.

Development of tools that integrate simple operator interfaces with detailed design and/or analysis software for modeling and enhancing the flow performance of flow system components such as valves, check valves, pressure regulators, flow meters, cavitating venturis, and propellant run tanks. In addition, new and improved methods to accurately model the transient interaction between cryogenic fluid flow and immersed sensors that predict the dynamic load on the sensors, frequency spectrum, heat transfer, and effect on the flow field are needed.

Propulsion System Exhaust Plume Flow Field Definition and Associated Plume Induced Environments (PIE)
An accurate definition of a propulsion system exhaust plume flow field and its associated PIE are required to support the design efforts necessary to safely and optimally accomplish many phases of any space flight mission from sea level or simulated altitude testing of a propulsion system to landing on and returning from the Moon or Mars. Accurately defined PIE result in increased safety, optimized design, and minimized costs associated with:

- Propulsion system and/or component testing of both the test article and test facility;
- Launch vehicle and associated launch facility during liftoff from the Earth, Moon, or Mars;
- Launch vehicle during the ascent portion of flight including staging, effects of separation motors, and associated pitch maneuvers;
- Effects of orbital maneuverings systems (including contamination) on associated vehicles and/or payloads and their contribution to space environments;
- Vehicles intended to land on and return from the surface of the Moon or Mars; and
- Effects of a vehicle propulsion system on the surfaces of the Moon and Mars including the contaminations of those surfaces by plume constituents and associated propulsion system constituents.

In general, the current plume technology used to define a propulsion system exhaust plume flow field and its associated plume induced environments is far superior to that used in support of the original Space Shuttle design. However, further improvements of this technology are required:

- To reduce conservatism, in the current technology, allowing greater optimization of any vehicle and/or payload design while keeping in mind crew safety through all mission phases; and
- To support the efforts to fill current critical technology gaps (below). PIE areas of particular interest include: single engine and multi-engine plume flow field definition for all phases of any space flight mission, plume induced acoustic environments, plume induced radiative and convective ascent vehicle base heating, plume contamination, and direct and/or indirect plume impingement effects.

Current critical technology gaps in needed PIE capabilities include:

- An accurate analytical prediction tool to define convective ascent vehicle base heating for both single engine and multi-engine vehicle configurations;
- An accurate analytical prediction tool to define plume induced environments associated with advanced chemical, electrical and nuclear propulsion systems; and
- A validated, user friendly, free molecular flow model for defining plumes and plume induced environments for low density external environments that exist on orbit, as well as interplanetary and other planets.

O2.03 Automated Collection and Transfer of Range Surveillance/Intrusion Data
Lead Center: KSC
Participating Center(s): GSFC

Range surveillance is a primary focus of launch range safety and often a cost and schedule driver. Launch delays, due to the difficulty of verifying a cleared range, are common and will increase as spaceports are developed in new areas. Proposals are sought for sensors and communications technologies that expedite range clearance such as sonobouys; high altitude airships (HAAs) and related developments for thermal and gas pressure management, power systems, propulsion systems, and flight control; UAVs; use of commercial communication satellites for data transfer over the horizon; imaging through atmosphere and self learning/neural networks for pattern recognition.

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9.2 STTR Research Topics

Each STTR Program Solicitation Topic corresponds to a specific NASA Center. Two subtopics per Topic reflect the current highest priority technology thrusts of that Center.

TOPIC: T1 Ames Research Center

NASA Ames Research Center is located at Moffett Field, California in the heart of Silicon Valley. Ames was founded December 20, 1939 as an aircraft research laboratory by the National Advisory Committee for Aeronautics (NACA). In 1958, Ames became part of National Aeronautics and Space Administration (NASA). Ames specializes in research geared toward creating new knowledge and new technologies that span the spectrum of NASA's interests.

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 for coordinating multi-agent systems in the presence of anomalies or threats;
- 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;
- Integrated software capabilities that allow automated science platforms, such as rovers, to respond to high-level goals. This could include perception of camera and other sensor data, position determination and path planning, science planning, and automated analysis of resulting science data;
- Data fusion, data mining, and automated reasoning technologies that can improve risk assessments, increase identification of system degradation, and enhance scientific understanding;
- 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;
- Software generation tools that capture designer intent and performance expectations and that embed extra knowledge into the generated code for use by automated software analysis tools doing validation and verification, system optimization, and performance envelope exception handling;
- Tools and techniques for program synthesis and program verification of high-assurance software systems; and
- Innovative communication, command, and control concepts for autonomous systems that require interaction with humans to achieve complex operations.

T1.02 Space Radiation Dosimetry and Countermeasures
Lead Center: ARC

As NASA embarks on a new exploration agenda, the study of the space radiation environment and its effects on living things and support technologies will be critical for the success of long-term missions. Our current understanding of the space radiation environment, particularly high atomic number and energy particles (HZE particles) and energetic protons, and its interaction with materials, technological systems, and living things is limited compared to our understanding of Gamma and X-rays. NASA has established a space radiation laboratory at Brookhaven National Labs capable of generating HZE particles and protons, and supports a facility at Loma Linda University Medical Center capable of generating energetic protons to enable research studies. We seek innovative technology solutions in the following areas:

Advanced Dosimetry Systems

- Real-time dosimetry providing dose and particle types and energies for use onboard spacecraft and planetary habitats;
- Real-time and cumulative dosimeters for characterizing space environments including planetary surfaces;
- Alarm systems for Solar Particle Events; and
- Microdosimetry for research applications including implantable dosimeters for biological studies.

Radiation Hardened Electronic Systems

- Methods for hardening pre-existing technologies; and
- Novel materials and circuit design.

Shielding Materials and Systems

- Multi-use materials for spacecraft and habitat fabrication (high strength, high shielding characteristics, embedded dosimetry, or warning devices);
- Materials for advanced EVA suits; and
- Alternative non-materials based shielding technologies.

Life Support Systems Composition and Monitoring

- Technologies to monitor the composition and health of biological components (microbial and plant) of life support and bio-remediation systems; and
- Development of radiation resistant organisms for life support and bio-remediation systems.

Biological Markers of Human Radiation Exposure

- Identify markers of radiation damage that can be obtained in a minimally invasive manner; and
- Technological systems to identify and quantitate biological markers onboard spacecraft and planetary habitats.

Astronaut Health Countermeasures

- Pharmaceuticals to counteract the deleterious effects of space radiation exposure;
- Gene therapy and other biological approaches; and
- Markers for genetic susceptibility to space radiation damage.

TOPIC: T2 Dryden Flight Research Center

Flight Research separates "the real from the imagined" and makes known the "overlooked and the unexpected." – Hugh L. Dryden. The Dryden Flight Research Center, located at Edwards, California, is NASA's primary installation for flight research. Projects at Dryden over the past 50 years have lead to major advancements in the design and capabilities of many civilian and military aircraft. The history of the Dryden Flight Research Center is the story of modern flight research in this country. Since the pioneering days after World War II, when a small, intensely dedicated band of pilots, engineers, and technicians dared to challenge the "sound barrier" in the X-1, Dryden has been on the leading edge of aeronautics, and more recently, space technology. The newest, the fastest, and the highest – all have made their debut in the vast, clear desert skies over Dryden.

T2.01 Flight Dynamic Systems Characterization
Lead Center: DFRC

This topic 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 computational fluid dynamics (CFD), structures, heat transfer, and propulsion disciplines, among others: in particular, 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 practical problems such as modern flight vehicles, like X-43 and F-18-AAW, 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 stability analysis is an important aspect of this topic. Primary concern is with the development and application of novel, multidisciplinary, simulation software using finite element and other associated techniques.

T2.02 Advanced Concepts for Flight Research
Lead Center: DFRC

This topic 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 with Remotely Operated Aircraft (ROA) within the National Air Space; and
- 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.

Proposals in any of these areas will be considered.

Online health monitoring is a critical technology for improving transportation 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 topic 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.

This topic 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 topic 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.

TOPIC: T3 Glenn Research Center

The NASA Glenn Research Center at Lewis Field, in partnership with other NASA Centers, U.S. industries, universities, and other Government institutions, develops critical technologies that address national priorities for space and aeronautics applications. NASA Glenn's world-class research and technology development is focused on space power, space flight, electric and nuclear space propulsion, space and aeronautic communications, advanced materials research, biological and physical microgravity science, and aerospace propulsion systems for safe and environmentally friendly skies. One-third of NASA Glenn's program responsibilities are in space and microgravity, one-third in space exploration systems, and one-third in aeronautics. We support NASA's commitment to safely return the shuttle to flight through ballistic impact testing, rudder speed brake actuator analysis, on-orbit repair of the wing, leading edge research, aging analysis, and wind tunnel tests of the external tank. NASA Glenn has two sites in northern Ohio. Situated on 350 acres of land adjacent to the Cleveland Hopkins International Airport, the Cleveland site in northeast Ohio comprises more than 140 buildings including 24 major research facilities and over 500 specialized research and test facilities. Plum Brook Station is 50 miles west of Cleveland and has four major world-class facilities for space research available for Government and industry programs. The staff consists of over 3200 civil service and support service contractor employees. Scientists and engineers comprise more than half of our workforce with technical specialists, skilled workers, and administrative staff supporting them. Over 60 percent of our scientists and engineers have advanced degrees, and 25 percent have earned Ph.D. degrees.

T3.01 Aerospace Communications
Lead Center: GRC

The research sought under Aerospace Communications focuses on the development of innovative communications, architectures, networks, and subsystems that significantly increase the capacity and connectivity among satellites, spacecraft, aircraft and ground networks thereby enabling new applications and services. These technologies are aimed at improving the power, bandwidth, and cost efficiency of communications at millimeter-wave frequencies and higher, and the interoperability, reliability, security, and quality of services of aerospace networks. The goal is to address the requirements of: NASA's Vision for Space Exploration, National Airspace System capacity, safety, and transportation initiatives; NASA's mission-unique applications; and NASA's utilization of emerging commercial communications services.

Innovations solicited include:

- Development of monolithic microwave integrated circuit (MMIC)-based arrays and array feeds, large-aperture inflatable antennas, miniaturized antennas, and trade-off studies among different antenna technologies for space applications. Potential lower cost, space-fed, active array and reflectarray approaches are also of interest as well as other MMIC and non-MMIC-based approaches (e.g., MEMS-, ferroelectric-, and optical-based approaches);
- Radio Frequency (RF) and optical propagation phenomena through atmosphere and turbulent media, development and validation of communication systems for aviation safety and aviation capacity, and other related electromagnetic phenomena;
- Digital communications, navigation, and surveillance technologies required for aeronautical communications, navigation, and surveillance (CNS) and space communications systems. Specific technologies include: software-defined radios; low-power, reconfigurable transceivers; multi-function, multi-mode digital avionics; network interface controllers, hubs, and routers for space; bandwidth- and power-efficient digital modems; advanced signal processing techniques; and integrated microelectronic or optoelectronic devices;
- Research and development of advanced microwave materials, devices, and circuits as well as the technologies required for integrating individual circuit components into microwave subsystems. Research in high-power transmitters focused on improving efficiency, RF power output, reliability, operating life, and communications qualities (such as linearity of a traveling wave tube amplifier for use in space communications). RF power combining techniques at Ka-Band frequencies are also of interest;
- Research on semiconductor circuits for transmit and receive modules in operational frequency bands designated for NASA's Exploration Systems vision. Specific technologies under development include: wide bandgap semiconductors, such as gallium nitride and silicon carbide; III-V semiconductors; silicon germanium; radio frequency micro-electromechanical systems (RF MEMS) devices/circuits; radio frequency integrated circuits including transmission lines and passive components; and microwave circuit packaging techniques;
- Cryocooled ultra-sensitive receivers for use in terrestrial antenna arrays for reception of signals from deep space and for inter-satellite links;
- Emerging technologies such as, multi-Gb/s photonic and nano-electronics based devices and circuits; and
- Research and development of advanced aerospace communications network architectures, protocols, standards, technologies, and network-based applications. Specific areas of interest include transmission control protocols, modifications, and enhancements to mitigate variable delays and high latency, next generation transport protocols, mobile-Internet protocols/routing, ad-hoc networking, and quality-of-service protocols, design, and implementation of advanced hybrid architectures to support NASA applications.

T3.02 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, thereby enabling future NASA missions.

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 nano-materials; 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 as well as dynamic power generation systems for nuclear power conversion. In energy storage systems, advances are needed in batteries—primary and rechargeable—regenerative fuel cells, and flywheels. 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, advances are needed for ion, Hall, and advanced plasma thrusters 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 and nano- and autonomous systems that include nano-materials, high temperature shape memory alloys, and piezoelectric materials as well as control systems for autonomous, adaptive engine control and sealing.

TOPIC: T4 Goddard Space Flight Center

The mission of the Goddard Space Flight Center is to expand knowledge of the 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 subtopic is to solicit advanced remote sensing technologies to enable future Earth Science measurements.

Active Remote Sensing Instruments (Lidar)
Lidar remote sensing systems are required to meet the demanding measurement requirements for future Earth science missions. 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;

- Wind measurements (direct-detection technology only);
- Tropospheric and stratospheric ozone and CO_2 (profiling and total column); and
- Measurement of the air/sea interface and mixed layer.

Systems and approaches will be considered that demonstrate a capability that is scalable to space or can be mounted on a relevant platform (UAV, long-duration balloon, or aircraft). New systems and approaches are sought that will:

- Enable one of the Earth Science measurements listed above;
- 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.

Passive Remote Sensing Instruments for Unmanned Aerial Vehicles (UAVs)
Spectral imaging devices for remote sensing onboard UAVs are also desired. In particular, uncooled infrared and thermal spectral imager instruments, with the following specifications, are solicited:

- Instrument must be less than 2 lbs and no larger than 0.05 m^3 in volume;
- Must operate autonomously in coordination with the onboard flight plan;
- Must have a built-in data acquisition system;
- Spectral bands must all be coregistered and the data must be GPS time tagged;
- Spectral bands should be centered at 3.75, 3.96, and 11 microns as well as a band in the visible at 0.6 microns; and
- Quantization bit resolution should be 10-bit minimum.

Microwave Measurements Using Large Aperture Systems
New breakthrough technologies are sought for the construction of extremely large (tens of meters and larger diameter) microwave antenna systems. The microwave wavelengths will be determined according to the geophysical measurement of interest. Antenna concepts may include large single apertures or apertures composed of multiple elements that are operated synergistically to produce the desired performance. The proposed antenna systems must:

- Be compact upon launch, which can be achieved either through folding technologies or from some assemblage of small components into the larger final system in space;
- Achieve high precision surface form factors. Surface characteristics of the microwave antenna must be accurate enough to produce microwave beam patterns with adequately small side lobes; and
- Include beam-scanning capabilities. The beam scanning must be facile and over many beam widths so as to enable cross-track scanning if in LEO, or scanning over the full globe if at GEO. Beam widths must be small enough to resolve the few kilometer scales needed for many geophysical observations.

T4.02 Space Science Sensors and Instruments
Lead Center: GSFC

Sensors and Instruments for space science applications are:

Analytical Instrumentation
Technical innovations are sought for sensitive, high-precision, analog electronics for measurements of low voltages, currents, and temperatures. Work on cryogenic transition edge detection techniques for X-ray astronomy in particular, and IR sensors with high quantum efficiency. New robust, efficient integration techniques that are scalable to commercial manufacturing efforts are sought.

- High-resolution IR sensors with high quantum efficiency, especially novel ion-implanted silicon devices, and arrays. Sensitivities better than 10–16 W per root Hz;
- Cryogenic devices, such as SQUID amplifiers and SQUID multiplexers, superconducting transition-edge temperature sensors, and miniature, self-contained low-temperature He refrigerators;

- Analog application-specific integrated circuits (ASICS) with large dynamic range (>105) and low power (<100 microwatts per channel); and
- Novel packaging techniques and interconnection techniques for analog and digital electronics.

Optics

Larger telescopes in space (compared to the 6 m James Webb Space Telescope [JWST]) demand lighter weight materials and new concepts. For example: designs including inflatable structures for lenses, mirrors, or antennas. Order of magnitude increases are envisioned. Applications of new materials could bring a new dimension to astronomy.

Goals for future NASA Optical Systems

	X-ray Mirrors	UV Mirrors	Visible Scanning	Lidar Telescope	NIR* Earth Science Systems	Far Infrared to submillimeter Wavelength
Energy Range	0.05–15 keV	100–400 nm	400–700 nm	355–2050 nm	0.7–4 mm	20–800 mm
Size	1–4 m	1–2 m	6–10+ m	0.7–1.5 m	3m–4 m	10–25 m
Areal Density	<0.5 kg/m^2/grazing incidence	<10 kg/m^2	<5 kg/m^2	<10 kg/m^2	<5 kg/m^2	<5 kg/m^2
Surface Figure	l/150 at l = 633 nm	Diffraction Limited at l = 300 nm	l /150 at l = 500 nm	l/10 at l = 633 nm	l /75 at l = 1 mm	l /14 at l =20 mm

* Near-infrared

- Large-area, lightweight (<15 kg/m2) focusing optics, including inflatable or deployable structures;
- Novel laser devices (e.g., for lidars) that are tunable, compact, lower power and appropriate for mapping planetary (and lunar) surfaces. Future lidar systems may require up to ~1.5 m optics and novel designs; and
- Fresnel-zone X-ray focusing optics to form large X-ray telescopes with small apertures but high angular resolution—better than 1 milli-arc-second. Besides newly developed optics, these missions will require formation flying of spacecraft to an unprecedented level.

Mars and Lunar Initiative Technologies

The new Exploration Initiative (Code T) will embark upon an ambitious plan of robotic and human exploration of Mars with intermediate work to be done on the Moon. A broad program of analysis and resource identification is being planned, including X-ray and Gamma-ray spectroscopy. Exploiting the existing resources will be an important part of these initiatives rather than moving resources from place to place. These resource investigations will be conducted from orbit and from landers, both of which have differing requirements. On missions to Mars and other planets, instruments are typically limited to ~5–10 kg maximum.

- Low-weight, high throughput X-ray diffraction systems at 60 keV so that sample spectra can be accumulated in minutes or hours, not days;
- Laser-based X-ray generators (up to 60 keV), both compact and lightweight;
- Improved scintillator resolution for Gamma-rays up to 10 MeV; and
- High spatial resolution X-ray detectors, for producing ~50 meters or less maps from orbiting spacecraft, also with high throughput.

Computing

Massively parallel computer clusters for ever more complicated problems (in General Relativity, electrodynamics and "space weather," for example) are becoming more important. Ways to increase performance and reliability and lower cost are called for.

- Novel computing techniques for simulations (including hydrodynamics, stellar evolution, general relativity calculations, etc.);
- New high-performance, low-cost, reliable massively-parallel computers (i.e., Beowulf clusters); and
- Validation tools and software for space weather simulations and modeling.

UAV and Balloon-craft Technologies
Both remotely piloted (unmanned airborne vehicles [UAVs]) and balloon instrumentation technologies are sought. New techniques and materials for forming "super-pressure" balloons and ways of formation flying or station-keeping with balloons would enable new science from this inexpensive platform, especially in the unmanned exploration of other planets.

- Super-pressure balloon manufacturing technologies;
- Station-keeping and trajectory control devices for balloons;
- New architectures and technologies for remote sensing applications; and
- Trajectory simulation tools and software.

TOPIC: T5 Johnson Space Center

To achieve the Agency's mandate of a robust space exploration program, the Johnson Space Center's roles and goals are focused on advancing the development of highly effective and innovative crew support and robotics/virtual digital human technologies. Extensive mission durations and harsh environments will dictate that future space explorers will need significantly improved hardware and systems to permit them to achieve these objectives. The Johnson Space Center, recognized as a Center of Excellence for human operations, seeks innovative solutions to these major challenges for human space explorers.

T5.01 Advanced Crew Support Technology
Lead Center: JSC

Advanced Crew Support Technologies will be essential to provide capabilities to enable humans to live and work safely, effectively, and efficiently in space during long-duration missions away from Earth as outlined by the Vision for Human Exploration of Space. Special emphasis is placed on development of technologies that will have a dramatic impact on reduction of mass, power, volume and crew time, and increased safety and reliability. Areas being solicited include Advanced Life Support and Extravehicular Activity including development of direct energy conversion, energy storage, and applications utilizing nanotechnologies relevant to these areas. Research and technology development with dual uses pertinent to Earth-based applications to improve environmental sustainability are of interest.

Life Support and Habitation (LSH)
Closed-loop life support systems were identified by the President's Commission on Implementation of United States Space Exploration Policy as an enabling technology critical to attainment of exploration objectives within reasonable schedules and affordable costs. Subsystems are needed to fully recycle air and water, recover resources from solid wastes, and produce food from plants. Requirements include: safe operability in micro-and partial-gravity, high reliability, minimal use of expendables, ease of maintenance, and low system volume, mass, and power. Specific areas of interest include:

- Waste Management: Technologies to safely and effectively manage dry and wet solid wastes expected on near-term missions (plastics, food scraps, clothing, paper, tape, hygiene materials, and/or feces) performing the following functions: compaction, stabilization, dewatering, storage, and control of odor release;
- Water Recovery: technologies in two specific areas are solicited: 1) low-temperature catalysts for destruction of organic carbon and nitrogen residuals in processed wastewater that operate at temperatures below

100º C; 2) technologies for recovery of water from brines generated from primary and secondary water processors including distillation and reverse osmosis systems that do not require use of consumable media;

- Filtration of Air and Water: techniques and technologies for separation and removal of particulates from water and gas streams, including air, potable water, and wastewater, that are regenerable, do not require consumable materials, have low pressure drop, and are suitable for use in micro- and hypo-gravity including consideration for collection and disposal of the solid phase;
- Food Provisioning and Galley: proposals are being sought in two areas: 1) Development of a non-metallic, high barrier packaging material with less mass and volume and/or is biodegradable, recyclable, or reusable, to minimize a potentially significant trash management problem. All packaging materials must have adequate oxygen and water barrier properties to maintain the food's 3- to 5-year shelf life. 2) Development of efficient and reliable food preparation or food processing equipment that can be used in hypogravity and reduced atmospheric pressure;
- Habitation Systems: Clothing Management Systems for reuse of clothing during long duration spaceflight, including clothes washing and drying technologies and which consider new advances in fabrics and materials;
- Crop Systems: new or more efficient technologies for lighting systems for crop growth, for use for fresh vegetable production within spacecraft or crop production systems on planetary surfaces. Lighting technologies must provide high irradiance and meet the spectral requirements for crops. These may include development of highly efficient electric light sources, highly efficient systems for collection, distribution, and re-emission of solar radiation or selectively transparent materials for direct solar lighting;
- Nanomaterials Applications: proposals are also solicited for development of advanced life support technologies that utilize unique properties of nanomaterials that are not possible with conventional materials, with emphasis on applications using single wall carbon nanotubes; and
- Direct Energy Conversion and Storage: proposals are sought on advanced concepts that can provide significant increases in specific energy and energy density (Wh/kg and Wh/L), in specific power and power density (W/kg and W/L), and in calendar life while improving or maintaining safety and maintainability commensurate with in-cabin applications in crewed vehicles.

Advanced Extravehicular Activity (AEVA)

Complex missions require innovative approaches for maximizing human productivity and for providing the capability to perform useful work tasks. Requirements include reduction of system hardware weight and volume; increased hardware reliability, durability, operating lifetime, and increased human comfort. Specific areas of interest are as follows:

- Lightweight Structural and Protective Materials: proposals are sought for development of lightweight structural and protective materials for use in space suits to provide integral shell structure strength, impact, and puncture protection from shape edges, micrometeoroids and orbital debris, radiation protection, and prevention of abrasion, adhesion, and mitigation from Lunar and Martian dust;
- Protective Suits for Hazardous Environments: proposals are sought for development of a protective suit based on EVA technologies and concepts for Homeland Security and hazmat applications including hazardous materials handling and minimizing exposures to chemical and biological agents;
- Airlocks with minimum gas loss and volume: proposals are sought for development of both in-space and surface vehicle airlocks that minimize gas loss during depressurization and repressurization operations and also require minimum volume for airlock hatch and EVA crewmembers.
- Nanomaterials Applications: proposals are also solicited for development of technologies for Advanced Extravehicular Activity that utilize unique properties of nanomaterials that are not possible with conventional materials with special emphasis on applications using single wall carbon nanotubes; and
- Direct Energy Conversion and Storage: proposals are sought on advanced concepts that can provide significant increases in specific energy and energy density (Wh/kg and Wh/L), in operating temperature range, in specific power and power density (W/kg and W/L), and in calendar life while improving or maintaining safety commensurate with in-cabin and exterior applications in crewed vehicles.

T5.02 Robotics and Virtual Digital Human Technologies
Lead Center: JSC

An Integrated Approach with Digital Virtual Humans(DVH) and Robotic Simulations
NASA is targeting a new level in space exploration operations. Critical advancements in crew and ground support technologies will be needed as NASA develops new operational capabilities to support multiple-manned, robotic, and long-duration/distance missions. Two potential areas for research are the ever-evolving Robotics and 3D DVH training procedures and simulation technologies providing operational robustness and intelligence. Furthermore, advanced capabilities for information integration and real-time interaction provide foundation for more simulation interaction between the two technologies. More advanced inter-system support capabilities (performance, maintenance, etc.) coordinated with a reliable knowledge base will be needed.

Proposals that improve operator efficiency via advanced displays, controls, and telepresence interfaces and improve the ability of humans and computers to seamlessly control robotic systems are sought. Specific technology requirements include the following hardware:

- Thermal feedback device for protecting the Robotic End-Of-Effector from grasping a hot/cold object that will damage its hand;
- Tactile feedback interface for collision awareness between workspace and avatar objects and robotic structure;
- Force feedback device for operator awareness of manipulator and payload inertia, gripping/slipping force, and forces and moments due to contact with external objects;
- Stereographic/autostereoscopic display systems for high-fidelity depth perception, field of view, and high resolution; and
- Spatial tracking for user appendages (i.e., head, arms, legs, fingers, and eyes) and avatar/robotic motion.

Based on the new Mission Control Center System (MCCS) Architecture framework, integrated support for Digital Virtual Human (DVH) in the loop and teleoperational interfaces are also the focus of this solicitation. Proposals offering innovation in the form of 3D visualization and simulation capabilities of robotic systems (direct manipulation, telerobotics, telepresence, etc.) with relation to the 3D DVH in the loop concept are being sought. The application targets would be flight and ground operations development, analyses, planning, training, and support. The main result desired is an interactive system that enhances operator and IVA/EVA procedure tasks efficiency via the teleoperational technologies and distributed collaborative virtual environments. The introduction of the DVH in a Virtual Reality (VR) robotic scenario is necessary for task and robotic device design, development, testing, planning, training, and operations functioning as integrated systems.

The core element of this project is the implementation of the Digital Virtual Human (DVH). This innovative human modeling technology comprises a combination of anatomical, biomechanical, and anthropometric functionality to fully simulate the somatic components and systems of the human body. Based on the tenets of the Visible Human Project, this DVH technology provides the opportunity to simulate real-world problems on the DVH in a simulated, virtual environment (VE) interfacing with virtual objects. The main objective is to apply a high-fidelity DVH in a scenario that "re-creates" a real world. Scenes involving the DVH imply rich, complex problems to solve, visualize, and predict outcomes. The DVHs will have a key role in Shared VEs and truly interactive scenarios based on real-time data/information. More complex DVH embodiment increases natural interaction within the environment. The users' more natural perception of each other (and of autonomous actors/avatars) increases their sense of being together and thus the overall sense of shared presence in the environment.

Immersive technologies such as Virtual Reality (VR), Digital Virtual Human (DVH), and 3D DVH training procedure and simulation modeling have become a significant vehicle for NASA's effort to generate and communicate knowledge/understanding to K-12 levels through university/academic institutions to continuing education modalities. The ability to share aerospace-related operation simulations such as International Space Station and Space Shuttle/Space Transport System (STS) operations, robotics, intravehicular/extravehicular activities, Mission

Control Center Systems (MCCS) conduct, interplanetary space flight, and microgravity simulation provides opportunity for educational and commercial growth for NASA and its research and development partners.

Human/Robotic Operations in Space

- Small, low power machine advanced vision systems for tracking a moving, articulated object;
- Machine vision techniques including the construction of image mosaics, for detection of unspecified changes in objects being inspected under diverse or changing lighting and viewing conditions;
- Small, lower power, range/range-rate sensors;
- Control interfaces that allow for seamless human/robot operations;
- 3D path planning systems and intelligent trajectory assessment feedback during teleoperations;
- Miniaturized motor control and drive electronics;
- Miniaturized sensing systems for manipulator position, rate, acceleration, force and torque; and
- Reduced-part-count miniaturized propulsion hardware (e.g., compressed gas storage with output pressure regulation via valve control only).

TOPIC: T6 Kennedy Space Center

NASA's launch headquarters, John F. Kennedy Space Center (KSC), is America's gateway to the universe and its busiest launch and landing facility. KSC at the Cape Canaveral Spaceport is NASA's Spaceport Technology Center, a world-class resource for the space transportation industry. KSC is helping to set the standard for future spaceports everywhere. Designers of new space transportation systems and architectures are integrating KSC-developed spaceport and range technologies into those designs to lower not only the costs of building the flight and ground systems but also of maintaining and operating them. Visionary approaches and strategies being developed today at KSC are laying the groundwork for the Cape Canaveral Spaceport and other spaceports and ranges of the future. We want to continue to offer safe and cost-effective space access for our nation and international partners' needs.

T6.01 Self-Healing Repair Technologies
Lead Center: KSC

It is highly desirable to develop technologies for polymeric materials used in electrical wire insulation that have the ability to self-heal. One example of self-healing is the repair process for composite materials, which uses the stress induced by a microfissure to rupture microcapsules of repair materials. In this system, a monomer is microencapsulated and then dispersed along with a catalyst. Once the microcapsules rupture, the monomer is polymerized by the dispersed catalyst and the microfissure is filled. Applications for self-healing processes for materials can be found in areas where failures could result in catastrophic consequences. For example, failure of structural members in spacecraft or aircraft; failure of electrical wire insulation materials used in spacecraft, aircraft, or buildings; or failure of polymer membranes used in critical separations in space exploration or medical devices. The key to any self-healing process is to use the change that occurs during the onset of the failure to initiate the repair process. This change could be the result of an impact to the insulation or the beginning of the electrical breakdown of the insulation. What is required would be an action that provided sufficient energy to start a second reaction or process that ultimately produced and/or bonded the repair material to the damaged insulation.

Wire insulation failure is considered a major problem on spacecraft and proposals should support concepts to develop self-healing technologies that have the ability to repair damaged Kapton or Teflon wire insulation. Of particular importance will be the methods needed to induce the self-repair process in wire insulation that has been manufactured. It is important to recognize the impact of the manufacturing process used to produce the insulated wire on the final product. These methods must produce a flexible, watertight seal over the damaged area. The physical and chemical properties of the final repair material should be similar to the initial insulating materials.

Proposals are also sought for innovative technologies and technology concepts in combining or bonding self-healing materials to conductor materials for an integrated, advanced, next-generation wiring system. Technologies for advancing conductor materials to allow for this integrated system should be considered since this is a topic area of concern in the Human and Robotic Technology Program.

T6.02 Batteryless, Wireless Remote Sensors
Lead Center: KSC

Recently, an innovative communication scheme was demonstrated that increases the attractiveness of using Surface Acoustic Wave (SAW) sensors as the basis for wireless, passive, sensor networks. It now appears feasible that a moderate number of sensors could be distributed throughout a volume of space and interrogated remotely and individually. Such a capability is of interest to the space program in that it may provide a lightweight (no wires and small sensors), low maintenance (no batteries), sensing network that can be used in harsh environments (predicted temperature ranges are from cryogenic through 900° C). NASA is currently funding work on a distributed temperature-sensing network but seeks other advances in this area.

At the recent 2004 IEEE International Ultrasonics, Ferroelectrics, and Frequency Control 50th Anniversary Joint Conference, two papers on Orthogonal Frequency Coding for SAW Sensors were presented. This new communication scheme for SAW devices and sensors appears to offer the capability to develop sensing networks where individual sensors can be interrogated from among a distributed array of devices. It also appears to provide scaling of the system in both number and range while suffering minimal degradation in the time resolution of the echoed signals. Consequently, NASA has recently decided to fund the development of a demonstration system using this concept and using a selected sensor (most likely temperature).

But, further advances are sought in this area, particularly, but not limited to, the area of novel sensors. Both the Space Shuttle as well as future vehicles could benefit from distributed strain sensors allowing high resolution monitoring of airframe stress. Embedded sensors within high pressure dewars might indicate fracturing before destructive failure occurs. Sensors that can operate within a cryogenic environment without the heat loss associated with wires could offer level, pressure, or temperature monitoring capabilities that are difficult or impossible to achieve with current technology. Embedded corrosion sensors or other process monitors could provide useful data. For example, it might be advantageous to locate moisture sensors under the Shuttle's thermal protection system materials. Also, there is interest in distributed leak detection systems, where, for example, hydrogen could be detected before it accumulates to the 4% explosive level in air. In addition to sensor development, improvements to the overall system are sought. For example, improvements are desirable in antenna design or system architecture that increase range or sensitivity.

The goal is to provide new sensors and capabilities that are compatible with the Orthogonal Frequency Coding scheme recently demonstrated under NASA funding in order to increase the range of applicability of this concept.

TOPIC: T7 Langley Research Center

In alliance with industry, other agencies, academia, and the atmospheric research community in the areas of aerospace vehicles, aerospace systems analysis, and atmospheric science, the Langley Research Center undertakes innovative, high-payoff activities beyond the risk limit or capability of commercial enterprises and delivers validated technology, scientific knowledge, and understanding of the Earth's atmosphere. Our success is measured by the extent to which our research results improve the quality of life of all Americans.

T7.01 Personal Air Transportation Technologies for Flight Demonstration
Lead Center: LaRC

NASA is performing technology research for future, on-demand, personal air transportation that is more robust and consumer focused than current commercial airline operations. The current studies involve the investigation of missions, concepts, and technologies for the purpose of augmenting on-demand personal transportation mobility and capacity over the next 20 years. The intent of this research is to perform the analyses and demonstrations required to provide radical improvements to the key metrics that currently inhibit market growth of these small, personal-use vehicles. Initial markets would build on the near-term, existing general aviation infrastructure with takeoff and landing field lengths of approximately 2500 feet. Next-generation general aviation markets will encompass a class of vehicles that have utility, comfort, public acceptance, efficiencies, cost, and ease of use which can be more closely associated with automobile-like characteristics. Long-term markets would involve mission concepts that are capable of much closer proximity operations and the ability to perform near door-to-door transportation service, but with significantly greater speed and reach.

This PAV research will include focused technology efforts leading towards the following goals and objectives:

1) Reducing small aircraft certified flyover community noise by 24 dbA from the state-of-the-art values of approximately 84 dbA while still achieving reasonable cost and efficiency with integrated vehicle concepts capable of 200-mph performance. This noise reduction equates to a tenfold reduction in the perceived noise so that these aircraft are no noisier than current motorcycle regulations. The intent of this effort is to demonstrate that significant increases in small aircraft operations can be acceptable to communities, as these vehicles are designed with technologies that permit them to be good neighbors. These community noise reductions should also provide a significant reduction in cabin noise which will provide improved comfort levels for passengers.

2) Reducing the aircraft acquisition cost on the order of 60% from current price levels while still at relatively modest production volumes of approximately 2000 units/year. This effort will include investigation of advanced quality assurance certification processes and procedures instead of the current quality control methods. Significant industry investment has not occurred because a sizable market is not envisioned at cost levels where only a small fraction of the population can enter the market. Future production of such vehicles could be on the scale of limited production luxury cars, however the demonstration of affordable vehicles at relatively low volume is a critical step for market growth that would provide the capital for rapid expansion.

3) Simplify the operation of small aircraft such that the specialized skills, knowledge, and associated training are reduced to levels comparable to operating an automobile or boat. This reduction must be achieved during near-all-weather operations and with a level of safety that is superior to comparable operations today.

4) Additional mid-term and long-term technology investigations could also include efforts that provide improved performance, efficiency, and short field length takeoff and landing capability. Implicit to all these investigations will be enhancing the vehicle safety, versatility, ease of entry, interior environment, visibility, and maintenance and operations cost.

Research that can be demonstrated, through flight or ground experiment, will be especially helpful in establishing a credible foundation from which personal mobility technologies can proceed in the private marketplace. Information is desired on current research efforts in these focused areas for respondents interested in partnering with NASA on collaborative investigation. It is anticipated that subsystem design and testing will be performed on selected technologies or concepts.

T7.02 Non-destructive Evaluation and Structural Health Monitoring
Lead Center: LaRC

Innovative concepts are being solicited for the development of non-destructive evaluation (NDE) and health-monitoring technologies for vehicles and structures involved in exploration missions. The highest priority is structural health monitoring systems that provide real time *in situ* diagnostics and evaluation of structural integrity. Emphasis is focused on highly miniaturized, lightweight, compact systems that deliver accurate assessment of structural health. The sensors, data acquisition and analysis systems and associated electronics must perform in high stress and hostile conditions expected on launch vehicles and space environments. Diagnostic systems intended for external inspection of space vehicles and structures will be highly autonomous, remotely operated and preferably non-contacting.

Evaluation sciences include ultrasonics, laser ultrasonics, optics and fiber optics, video optics and laser metrology, thermography, electromagnetics, acoustic emission, X-ray and terahertz radiation. Innovative and novel evaluation approaches are sought for the following materials and structural systems:

- Adhesives and bonded joints, sealants, bearings, coatings, glasses, alloys, laminates, monolithics, material blends, wire insulating materials, and weldments;
- 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:

- Characterization of material properties;
- Assessment of effects of defects in materials and structures;
- Evaluation of mass-loss in materials;
- Detection of cracks, porosity, foreign material, inclusions, and corrosion;
- Dis-bonded adhesive joints;
- Detection of cracks around fasteners such as bolts and rivets;
- Real-time and *in situ* monitoring, reporting, and damage characterization for structural durability and life prediction;
- Repair certification;
- Environmental sensing;
- Planetary entry aero-shell validation;
- Micro-meteor and orbital debris impact location and damage assessment;
- Electronic system/wiring integrity assessment; wire insulation integrity and condition (useful life) and arc location for failed insulation;
- Characterization of load environment on a variety of structural materials and geometries including thermal protection systems and bonded configurations;
- Identification of loads exceeding design;
- Monitoring loads for fatigue and preventing overloads;
- Suppression of acoustic loads;
- Early detection of damage; and
- *In situ* monitoring and control of materials processing.

Measurement and analysis innovations will be characterized by:

- Advanced integrated multi-functional sensor systems;
- Autonomous inspection approaches;
- Distributed/embedded sensors;

- Roaming inspectors;
- Shape adaptive sensors;
- Concepts in computational models for signal processing and data interpretation to establish quantitative characterization;
- Advanced techniques for management and analysis of digital NDE data for health assessment and lifetime prediction; and
- Biomimetic, and nano-scale sensing approaches for structural health monitoring that meet size and weight limitations for long duration space flight.

TOPIC: T8 Marshall Space Flight Center

Continued technological innovation is critical to a strong manufacturing sector in the United States economy. The Federal Government has an important role in helping to advance innovation including innovation in manufacturing, through small businesses. The President issued an executive order directing Agencies, to the extent permitted by law and in a manner consistent with the mission of the Agency, to give high priority within such programs to manufacturing-related research and development. NASA is interested in innovative manufacturing technologies that enable sustained and affordable human and robotic exploration of the Moon, Mars, and solar system. The nation's ability to decrease the cost and schedule required to develop new space transportation systems that are required to support NASA's exploration missions is hampered by inadequacies in our design tools and databases. Space transportation systems operate at the extremes of our materials capabilities, therefore any shortcomings in our ability to predict the internal operating environments during the design process will almost always lead to redesigns during the development of the system. These redesigns are costly and always compromise the project’s schedule. One way to address this issue is to increase the fidelity and accuracy of the tools used to predict the internal operating environments during design.

T8.01 Aerospace Manufacturing Technology
Lead Center: MSFC

Continued technological innovation is critical to a strong manufacturing sector in the United States economy. NASA is interested in innovated 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 components. 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; advanced materials and manufacturing processes for both cryogenic and high-temperature applications; and improved thermal protection systems (e.g., integrated structures, integral cryogenic tanks and insulations).

Ceramic Matrix Composite (CMCs)
Materials and processes that are projected to significantly increase safety and reduce costs simultaneously while decreasing weight for space transportation propulsion. 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.

Manufacturing Nanotechnology
Innovations that use nanotechnology processes to achieve highly reliable or low-cost manufacturing of high-quality materials for engineered structures.

T8.02 Advanced High Fidelity Design and Analysis Tools For Space Propulsion
Lead Center: MSFC

The pace at which the United States, through NASA, explores space will largely be driven by the cost of developing the systems required to make future explorations practical. The nation's ability to decrease the cost and schedule required to develop new space transportation systems that are required to support NASA's exploration missions is hampered by inadequacies in our design tools and databases. Space Transportation systems operate at the extremes of our materials capabilities, therefore, any shortcomings in our ability to predict the internal operating environments during the design process will almost always lead to redesigns during the development of the system. These redesigns are costly and always compromise the project’s schedule. One way to address this issue is to increase the fidelity and accuracy of the tools used to predict the internal operating environments during design.

Universities are at the leading edge of development of new, "first principles" physical models of development of new high-fidelity numerical approaches for simulating operation of space transportation systems and of developing experimental approaches and data required to validate these tools. Transition of these technologies, however, from an academic setting to a production, applications-centered environment, where it can be applied to the design of NASA's space transportations systems, requires focused effort. Efficient and timely transfer of these capabilities from the university setting to the operational (production) setting is required to reduce the developmental risks associated with NASA's space transportation systems and to maximize the return on NASA's investments at the nation's colleges and universities.

This subtopic solicits partnerships between academic institutions and small businesses for the purpose of developing novel design and analysis approaches and the methods by which to validate them into useful production tools that can be used to develop NASA's space transportation systems. Examples of specific areas where innovations are sought follow:

- Efficient, three-dimensional (3D), time-accurate analysis tools for modern rocket engine combustion chamber and turbomachinery environments and performance;
- Efficient, three-dimensional (3D), time-accurate analysis tools for predicting the environment and loads internal to valves, lines, and ducts in modern rocket engines;

- Practical 3D, steady and time-accurate, multidisciplinary analysis (MDA) tools for design of space transportations systems components and subsystems;
- Practical approaches for predicting the time-varying, 3D flow field in cases involving relative motion between objects;
- Practical Large Eddy Simulation (LES) tools for the analysis of high pressure reacting flows;
- Automated hybrid grid generation tools and grid adaptation tools;
- Efficient and accurate fluid properties routines for the range of conditions applicable to rocket engines;
- Automated approaches for extracting key engineering information and flow features from 3D flow simulations;
- Automated approaches for validating and assuring quality of application software;
- Practical, unsteady, 3D cavitation models for implementation into Reynolds-Averaged Navier-Stokes (RANS) analysis codes;
- Advanced instrumentation and diagnostic techniques necessary for acquisition of steady and unsteady code validation data; and
- Validation data for all of the tool types mentioned above.

TOPIC: T9 Stennis Space Center

The John C. Stennis Space Center (SSC) in south Mississippi is NASA's primary center for testing and flight certifying rocket propulsion systems for the Space Shuttle and future generations of space vehicles. Because of its important role in engine testing for four decades, Stennis Space Center is NASA's program manager for rocket propulsion testing with total responsibility for conducting and/or managing all NASA propulsion test programs. Stennis Space Center tests all Space Shuttle main engines. These high-performance, liquid-fueled engines provide most of the total impulse needed during the Shuttle's eight and one-half-minute-flight to orbit. All shuttle main engines must pass a series of test firings at Stennis Space Center prior to being installed in the back of the orbiter. The Earth Science Applications Directorate is NASA's Program Manager for Earth Science Applications. The Directorate matches NASA's scientific and technical knowledge with issues of national concern and the needs of our partners. Partners include local, state, and tribal governments, commercial industry, with educational and other non-profit institutions. Through the Directorate's co-funded partnerships, public and private sector decision makers learn how to apply new technologies to critical environmental, resource management, community growth, and disaster management issues. The Directorate also provides the remote sensing community with a comprehensive array of manmade and natural ground targets, measurement systems, and benchmark processes to help test airborne and space remote sensing systems against performance specifications and customer needs. Stennis Space Center began "re-inventing Government" decades ago before the concept became popular. Over the years, SSC has evolved into a multiagency, multidisciplinary center for Federal, state, academic, and private organizations engaged in space, oceans, environmental programs, and the national defense. In addition to NASA, there are 30 other agencies located at Stennis. Of approximately 4500 employees, about l600 work in the fields of science and engineering. These agencies work side by side and share common costs related to infrastructure, facility, and technical services which makes it cheaper for each to accomplish its independent mission at SSC.

T9.01 Rocket Propulsion Testing Systems
Lead Center: SSC

Proposals are sought for innovative technologies and technology concepts 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. As a minor element in a proposal for this topic, the offeror may include specific educational related research, technology advances, or other deliverables that address and support the Agency’s education mission such as the enhancement of science, technology, engineering, and mathematics instruction with unique teaching tools and experiences. Specific areas of interest in this subtopic include the following:

Facility and Test Article Health-Monitoring Technologies
Innovative, nonintrusive sensors for measuring flow rate, temperature, pressure, rocket engine plume constituents, and effluent gas detection. Sensors must not physically intrude at all into the measurement space. 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 LH_2) 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 LH_2). 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 LH_2. Pressure sensors must have a range up to 15,000 psi. Rocket plume sensors must determine gas species, temperature, and velocity for H_2, O_2, hydrocarbons (kerosene), 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 LH_2) 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 LH_2). Response time must be on the order of a few milliseconds to sub-milliseconds.

Phenomenology, 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 optical-based sensor systems that will be nonintrusive in the test article hardware or plume.

Improvement in Ground-Test Operation, Safety, Cost-effectiveness, and Reliability
Smart system components (control valves, regulators, and relief valves) that provide real-time, closed-loop control, component configuration, automated operation, and component health. Components must be able to operate in cryogenic temperatures (as low as 160R for LOX and 34R for LH_2) under high pressure (up to 15,000 psi) high flow rate conditions (2000 lb/s - 82 ft/s for LOX; 500 lb/sec - 300 ft/s for LH_2). Components must be able to operate in the elevated temperatures associated with a rocket engine testing environment. Response time must be on the order of a few milliseconds to sub-milliseconds.

Improved, long-life, liquid oxygen compatible seal technology. Materials and designs suitable for oxygen service at pressures up to 10,000 psi. Both cryogenic and elevated temperature candidate materials and designs are of interest. Typical temperature ranges will be either -320°F to 100°F, or -40°F to 300°F. Seal designs may include both dynamic and static use. Plastic, metal, or electrometric materials, or combinations thereof are of particular interest.

Miniature front-end electronics to support embedding of intelligent functions on sensors. Requirements include: computational power comparable to a 200 MHz PC with approximately 32 MB of RAM and similar non-volatile storage; analog input/output (I/O) (at least two of each with programmable amplification and anti-aliasing filters plus automatic calibration); digital I/O (at least eight) communication port for Ethernet bus protocol (one high speed and one low speed); support for C programming (or other high level language); and a development kit for a PC. The package should occupy a space no larger than 4" x 4" x 2". The system should include an embedded temperature sensor, an embedded stable voltage calibration source, and programmable switching to connect calibration source input and output.

New and innovative acoustic measurement techniques and sensors for use in a rocket plume environment. Current methods of predicting far-field and near-field acoustic levels produced by rocket engines rely on empirical models and require numerous physical measurements. New and innovative acoustic prediction methods are required which can accurately predict the acoustic levels a priori or using fewer measurements. New, innovative techniques based on energy density measurements rather than pressure measurements show promise as replacements for the older models.

Development of tools that integrate simple operator interfaces with detailed design and/or analysis software for modeling and enhancing the flow performance of flow system components such as valves, check valves, pressure regulators, flow meters, cavitating venturis, and propellant run tanks.

New and improved methods to accurately model the transient interaction between cryogenic fluid flow and immersed sensors that predict the dynamic load on the sensors, frequency spectrum, heat transfer, and effect on the flow field, are needed.

Modeling of atmospheric transmission attenuation effects on test spectroscopic measurements. Atmospheric transmission losses can be significant in certain wavelength regions for radiometric detectors located far from the rocket engine exhaust plume. Consequently, atmospheric losses can result in over-prediction of the incident radiant flux generated by the plume. Accurate atmospheric transmission modeling is needed for high-temperature rocket engine plume environments. The capabilities should address both the losses from ambient atmosphere and localized environments such as condensation clouds generated by cryogenic propellants.

Application of System Modeling to Ground Test Operations in a Resource Constrained Environment
New innovative approaches to incorporating knowledge and information processing techniques (prepositional logic, fuzzy logic, neural nets, etc.) to support test system decision making and operations. A requirement exists to develop, apply, and train intelligent agents, behavioral networks, and logic streams for rocket engine testing modes of operations and practice. Applications must operate statistically well on small and disparate data sources. The resulting products are inferential, representative, and they capture tacit and explicit knowledge. Statistical analysis must be supported.

Techniques to reduce required sample size to maintain acceptable levels of confidence in cost data. In order to use appropriate models and to manage the cost of data acquisition and maintenance, the minimization of required data sample sizes is critical.

Measurements and data are the product of ground testing. High accuracy, precision, uncertainty bands, and error bands are important elements of the data that is generated; this must be quantified. Techniques and models to determine these parameters for active test facilities are required.

T9.02 Integrated Life-Cycle Asset Mapping, Management, and Tracking
Lead Center: SSC

To support NASA's need for reliable and low-cost asset management in all of its programs including Earth-based activities, robotic and human lunar exploration, and planning for later expeditions to Mars and beyond, the Earth Science Applications Directorate at Stennis Space Center seeks proposals supporting NASA's requirements for asset management. With proper physical infrastructure and information systems, identification tags should allow any item to be tracked throughout its life cycle. When combined with Earth and lunar GIS, and related supporting documentation, any significant asset should be located, through time and space, as well as organization. Starting with programmatic requirements and design data, assets would be tracked through manufacture, testing, possible launch, use, maintenance, and eventual disposal. Innovative technology and information architectures should integrate and visually map infrastructure, assets, and associated documentation with the ability to link to program structure, budget, and workflow. Innovative solutions will facilitate information flow between the various NASA Centers and Programs. The system must maintain signature authority and restrict unauthorized moves. Ideally, if fully implemented, any remote item could be actively located throughout the NASA system with minimal delay. Any tagged item should be able to be queried at its location to retrieve associated records, e.g., maintenance, inspection, configuration management, chain-of-custody, engineering specifications, etc. A simple operator interface would provide "finger-tip knowledge" about the asset. It should be possible to provide secure access to this information for both domestic and international partners. The proposed solution will minimize capital cost and human work effort required for inventory and tracking of nonconsumable assets while exceeding the performance of current systems. Note that tagged assets may be subject to extreme environments in space and on Earth.

The innovation may eventually interoperate with a holistic information system, and may not preclude other uses for a terrestrial and lunar GIS such as:

- Operational infrastructure support AM/FM (automated mapping / facilities management);
- Asset and resource management, including waste disposal;
- Lunar landing and facility site selection, and optimization;
- Conceptual site infrastructure and layout design;
- Surface navigation;
- Emergency response information; and
- A comprehensive portal for Earth and lunar mapping data, both image- and vector-based.