SBIR/STTR 2004-1

National Aeronautics and Space Administration

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

Program Solicitations

Opening Date: July 7, 2004
Closing Date: September 9, 2004

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

TABLE OF CONTENTS

1. Program Description 1

1.1 Introduction 1
1.2 Program Authority and Executive Order 1
1.3 Program Management 1
1.4 Three-Phase Program 2
1.5 Eligibility Requirements 3
1.6 General Information 4

2. Definitions 5

2.1 Commercialization 5
2.2 Cooperative R/R&D Agreement 5
2.3 Cooperative Research or Research and Development 5
2.4 Essentially Equivalent Work 5
2.5 Funding Agreement 5
2.6 HUBZone-Owned SBC 5
2.7 Innovation 6
2.8 Intellectual Property 6
2.9 Principal Investigator 6
2.10 Research Institution 6
2.11 Research or Research and Development (R/R&D) 6
2.12 SBIR/STTR Technical Data 6
2.13 SBIR/STTR Technical Data Rights 6
2.14 Small Business Concern 6
2.15 Socially and Economically Disadvantaged Individual 7
2.16 Socially and Economically Disadvantaged Small Business Concern 7
2.17 Subcontract 7
2.18 United States 7
2.19 Women-Owned Small Business 7

3. Proposal Preparation Instructions and Requirements 8

3.1 Fundamental Considerations 8
3.2 Phase I Proposal Requirements 8
3.3 Phase II Proposal Requirements 13
3.4 SBA Data Collection Requirement 16

4. Method of Selection and Evaluation Criteria 17

4.1 Phase I Proposals 17
4.2 Phase II Proposals 18
4.3 Debriefing of Unsuccessful Offerors 20

5. Considerations 21

5.1 Awards 21
5.2 Phase I Reporting 21
5.3 Payment Schedule for Phase I 22
5.4 Release of Proposal Information 22
5.5 Access to Proprietary Data by Non-NASA Personnel 22
5.6 Final Disposition of Proposals 22
5.7 Proprietary Information in the Proposal Submission 22
5.8 Limited Rights Information and Data 23

5.9 Cost Sharing 24
5.10 Profit or Fee 24
5.11 Joint Ventures and Limited Partnerships 24
5.12 Similar Awards and Prior Work 24
5.13 Contractor Commitments 24
5.14 Additional Information 26
5.15 Property and Facilities 26
5.16 False Statements 26

6. Submission of Proposals 27

6.1 Submission Requirements 27
6.2 Submission Process 27
6.3 Deadline for Phase I Proposal Receipt 28
6.4 Acknowledgment of Proposal Receipt 28
6.5 Withdrawal of Proposals 29
6.6 Service of Protests 29

7. Scientific and Technical Information Sources 30

7.1 NASA SBIR/STTR Homepage 30
7.2 NASA Commercial Technology Network 30
7.3 NASA Technology Utilization Services 30
7.4 United States Small Business Administration 31
7.5 National Technical Information Service 31

8. Submission Forms and Certifications 32

FORM A – SBIR Cover Sheet 33
Guidelines for Completing SBIR Cover Sheet 34
FORM B – SBIR Proposal Summary 35
Guidelines for Completing SBIR Proposal Summary 36
FORM C – SBIR Budget Summary 37
Guidelines for Preparing SBIR Budget Summary 38
SBIR Check List 40
FORM A – STTR Cover Sheet 41
Guidelines for Completing STTR Cover Sheet 42
FORM B – STTR Proposal Summary 44
Guidelines for Completing STTR Proposal Summary 45
FORM C – STTR Budget Summary 46
Guidelines for Preparing STTR Budget Summary 47
Model Cooperative R/R&D Agreement 49
Model Allocation of Rights Agreement 50
STTR Check List 54
Appendix A: Phase I Sample Table of Contents 55
Appendix B: Example Format for Briefing Chart 55

9. Research Topics for SBIR and STTR 56

9.1 SBIR Research Topics 56
9.1.1 Aeronautics 57
9.1.2 Biological and Physical Research 71
9.1.3 Earth Science 99
9.1.4 Exploration Systems 121
9.1.5 Space Science 167
9.2 STTR Research Topics 193

2004 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 2004 Solicitation period for Phase I proposals begins July 7, 2004, and ends September 9, 2004.

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. Selection preference will be given to eligible proposals where the innovations are judged to have significant potential for commercial application.

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 I proposals will be selected for negotiation of fixed-price contracts in November 2004. Historically, the ratio of Phase I proposals to awards is approximately 8:1 for SBIR and 5:1 for STTR, and approximately 40% of the selected Phase I contracts are selected for Phase II 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 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 Office of Exploration Systems provides overall policy direction for the NASA SBIR/STTR programs. The Program Management Office is hosted at the Goddard Space Flight Center. The Procurement Management Office is hosted at Glenn Research Center.

The SBIR Program Solicitation is aligned with NASA's Strategic Enterprises (http://www.nasa.gov). The needs of all Strategic Enterprises are reflected in the research topics 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 Strategic Enterprises and the NASA Centers can be obtained at the following web sites:

NASA Strategic Enterprises	
Aeronautics	http://www.hq.nasa.gov/office/aero
Biological and Physical Research	http://spaceresearch.nasa.gov
Earth Science	http://www.earth.nasa.gov
Education	http://education.nasa.gov/
Exploration Systems	http://www.nasa.gov
Space Flight	http://www.hq.nasa.gov/osf
Space Science	http://spacescience.nasa.gov

NASA Installations	
Ames Research Center (ARC)	http://www.arc.nasa.gov
Dryden Flight Research Center (DFRC)	http://www.dfrc.nasa.gov
Glenn Research Center (GRC)	http://www.grc.nasa.gov
Goddard Space Flight Center (GSFC)	http://www.gsfc.nasa.gov
Jet Propulsion Laboratory (JPL)	http://www.jpl.nasa.gov
Johnson Space Center (JSC)	http://www.jsc.nasa.gov
Kennedy Space Center (KSC)	http://www.ksc.nasa.gov
Langley Research Center (LaRC)	http://www.larc.nasa.gov
Marshall Space Flight Center (MSFC)	http://www.msfc.nasa.gov
Stennis Space Center (SSC)	http://www.ssc.nasa.gov

1.4 Three-Phase Program

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

1.4.1 Phase I. The purpose of Phase I 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 II. Successful completion of Phase I objectives is a prerequisite to Phase II consideration.

Phase I 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 II. 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 I results.

Maximum value and period of performance for Phase I contracts:

Phase I Contracts	SBIR	STTR
Maximum Contract Value	$ 70,000	$ 100,000
Maximum Period of Performance	6 months	12 months

1.4.2 Phase II. The objective of Phase II is to continue the Research or Research and Development (R/R&D) effort from Phase I. Only SBCs awarded Phase I contracts are eligible for Phase II funding agreements. Phase II 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 II contracts is $600,000 with a maximum period of performance of 24 months.

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

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

1.5 Eligibility Requirements

1.5.1 Small Business Concern. Only firms qualifying as SBCs, as defined in Section 2.14, 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 I and Phase II, 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 PI must be with the SBC under the SBIR Program, while under the STTR Program the PI may be employed with the 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.

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 2004 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 I 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 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

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

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 this section), 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

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

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 in 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

An SBC is one that, at the time of award of Phase I and Phase II funding agreements, meets the following criteria:
(1) Is organized for profit, with a place of business located in the United States, which operates primarily within the United States or which makes a significant contribution to the United States economy through payment of taxes or use of American products, materials or labor;

(2) is in the legal form of an individual proprietorship, partnership, limited liability company, corporation, joint venture, association, trust or cooperative, except that where the form is a joint venture, there can be no more than 49 percent participation by business entities in the joint venture;
(3) is at least 51 percent owned and controlled by one or more individuals who are citizens of, or permanent resident aliens in, the United States, except in the case of a joint venture, where each entity to the venture must be 51 percent owned and controlled by one or more individuals who are citizens of, or permanent resident aliens in, the United States; and
(4) has including its affiliates, not more than 500 employees.

The terms “affiliates” and “number of employees” are defined in greater detail in 13 CFR Part 121.

2.15 Socially and Economically Disadvantaged Individual

A member of any of the following groups: African Americans, Hispanic Americans, Native Americans, Asian-Pacific Americans, Subcontinent-Asian Americans, 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 Part 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. 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 I proposals must provide sufficient information to convince NASA that the proposed SBC/RI cooperative effort represents a sound approach for converting technical information resident at the 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 I 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 II contracts include products or services in addition to required reporting of further developments or applications of the Phase I results. These deliverables may include prototypes, models, software, or complete products or services. The reported results of Phase II 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, and encourages companies to do so. Other acceptable formats are MS Word, MS Works, and WordPerfect.

3.2 Phase I Proposal Requirements

3.2.1 General Requirements

Page Limitation. A Phase I 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 is to 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. The technical abstract portion is limited to 200 words and shall summarize the implications of the approach and the anticipated results of both Phase I and Phase II. Potential NASA and non-NASA commercial applications of the technology should also be presented. If the technical abstract is judged to be non responsive to the subtopic, the proposal will be rejected without further evaluation.

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 Summary Budget, 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 facility acquisition as a direct cost (Section 5.15).

Travel. Travel during Phase I 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 I 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. A sample table of contents is included in Appendix A.

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 I 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 I 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: 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 I activities whose expertise and functions are essential to the success of the project. Provide bibliographic information including directly related education and experience.

The PI is considered key to the success of the effort and must make a substantial commitment to the project. The following requirements are applicable:

Functions. The functions of the PI are: planning and directing the project; leading it technically and making substantial personal contributions during its implementation; serving as the primary contact with NASA on the project; and ensuring that the work proceeds according to contract agreements. Competent management of PI functions is essential to project success. The Phase I proposal shall describe the nature of the PI's activities and the amount of time that the PI will personally apply to the project. The amount of time the PI proposes to spend on the project must be acceptable to the Contracting Officer.

Qualifications. The qualifications and capabilities of the proposed PI and the basis for PI selection are to be clearly presented in the proposal. NASA has the sole right to accept or reject a 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 2004 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 II or Future R/R&D. State the anticipated results of the proposed R/R&D effort if the project is successful (through Phase I and Phase II). Discuss the significance of the Phase I effort in providing a foundation for the Phase II R/R&D 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 I and projected Phase II and Phase III 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 I 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 Small Business Administration (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 a Government facility for successful completion, the offeror must provide a statement, signed by the appropriate Government official at the facility, verifying that it will be available for the required effort. The proposal must confirm that such facilities are not available from private sources, and include relevant information on funding sources(s) (private, other Government, internal) for the effort.

Part 9: Subcontracts and Consultants (Including Signed Commitment Letters). 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. The proposal **must** include a signed statement by each participating organization or individual that they will be available at the times required for the purposes and extent of effort described in the proposal. The signed statement should be scanned and included in the technical content. **This statement is included in the 25-page limit.** Failure to provide certification(s) may result in rejection of the proposal. 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).

Note: For STTR, the Cooperative Agreement is the signed commitment from the RI, thus no additional letter from the RI is required in Part 9.

Part 10: Potential Applications. The Phase I proposal shall forecast both the NASA and the non-NASA commercial potential of the project assuming success through Phase II. The offeror, in the Phase II proposal, will be required to provide more detailed information regarding product development and potential markets (Sections 3.3.4 and 4.2.2).

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) shall be a single-page document (see example in Section 8) signed by the SBC and the RI. 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 II awards in the prior 5 fiscal years, submit name of awarding agency, date of award, funding agreement number, amount, topic or subtopic title, follow-on agreement amount, source, and date of commitment and current commercialization status for each Phase II. 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 should not contain any proprietary data. An example chart has been provided in Appendix B.

3.3 Phase II Proposal Requirements

3.3.1 General Requirements. The Phase I contract will serve as a request for proposal (RFP) for the Phase II follow-on project. Phase II proposals are more comprehensive than those required for Phase I. Phase II proposals are required to be submitted electronically by utilizing the electronic handbook system hosted on the NASA SBIR homepage (http://sbir.nasa.gov). Submission of a Phase II proposal is strictly voluntary and NASA assumes no responsibility for any proposal preparation expenses.

Page Limitation. A Phase II proposal shall not exceed a total of 50 standard 8 1/2 x 11 inch (21.6 x 27.9 cm) pages. 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 is to 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).

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 copy of the Proposal Summary is provided in Section 8. The offeror shall provide complete information for each item and submit Form B as required in Section 6. The technical abstract portion is limited to 200 words and shall summarize the implications of the approach and the anticipated results of Phase II. Potential NASA and non-NASA commercial applications of the technology should also be presented. If the technical abstract is judged to be non responsive to the subtopic, the proposal will be rejected without further evaluation.

Note: The Proposal Cover (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. Sufficient 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 facility acquisition under Phase II as a direct cost (Section 5.15).

Travel. Travel during Phase II 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 II 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.

3.3.4 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

Part 2: Identification and Significance of the Innovation and Results of the Phase I 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 I 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 II 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 II, and discuss their qualifications in terms of education, work experience, and accomplishments relevant to the project.

Part 7: Phase III Efforts, Commercialization and Business Planning. Describe plans for Phase III 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 II and Phase III 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 II 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 II contracts as a direct cost. Special tooling may be allowed. (Section 5.15)

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 a Government facility for successful completion, the offeror must provide a statement, signed by the appropriate Government official at the facility, verifying that it will be available for the required effort. The proposal must confirm that such facilities are not available from private sources, and include relevant information on funding sources(s) (private, other Government, internal) for the effort.

Part 9: Subcontracts and Consultants (Including Subcontract Commitment Letters). Describe in detail any subcontract, consultant, or other business arrangements involving participation in performance of the proposed R/R&D effort and provide written evidence of their availability for the project. The proposal **must** include a signed statement from each subcontractor and/or consultant that they will be available at the times required for the purposes and extent of effort described in the proposal. The signed statement should be scanned and included in the technical content. **This statement is included in the 50-page limit.** Failure to provide certification(s) may result in rejection of the proposal. Subcontractors' and consultants' work must be performed in the United States. Note the following restrictions on subcontracts/consultants:

SBIR Phase II Proposal	STTR Phase II 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.

Note: The Cooperative Research established with a specific RI in STTR Phase I contracts shall continue with the same RI in Phase II.

Part 10: Potential Applications: 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 I Proposal Requirements, Part 11).

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

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

3.3.6 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 should 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 II award is required to update the appropriate information in the Tech-Net database for any of its prior Phase II awards. In addition, upon completion of Phase II, 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 I and II 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 I 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 a knowledge of the subtopic area.

4.1.1 Evaluation Process. Proposals should provide all information needed for complete evaluation and evaluators are not expected to 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 I 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 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 I 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 Merit 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 score for Commercial Merit 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 and will rank those proposals recommended for award relative to all other recommended proposals at that Center. Center rankings will be forwarded to the Program Management Office for analysis and presented to the Source Selection Official and Strategic Enterprise Representatives. Final selection decisions will consider the Center rankings as well as overall NASA priorities, program balance and available funding. However, recommendations and relative rankings developed 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 selections 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 I contract negotiations, but before the contract starts, the offeror shall, if requested, 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 II Proposals

4.2.1 Evaluation Process. The Phase II evaluation process is similar to the Phase I 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 II 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 I objectives were met, the feasibility of the innovation, and whether the Phase I results indicate a Phase II project is appropriate.

Factor 2. Experience, Qualifications and Facilities
The technical capabilities and experience of the PI or project manager, key personnel, staff, consultants and subcontractors, if any, are evaluated for consistency with the research effort and their degree of commitment and availability. The necessary instrumentation or facilities required must 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 I objectives. The methods planned to achieve each objective or task should be discussed in detail.

Factor 4. Commercial Potential. 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 planning; (c) the likelihood that the offeror will be able to obtain the remaining necessary financial, technical, and personnel-related resources to bear; 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 I proposals. Where technical evaluations are essentially equal in potential, cost to the Government may be considered in determining successful offerors. For Phase II proposals, commercial merit is a critical factor.

Each Center will make recommendations for award among those proposals that it evaluates and will rank those proposals recommended for award relative to all other recommended proposals at that Center. The Center Recommendation Report (which includes the Center analysis and ranking) will be forwarded to the Program Management Office for analysis and presented to the Source Selection Official and Strategic Enterprise Representatives. Final selection decisions will consider the Center rankings as well as overall NASA priorities, program balance and available funding, as well as any other evaluations or assessments (particularly pertaining to commercial potential) that may become available. However, recommendations and relative rankings developed 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.

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 I and Phase II 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, nor provide proposal scores, rankings in the competition, the content of or comparisons with, other proposals.

4.3.1 Phase I Debriefings. For Phase I proposals, debriefings will be automatically e-mailed to the designated business official within 60 days. 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 II Debriefings. To request debriefings on Phase II proposals, offerors must request via e-mail to the SBIR/STTR Program Support Office at sbir@reisys.com within 60 days after selection announcement. The offeror will be contacted by the appropriate Field Center for debriefing. Late requests will not be honored.

5. Considerations

5.1 Awards

5.1.1 Availability of Funds. Both Phase I and Phase II awards are subject to availability of funds. NASA has no obligation to make any specific number of Phase I or Phase II 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 I contracts with values not exceeding $70,000. Following contract negotiations and awards, Phase I contractors will have up to 6 months to carry out their programs, prepare their final reports, and submit Phase II proposals. ➢ NASA anticipates that approximately 40 percent of the successfully completed Phase I projects from the SBIR 2004 Solicitation will be selected for Phase II. Phase II agreements are fixed-price contracts with performance periods not exceeding 24 months and funding not exceeding $600,000.	➢ NASA plans to announce the selection of approximately 40 proposals resulting from this Solicitation, for negotiation of Phase I contracts with values not exceeding $100,000. Following contract negotiations and awards, Phase I contractors will have up to 12 months to carry out their programs, prepare their final reports, and submit Phase II proposals. ➢ NASA anticipates that approximately 40 percent of the successfully completed Phase I projects from the STTR 2004 Solicitation will be selected for Phase II. Phase II 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 I and Phase II 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 I 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 I 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 I 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 I contract, identifying the purpose of the R/R&D effort and describing the findings and results, including the degree to which the Phase I objectives were achieved, and whether the results justify Phase II continuation. The potential applications of the project results in Phase III 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 I

Payments can be 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 information (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 I proposals will be retained for one year after the Phase I selections have been made, after which time unsuccessful proposals will be destroyed. 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. If 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 I or Phase II 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. The Government, for a period of 4 years from acceptance of all items to be delivered under an SBIR/STTR contract, shall use the data, *i.e*., data first produced by the contractor in performance of the contract, where such data are not generally known, and which data without obligation as to its confidentiality have not been made available to others by the contractor or are not already available to the Government, agrees to use these data for Government purposes. These data shall not be disclosed outside the Government (including disclosure for procurement purposes) during the 4-year period without permission of the contractor, except that such data may be disclosed for use by support contractors under an obligation of confidentiality. After the 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 the Government is relieved of all disclosure prohibitions and assumes no liability for unauthorized use 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. SBIR 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 summary budget. 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 I and Phase II contracts may include a reasonable profit. The reasonableness of proposed profit is determined by the Contracting Officer during contract negotiations.

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 I proposal.

5.12 Similar Awards and Prior Work

If an award is made pursuant to a proposal submitted under either SBIR or STTR Solicitation, 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 I 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 I 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).

5.15 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 a Government facility for successful completion, the offeror must provide a statement, signed by the appropriate Government official at the facility, verifying that it will be available for the required effort. The proposal must confirm that such facilities are not available from private sources, and include relevant information on funding sources(s) (private, other Government, internal) for the effort.

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 no longer 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 will be through a secure connection. Communication between NASA and the firm will be via 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 on line, upload their technical proposal in an acceptable format, and have the Business Official electronically endorse the proposal. Electronic endorsement of the proposal is handled on line 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 I and 3.3.4 for Phase II.

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 at https://sbir.gsfc.nasa.gov/SBIR04/phase1/submissions/

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 3.2.8 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, please 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 EHB are encrypted for security. Proposals can be uploaded multiple times with each new upload replacing the previous version. An e-mail will be sent acknowledging each successful upload. An example is provided below:

Sample E-mail for Successful Upload of Technical Proposal

Subject: Successful Upload of Technical Proposal

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

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

Proposal No. ____________
(Uploaded File Name/Size/Date)

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

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

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

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

NASA SBIR/STTR Program Support Office

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

6.3 Deadline for Phase I Proposal Receipt

All Phase I proposal submissions must be received no later than 5:00 p.m. EDT on Thursday, September 9, 2004, 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 2004 Phase I xx.xx-xxxx (Title)
Form A completed on:
Form B completed on:
Form C completed on:
Technical Proposal Uploaded on:
  File Name:
  File Type:
  File Size:
Briefing Chart (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 19, 2004, and will be posted via the SBIR/STTR homepage (http://sbir.nasa.gov).

Thank your 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 the 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

Mid-Atlantic:
Technology Commercialization Center, Inc.
12050 Jefferson Avenue, Suite 340
Newport News, VA 23606
Phone: 757-269-0025
URL: http://www.teccenter.org

Southeast:
Georgia Institute of Technology
151 6th Street
216 O'Keefe Building
Atlanta, GA 30332-0640
Phone: 800-472-6785
URL: http://www.edi.gatech.edu/nasa/

Mid-West:
Great Lakes Industrial Technology Center
Battelle Memorial Institute
20445 Emerald Parkway Drive, SW, Suite 200
Cleveland, OH 44135
Phone: 216-898-6400
URL: http://www.glitec.org

Mid-Continent:
Mid-Continent Technology Transfer Center
Texas Engineering Extension Service
301 Tarrow Street
College Station, TX 77840-7896
Phone: 800-472-6785
URL: http://www.mcttc.com/

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 33
Guidelines for Completing SBIR Cover Sheet 34
FORM B – SBIR Proposal Summary 35
Guidelines for Completing SBIR Proposal Summary 36
FORM C – SBIR Budget Summary 37
Guidelines for Preparing SBIR Budget Summary 38
SBIR Check List 40
FORM A – STTR Cover Sheet 41
Guidelines for Completing STTR Cover Sheet 42
FORM B – STTR Proposal Summary 44
Guidelines for Completing STTR Proposal Summary 45
FORM C – STTR Budget Summary 46
Guidelines for Preparing STTR Budget Summary 47
Model Cooperative R/R&D Agreement 49
Model Allocation of Rights Agreement 50
STTR Check List 54
Phase I Sample Table of Contents 55
Example Format for Briefing Chart 55

FORM A – SBIR COVER SHEET

Subtopic Number

1. PROPOSAL NUMBER: **04 -** _ _ . _ _   _ _ _ _
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
b. As referenced in Section 5.13.16, PI is U.S. Citizen or Permanent Resident	Yes	No
As defined in Section 2 of the Solicitation, the offeror qualifies as a:		
c. SBC Number of employees: _____	Yes	No
d. Socially and economically disadvantaged SBC	Yes	No
e. Woman-owned SBC	Yes	No
f. HUBZone-owned SBC	Yes	No
As defined in Section 3.2.4 Part 11 of the Solicitation indicate if		
g. Work under this project has been submitted for Federal funding only to the NASA SBIR Program	Yes	No
h. 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:		
i. All 11 parts of the technical proposal are included in part order	Yes	No
j. Subcontracts/consultants proposed?	Yes	No
i) If yes, limits on subcontracts/consultants met	Yes	No
ii) If yes, copy of agreement enclosed	Yes	No
k. 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

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, 6g and 6h (see the referenced sections for definitions).

   6b. 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. Violations of these regulations can result in criminal or civil penalties.

   6h. SBCs should choose “No” to confirm that work under this project has not been funded under any other Federal grant, contract or subcontract.

   6j. 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.

   ii) If yes, copy of agreement enclosed: By answering yes, the SBC certifies that a copy of any subcontracting or consulting agreements described in Section 3.2.4 Part 9 is included as required. Copy of the agreement may be submitted in a reduced-size format.

   6k. 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 5, 5.17). By answering no, the SBC 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 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.

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 **04 -** _ _ . _ _ _ _ _ _.

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 200 words or 2,000 characters, whichever is less):

7. Potential NASA Application(s): (Limit 100 words or 1,500 characters, whichever is less)

8. Potential Non-NASA Commercial Application(s): (Limit 100 words or 1,500 characters, whichever is less)

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.

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 I 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 I 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 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 5.11 and 5.12. 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 Thursday, September 9, 2004** (Section 6.3).

FORM A – STTR COVER SHEET

1. PROPOSAL NUMBER: **04 -** _ _ _ _
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.	As referenced in Section 5.13.16, PI is U.S. Citizen or Permanent Resident	Yes	No
c.	Socially and economically disadvantaged SBC	Yes	No
d.	Woman-owned SBC	Yes	No
e.	HUBZone-owned SBC	Yes	No
As described in Section 2.8 of the Solicitation, the partnering institution qualifies as a:			
f.	FFRDC	Yes	No
g.	Nonprofit research institute	Yes	No
h.	Nonprofit college or university	Yes	No
As described in Section 3 of the Solicitation, the offeror meets the following requirements completely:			
i.	Cooperative Agreement signed by the SBC and RI enclosed	Yes	No
j.	All eleven parts of the technical proposal included in part order	Yes	No
k.	Subcontracts/consultants proposed? (Other than the RI)	Yes	No
	i) If yes, limits on subcontracts/consultants met	Yes	No
	ii) If yes, copy of agreement enclosed	Yes	No
l.	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
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

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. 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 and 6g (see Section 2 for definitions).

   6b. 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. Violations of these regulations can result in criminal or civil penalties.

   6i. 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. All eleven parts of the technical proposal included: By answering yes, the SBC/RI certifies that the proposal consists of all eleven parts numbered and in the prescribed order (see Section 3.2.4).

   6k. 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.

   ii) If yes, copy of agreement enclosed: By answering yes, the SBC/RI certifies that a copy of any subcontracting or consulting agreements described in Section 3.2.4 Part 9 is included as required. Copy of the agreement may be submitted in a reduced size format.

   6l. 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.

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 **04 - __ __ __ __**

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 200 words or 2,000 characters, whichever is less):

8. Potential NASA Application(s): (Limit 100 words or 1,500 characters, whichever is less)

9. Potential Non-NASA Commercial Application(s): (Limit 100 words or 1,500 characters, whichever is less)

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.

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 I 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 I for acceptance by NASA. Show how this rate is determined. The offeror may use whatever number and types of overhead rates are in accordance with the firm's accounting system and approved by the cognizant Federal negotiating agency, if available. Multiply Direct Labor Cost by the Overhead Rate to determine the Overhead Cost.

Example: A typical SBC might have an overhead rate of 30%. If the total direct labor costs proposed are $50,000, the computed overhead costs for this case would be .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 I activities, at a minimum. If the (Proposal Title) Project is selected to continue into Phase II, the agreement may also be binding in Phase II 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 III activities that are funded by NASA.

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

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

Signature

Name/title

Small Business Concern

Signature

Name/title

Research Institution

SMALL BUSINESS TECHNOLOGY TRANSFER (STTR) PROGRAM
MODEL ALLOCATION OF RIGHTS AGREEMENT

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

1. Applicability of this Agreement.

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

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

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

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

2. Background Intellectual Property.

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

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

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

(2) The following Background Intellectual Property of RI may be used nonexclusively and, except as noted, without compensation by SBC in connection with research or development activities for this STTR project

(if "none" so state): ____;

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

3. Project Intellectual Property.

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

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

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

SBC Percent: ________ RI Percent: ________

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

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

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

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

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

(1) Where Project Intellectual Property of RI is a potentially patentable invention, SBC will have an exclusive option for a license to such invention, for an initial option period of _______ months after such invention has been reported to SBC. SBC may, at its election and subject to the patent expense reimbursement provisions of this section, extend such option for an additional _______ months by giving written notice of such election to RI prior to the expiration of the initial option period. During the period of such option following notice by SBC of election to extend, RI will pursue and maintain any patent protection for the invention requested in writing by SBC and, except with the written consent of SBC or upon the failure of SBC to reimburse patenting expenses as required under this section, will not voluntarily discontinue the pursuit and maintenance of any United States patent protection for the invention initiated by RI or of any patent protection requested by SBC. For any invention for which SBC gives notice of its election to extend the option, SBC will, within ______ days after invoice, reimburse RI for the expenses incurred by RI prior to expiration or termination of the option period in pursuing and maintaining (i) any United States patent protection initiated by RI and (ii) any patent protection requested by SBC. SBC may terminate such option at will by giving written notice to RI, in which case further accrual of reimbursable patenting expenses hereunder, other than prior commitments not practically revocable, will cease upon RI's receipt of such notice. At any time prior to the expiration or termination of an option, SBC may exercise such option by giving written notice to RI, whereupon the parties will promptly and in good faith enter into negotiations for a license under RI's patent rights in the invention for SBC to make, use and/or sell products and/or services that embody, or the development, manufacture and/or use of which involves employment of, the invention. The terms of such license will include: (i) payment of reasonable royalties to RI on sales of products or services which embody, or the development, manufacture or use of which involves employment of, the invention; (ii) reimbursement by SBC of expenses incurred by RI in seeking and maintaining patent protection for the invention in countries covered by the license (which reimbursement, as well as any such patent expenses incurred directly by SBC with RI's authorization, insofar as deriving from RI's interest in such invention, may be offset in full against up to _______ of accrued royalties in excess of any minimum royalties due RI); and, in the case of an exclusive license, (iii) 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. (Sections3.2.5 and 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 Thursday, September 9, 2004** (Section 6.3).

Phase I Sample 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 II or Future R/R&D
Part 8: Company Information and Facilities
Part 9: Subcontracts and Consultants
Part 10: Commercial Applications Potential.
Part 11: Similar Proposals and Awards

Example Format for Briefing Chart

<table>
<tr><td colspan="2">NASA SBIR/STTR Technologies
Title of Proposal
PI: PI’s Name / Firm – City, ST
Proposal No.: 04-I</td></tr>
<tr><td><u>Identification and Significance of Innovation</u></td><td><Place Picture Here></td></tr>
<tr><td><u>Technical Objectives and Work Plan</u></td><td><u>NASA and Non-NASA Applications</u>

<u>Contacts</u></td></tr>
</table>

9. Research Topics for SBIR and STTR

9.1 SBIR Research Topics

Introduction

The SBIR Program Solicitation topics are developed in coordination with the established NASA management structure of the Strategic Enterprises (http://www.hq.nasa.gov/hq/enterprise.htm). There are seven Enterprises fulfilling either Mission Direct or operational functions..

The Enterprises identify, at the most fundamental level, what NASA does and for whom. Each Strategic Enterprise is analogous to a strategic business unit employed by private-sector companies to focus on and respond to their customers' needs. Each Strategic Enterprise has a unique set of goals, objectives, and strategies. SBIR research topics and subtopics are organized under the five research and technology Enterprises:

Aeronautics
Biological and Physical Research
Earth Science
Exploration Systems
Space Science

Exploration Systems was created in 2004 to reflect the new vision for NASA encompassing a broad range of human and robotic missions, including the Moon, Mars, and destinations beyond.

Exploration Systems assumed the innovative research activities conducted by the **Space Flight Enterprise** in prior SBIR Solicitations. The Space Flight Enterprise still exists as an operations organization. Many of the research topic areas found in the 2003 Solicitation under Space Flight are now found in Exploration Systems.

In addition, the **Education Enterprise** is a crosscutting organization: It works to coordinate with the other Enterprises' in outreach activities for K-12 and universities and colleges. There are subtopics in this SBIR Solicitation that have an outreach and Education focus, matching the needs of one of the five technical Enterprise's missions. In addition, the required involvement of research institutions in the STTR Solicitation, which is announced concurrently with the SBIR Solicitation, adds an additional potential linkage to the Education Enterprise.

A more detailed description, with links, of the NASA Enterprises and the NASA Field Centers can be found at http://www.nasa.gov/about/sites.

9.1.1 AERONAUTICS

NASA's Aeronautics Enterprise pioneers the identification, development, verification, transfer, application, and commercialization of high-payoff aeronautics technologies. It seeks to promote economic growth and security and to enhance U.S. competitiveness through safe, superior, and environmentally compatible U.S. civil and military aircraft and through a safe, efficient national aviation system. In addition, the Enterprise recognizes that the space transportation industry can benefit significantly from the transfer of aviation technologies and flight operations to launch vehicles, the goal being to reduce the cost of access to space. The Enterprise will work closely with its aeronautics customers, including U.S. industry, the Department of Defense, and the Federal Aviation Administration, to ensure that its technology products and services add value, are timely, and have been developed to the level where the customer can confidently make decisions regarding the application of those technologies.

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

TOPIC A1 Aviation Safety and Security 58

A1.01 Crew Systems Technologies for Improved Aviation Safety 58
A1.02 Aviation Safety and Security: Fire, Icing and Propulsion-Safe and Secure CNS Aircraft Systems 59
A1.03 Technologies for Improved Aviation Security 60
A1.04 Automated Online Health Management and Data Analysis 61

TOPIC A2 Vehicle Systems 62

A2.01 Propulsion System Emissions and Noise Prediction and Reduction 62
A2.02 Electric and Intelligent Propulsion Technologies for Environmentally Harmonious Aircraft 63
A2.03 Revolutionary Technologies and Components for Propulsion Systems 64
A2.04 Airframe Systems Noise Prediction and Reduction 64
A2.05 Revolutionary Materials and Structures Technology for Propulsion and Power Components 65
A2.06 Smart, Adaptive Aerospace Vehicles With Intelligence 65
A2.07 Revolutionary Flight Concepts 66
A2.08 Modeling, Identification, and Simulation for Control of Aerospace Vehicles in Flight Test 67
A2.09 Flight Sensors and Airborne Instruments for Flight Research 67

TOPIC A3 Airspace Systems 68

A3.01 Next Generation Air-Traffic Management Systems 68

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 takes a crew-centered approach to improving aviation safety and, therefore, specifically investigates human error roots of accidents and incidents to identify the basis for innovating crew-centered automation and interface technologies. These technologies must be evaluated sensitively and in operationally-valid contexts. NASA develops evaluation methodologies and tools to sensitively and robustly assess aviation safety technologies. Finally, to ensure adoption, NASA investigates how innovative aviation safety technologies can be effectively used in airspace operations and be supported by pilot procedures and instruction.

NASA seeks highly innovative technologies to improve airspace safety with a crew-centered focus. Such advanced technologies may meet these goals 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 individuals have access to use the airspace system as appropriate. In addition, NASA seeks tools and methods for measuring and assessing pilots' and collaborating operators' performance in complex, dynamic systems. 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. Technologies should have a high potential for emerging as marketable products, of which there are a number of examples:

- Novel technologies to improve information presentation;
- 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 disparate sources of 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 pilots and pilot populations with special requirements;
- 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, and designs that consider presentation of uncertain data; and
- Individual and team performance metrics, analysis methods, and tools to better evaluate and certify human and system performance for use in operational airspace environments, simulation, and model-based analyses.

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

NASA is concerned with the prevention of hazardous conditions and the mitigation of their effects when they do occur. One particular emphasis is on the prevention and suppression of in-flight fire and explosions, as well as fuel tank explosions and post-crash fires. 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.

A second emphasis is on mitigating the safety risk and collateral damage due to unexpected failures of rotating components. Although the FAA mandates a blade containment and rotor unbalance requirement (FAR Part 33, Section 33.94) as part of the airworthiness standards for turbine aircraft engines, there are substantial potential (aircraft-engine) system benefits to be gained by enabling safety assured, lighter weight, lower cost, and more damage-tolerant designs for engine case/containment systems and associated (primary load path) structures.

A third emphasis for this subtopic is on propulsion system health management, in order to 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.

A fourth 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).

A final 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. Technology is needed to harden the CNS systems, both onboard and air-to-ground, and to provide next-generation airborne, ground- and space-based surveillance systems.

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:

- Technology for prevention and suppression of potential in-flight fires in fuel tanks, cargo bays, insulation, and other inaccessible locations due to accidents or deliberate acts.
- Technology to provide fuel tank vapor flammability reduction and onboard oxygen generation.
- Technology to minimize fire hazards in crashes and to prevent or delay fires.
- Advanced material or structural configuration concepts to prevent catastrophic failures of engine components, or to ensure fragment containment.
- Computational tools for analyzing blade-loss events and designing structural components and systems accordingly.
- Health management technologies such as instrumentation, ground and on-wing nondestructive inspection, health monitoring algorithms, and fault accommodating logic, which will predict, diagnose, prevent, assess, and allow recovery from propulsion system malfunctions or damage.
- 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 in-

clude 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, wide area ice detection, detection that serves both ground and in-flight applications, and de-icing systems that operate at near anti-icing performance. Any submittal must be cost competitive to current technologies.
- Next generation capabilities for remote monitoring of onboard systems and the aircraft environment.
- Secure onboard information processing, computing and air/ground networking.
- Technologies to harden aircraft communication, navigation, and surveillance systems against abnormality and deliberate attack.

A1.03 Technologies for Improved Aviation Security
Lead Center: LaRC
Participating Center(s): ARC

Following the attacks on September 11, 2001, NASA recognized that it now shared the responsibility for improving homeland security. 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, and ensuring the security of the nation from terrorist attacks is a high priority national challenge.

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 onboard 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 data links; 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 retrofitting, certification, system implementation, and cost-benefit analysis 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 (WMD); 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 data link systems, intrusion-tolerant communications networks and communications systems to support emerging aviation security applications; tools to support real-time management of security information; and chemical and biological sensor development. Technologies may take the form of tools, models, techniques, procedures, substantiated guidelines, prototypes, and devices:

- Intelligent systems monitoring and alerting technologies;
- Technologies that enable secure communications, navigation, and surveillance onboard the aircraft;
- 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;
- 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;

- 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;
- Decision-support tools and methods to improve communication, collaborative, and distributive decision-making;
- Data fusion technologies for integrating disparate sources of flight-related information;
- Computational approaches to monitoring crew health, stress level, state of duress, and performance; and
- Validation methods and tools for advanced safety and security critical systems.

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

Online health monitoring is a critical technology for improving transportation safety in the 21st century. 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 health monitoring emphasizes algorithms that minimize the time between data acquisition and decision-making.

This subtopic seeks solutions for online aircraft subsystem health monitoring. 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, Sensor Arrays 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;
- Automated nondestructive evaluation for faulty structural components;
- Electrical system monitoring and fire prevention;
- Applications that exploit wireless communication technology to reduce costs;
- Model-reference or model-updating schemes based on measured data, which operate autonomously;
- Proactive maintenance schedules for rocket or turbine engines, including engine life-cycle monitors;
- Predicting or detecting any equipment malfunction;
- Middleware or software toolkits to lower the cost of developing online health monitoring applications; and
- Innovative solutions for harvesting, managing, archival, and retrieval of aerospace vehicle health data.

TOPIC A2 Vehicle Systems

The Vehicle Systems Program is about Outcomes for the Public Good: Environmentally Friendly Aircraft, Air Vehicles for Public Mobility, Superior Air Power, and New Aeronautical Missions. Vehicle Systems does this by looking at three objectives: transportation system concepts, vehicle capabilities, and enabling technologies. The Vehicle Systems Program is developing revolutionary technologies at the laboratory, component, or subsystem level. The majority of the resources are allocated for fundamental research to find breakthrough technologies through three projects: Tailored Lightweight Structures, Robust Reliability, and Electric Hybrid Propulsion. These projects develop the fundamental technologies needed to enable the change state in aeronautics. Existing and newfound knowledge is refined through field tests through three more projects: Efficient Aerodynamic Configurations, Ultra-Efficient Engine Technology, and Quiet Aircraft Technology. These projects focus on the integration of these technologies into subsystems and systems that can be developed with industry partners into highly used products. To measure the overall progress, Vehicle Systems accelerates the technology integration and maturation through two Vehicle Sector Integration Projects: Strategic Vehicle Architectures and Flight and System Demonstrations. The Strategic Vehicle Architectures Project conducts system level integration studies, and the Flight and Systems Demonstrations Project conducts concept development and research flight-testing.

A2.01 Propulsion System Emissions and Noise Prediction and Reduction
Lead Center: GRC

Emissions
Current environmental concerns with subsonic and supersonic aircraft center around the impact of emissions on the Earth's climate. Carbon dioxide (CO_2) and oxides of nitrogen (NO_x) are the major emittants of concern coming from commercial aircraft engines. Current state-of-the-art engines and combustors in most subsonic aircraft are fuel-efficient and meet the 1996 ICAO nitrogen oxide (NO_x) limits, but may not able to meet the future stringent regulations. Recent observations of aircraft exhaust contrails (from both subsonic and supersonic flights) have resulted in growing concern over aerosol, particulate, and sulfur levels in the fuel. In particular, aerosols and particulates from aircraft are suspected of producing high altitude clouds, which could adversely affect the Earth's climatology. Advanced concepts research for reducing CO_2 and NO_x, and analytical and experimental research in characterization (intrusive and non-intrusive) and control (through component design, controls, and/or fuel additives) of gaseous, liquid, and particulates of aircraft exhaust emissions is sought. Specific aircraft operating conditions of interest include the landing-takeoff cycle, as well as the in-flight portion of the mission. There are a number of areas of particular interest:

- New concepts for reducing CO_2, oxides of nitrogen (NO, NO_2, NO_x), unburned hydrocarbons; carbon monoxide, particulate, and aerosols emittants (novel propulsion concepts, injector designs to improve fuel mixing, catalysts, additives, etc.)
- New fuels for commercial aircraft that minimize CO_2 and NO_x emissions
- Innovative active control concepts for emission minimization with an integrated systems focus including emission modeling for control, sensing, and actuation requirements, control logic development, and experimental validation are of interest.
- New instrumentation techniques are needed for the measurement of engine emissions such as NO_x, SO_x, and HO_x, atomic oxygen and hydrocarbons in combustion facilities and engines. Size, size distributions, reactivity, and constituents of aerosols and particulates are needed, as are temperature, pressure, density, and velocity measurements. Optical techniques that provide 2-D and 3-D data; time history measurements; and thin film, fiber optic, and micro-electrical-mechanical systems (MEMS)-based sensors are of interest.

Noise
Engine noise reduction technologies are required in the areas of propulsion source noise, nacelle aeroacoustics, and engine/airframe integration. Some of the key technologies needed to achieve these goals are revolutionary propulsion systems for reduced noise without significant increases in cost and emissions. Noise reduction concepts need to be identified that provide economical alternatives to conventional propulsion systems. NASA is soliciting proposals in one or more of the following areas for propulsion system noise reduction:

- Innovative acoustic source identification techniques for turbomachinery noise: The technique shall be described for a relevant source. Plans for a Phase II demonstration should be included for the Phase I proposal. A simple source may be used where the solution is known to demonstrate the technique. A clear explanation on how the technique can be applied to turbofan engines should be included. The technique should be capable of identifying sources contributing to dominant engine components, such as fan and jet noise.
- Fan Noise: The technique shall be capable of separating fan sources such as fan-alone versus fan/stator interaction for both tones and broadband noise. Sufficient resolution is needed to determine the location of the dominant sources on the aerodynamic surfaces. Jet Noise: The technique shall be capable of locating both internal and external mixing noise for dual-flow nozzles found in modern turbofans. Innovative turbofan source reduction techniques. Methods shall emphasize noise reduction methods for fan, jet, and core components without compromising performance for turbofan engines. A resulting engine system that incorporates one or more of the proposed methods should be capable of reducing perceived noise levels anywhere from 10 to 20 effective perceived noise level (EPNdB) relative to FAR 36, Stage 3 certification levels.
- Revolutionary propulsion concepts for lower emissions and noise (proposed as alternatives to turbofan engines). Feasibility studies shall be done that demonstrate the potential for 20 EPNdB engine noise reduction relative to FAR 36, Stage 3 certification levels and 90% reduction in NO_x emissions standards relative to current International Civil Aviation Organization (ICAO) regulations for commercial aircraft concepts.

Enabling technologies shall be identified for future research.

A2.02 Electric and Intelligent Propulsion Technologies for Environmentally Harmonious Aircraft
Lead Center: GRC

Electric aircraft propulsion and power systems have the potential to completely eliminate harmful emissions from aircraft while at the same time improving energy efficiency. Major strides have been achieved in the development of fuel cells, especially in the automotive field. NASA is pursuing the application of fuel cell technology for both aircraft power and propulsion. There are still major technical advances required to make a commercially viable electric aircraft a reality, but this goal now appears to be achievable, possibly even in the nearer term. To achieve the realization of environmentally harmonious 21st century air vehicles, innovations are needed to enable highly efficient, low cost, power dense (weight and volume) electric aircraft propulsion and power systems.

Technical areas of interest in electric aircraft propulsion and power include, but are not limited to, fuel cells, power management, power conditioning, power distribution, actuators, motors and drive systems, sensors and fuel storage (especially hydrogen). Highly integrated dual function components and systems that have the potential to reduce overall vehicle and subsystem weight are of special interest (e.g., power conductors that are integrated into the airframe structure, motors directly integrated into the fan/propeller structure). Synergistic use of onboard cryogenic hydrogen fuel is also of interest. Both component and system level technologies are solicited. Proposals must show improvements to the state-of-the-art and viable application to aircraft.

Implementation of intelligent propulsion concepts requires advancements in the area of robust control synthesis techniques and automated diagnostics, and development of advanced enabling technologies such as nanoelectronics, smart sensors, and actuators. Attention will also need to be paid to integration of the active component control and diagnostics technologies with the control of the overall propulsion system. This will require moving from the current analog control systems to distributed control architectures.

Intelligent propulsion technologies that address electric, turbine, jet and/or hybrid aerospace propulsion systems are of interest. Proposals focusing on development of advanced diagnostics, health monitoring and control concepts, smart sensors, electronics and actuators for enabling self-diagnosis and prognosis, and self-reconfiguration capabilities are being sought. Concepts of special interest include those that integrate distributed sensing with actuation and control logic for micro-level control of parameters (such as propulsion system internal flows that impact performance and environment). Novel instrumentation approaches that provide valuable information for development and validation of technologies for self-diagnosis, prognosis, and reconfiguration are also of interest.

A2.03 Revolutionary Technologies and Components for Propulsion Systems
Lead Center: GRC

NASA seeks highly innovative concepts for propulsion systems and components for advanced high-speed aerospace vehicles to support missions, such as access to space, global cruise, and high-speed transports. The main emphasis in this subtopic is on high-risk, breakthrough technologies in order to revolutionize aerospace propulsion over a broad flight spectrum, up to Mach 8. Proposals offering significant advancements in critical components and designs for propulsion systems and subsystems are sought. Specific technical areas include the following:

- Advanced cooling concepts that minimize coolant penalties can include innovative cooling systems, fuel cooling of the combustor, and endothermic fuels and/or fuel additives to increase the heat-sink capacity or cooling capacity of fuels.
- Innovative concepts relating to the combustion process, including fuel injectors, piloting, flame holding techniques for increased performance and decreased emissions, techniques to identify the onset of combustion instability in lean-burn and/or rich-burn, low NO_x combustor, ramjet combustion and active and passive combustion controls in order to extend the operability of the combustion components to a wider range of operating conditions.
- New inlet concepts to meet functional airflow needs of high Mach number propulsion. For instance, a variable geometry, supersonic, mixed compression inlet. Compatibility with turbomachinery and mode transition across the speed range should be addressed. Special attention should be given to combustor demands along a realistic flight corridor. This flight corridor must be compatible with turbine engine thermal-structure limits.
- New techniques to improve the aerodynamic performance and operability of the inlet, including highly offset subsonic diffusers and designs for boundary layer control, minimizing engine unstart susceptibility, and techniques to identify and control the onset of mode transition between different propulsion concepts within the same internal flow path or dual flow paths.
- New controllable and reliable nozzle concepts with optimum expansion efficiency and thrust vectoring capability, including a computational nozzle design methodology to study various geometries and chemistry effects.
- Enabling technologies of components and subsystems that allow turbomachinery to operate at high-speed flight conditions. Specific examples include 1) a lightweight, high-pressure ratio compressor which must be protected or removed from the extremely high temperature primary air stream; 2) applications of micro-electrical-mechanical systems (MEMS) that demonstrate the potential to enhance the performance and reduce the cost and weight; and 3) innovative inlet flow conditioning.
- New concepts for combined or combination cycles, in particular those including turbine propulsion. Alternate engine cycles that meet a unique mission requirement (e.g., global reach, access to space, etc.), including pulse detonation, ramjets, scramjets, and rockets. Proposals can also include development of unique components required for the maturation of alternate propulsion cycles, such as inlets, diffusers, nozzles, air valves, fuel injectors, combustors, etc.
- Innovative integration technologies among components or subsystems that significantly improve the performance or reduce the cost of the overall propulsion systems are sought. This includes new collaborative and concurrent engineering tools for analysis and design. These tools could reduce the need for empiricism, thus facilitating early evaluation of interactions among propulsion components. "Intelligent" design tools, based on technologies such as evolutionary algorithms and neural networks, are also of interest. All design/analysis tool proposals must include a propulsion technology development application.

A2.04 Airframe 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 aeroacoustic analysis, which can be adapted for design codes.
- Simulation and prediction of aeroacoustic noise sources particularly for airframe noise sources and situations with significant interactions between airframe and propulsion systems.
- Concepts for active and passive control of aeroacoustic 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.
- Prediction and control of high-amplitude aeroacoustic loads on advanced aerospace structures and the resulting dynamic response and fatigue.

A2.05 Revolutionary Materials and Structures Technology for Propulsion and Power Components
Lead Center: GRC

This subtopic addresses structural and mechanical components, subsystems and advanced materials for Aerospace Propulsion and Power Systems. Proposals are sought for innovative and commercially viable concepts that address objectives such as lighter weight, reduced operational costs, lower noise, lower emissions, higher temperature capability, increased efficiency and/or operational margin, greater safety and reliability, and more time on-station for aircraft, satellites, and power equipment.

One focus is on problems related to structural and mechanical components and subsystems that operate at high temperatures, in hostile aero-thermo-chemical environments or space environments, and at high stresses under cyclic loading conditions. Interests include magnetic, foil, and fluid film bearings, tribological coatings, seals, transmissions, noise reduction, flight weight electric motors, rotating equipment, aeroelasticity, ballistic impacts, fatigue, fracture, life prediction, probabilistic methods, and structural health monitoring (diagnostics and prognosis).

A second focus addresses advanced materials, their development, and their application to primary propulsion systems such as aircraft gas turbines, rocket and turbine-based combined cycle engines, and rocket engines as well as auxiliary power sources in aircraft and space vehicles. Materials of interest include any classes especially those used in propulsion systems such as high-temperature polymers and composites, metals including titanium alloys and nickel-based super alloys, ceramics and ceramic matrix composites, and coatings for these, and processes for their economical and reliable preparation.

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

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.

Specific areas of interest are:

- 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.
- 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 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, 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, retrofit threat detection capabilities for civil transports, damage mitigation concepts, streamlining airport operations concepts, retrofitting existing airports for next generation airliners, alternative external vision systems, shroudless launch of aerodynamic shapes on the front of ELVs, aerodynamic systems optimization for planetary aircraft (Venus, Mars, Io, and/or Titan), flexible system stability derivative identification, innovative approaches to thermal protection that mimize 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 in 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, 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, 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 aeroelastic model identification for stability and performance monitoring and prediction in adaptive control;
- Self-learning control strategies for aerostructural 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 the 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 provides 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 transportation 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
- 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.

This page has intentionally been left blank.

9.1.2 BIOLOGICAL AND PHYSICAL RESEARCH

NASA's Biological and Physical Research Enterprise conducts basic and applied research to support human exploration of space and to take advantage of the space environment as a laboratory. It creates unique cross-disciplinary research programs, bringing the basic sciences of physics, biology, and chemistry together with a wide range of engineering disciplines. This Enterprise asks questions that are basic to our future: How can human existence expand beyond the home planet to achieve maximum benefits from space? How do fundamental laws of nature shape the evolution of life?

http://spaceresearch.nasa.gov

TOPIC B1 Cross-Disciplinary Physical Sciences 72

B1.01 Exploiting Gravitational Effects for Combustion, Fluids, Synthesis, and Vibration Technology 72
B1.02 Gravitational Effects on Biotechnology 73
B1.03 Materials Science for In-Space Fabrication and Radiation Protection 73
B1.04 Bioscience and Engineering 74

TOPIC B2 Fundamental Space Biology 76

B2.01 Understanding and Utilizing Gravitational Effects on Plants and Animals 77
B2.02 Biological Instrumentation 78
B2.03 Understanding and Utilizing Gravitational Effects on Molecular Biology and for Medical Applications... 79

TOPIC B3 Biomedical and Human Support Research 80

B3.01 Environmental Control of Spacecraft Cabin Atmosphere 80
B3.02 Space Human Factors and Human Performance 82
B3.03 Human Adaptation and Countermeasures 83
B3.04 Food and Galley 84
B3.05 Biomedical R&D of Noninvasive, Unobtrusive Medical Devices for Future Flight Crews 85
B3.06 Waste and Water Processing for Spacecraft Advanced Life Support 86
B3.07 Biomass Production for Planetary Missions 87
B3.08 Software Architectures and Integrated Control Strategies for Advanced Life Support Systems 89
B3.09 Radiation Shielding to Protect Humans 90
B3.10 Sensors for Advanced Human Support Technology 91

TOPIC B4 Partnerships and Market Driven Research 92

B4.01 Space Market Driven Research 92
B4.02 Market Driven Space Exploration Payloads 93
B4.03 Market Driven Space Infrastructure 94
B4.04 Partnering Innovations for Security and Safety 95

TOPIC B5 Flight Payload Technologies and Outreach 95

B5.01 Telescience and Flight Payload Operations 95
B5.02 Flight Payload Logistics, Integration, Processing, and Crew Activities 96
B5.03 Development of Improved Outreach Planning and Implementation Products 97

TOPIC B1 Cross-Disciplinary Physical Sciences

The NASA Office of Biological and Physical Research (OBPR) Physical Sciences Research Program carries out basic and applied research to enable the NASA Vision "to improve life here, to extend life to there, and to find life beyond." Two primary research thrusts are implemented: 1) utilization of the space environment to advance the understanding of physical, chemical, and biophysical processes that are relevant to both Earth and space exploration applications, 2) research pre-requisite to the implementation of enabling technologies for human space exploration. Cross-disciplinary teaming across research areas is strongly encouraged in order to address scientific and technological challenges in complex engineering and living systems. The current areas of emphasis are focused on enabling technologies for space exploration:

1. Biophysics and Bioengineering research and development targeting the understanding of low-gravity physiological effects and the deployment of distributed biomedical sensors for targeted diagnostics;
2. Advanced materials fundamental research and development for spacecraft structure, power and propulsion, radiation shielding, and advanced sensors;
3. Micro and reduced-gravity engineering systems for closed-loop life support, power generation and propulsion, fire research, detection, and suppression; and
4. *In situ* resources development for in-space fabrication and for extra-terrestrial exploration and habitation, including the development of advanced biology-inspired approaches for novel space technologies and robotic enhancement of human capabilities.

B1.01 Exploiting Gravitational Effects for Combustion, Fluids, Synthesis, and Vibration Technology
Lead Center: GRC
Participating Center(s): MSFC

In preparation for future human exploration we must advance our ability to live and work safely in space, and at the same time, develop technologies to reach the Moon and other planets. The objective of this subtopic is to introduce new technology in the form of devices, models, and/or instruments for use in microgravity, extraterrestrial habitats, and/or for commercial applications on Earth. Research should target spacecraft and planetary life-support systems (such as Extra-Vehicular Activity [EVA] suits, extraterrestrial habitats, oxygen generation, and waste disposal), environmental monitors, and hazard controls (contaminants, fire safety, etc.). For Biofluids, please see subtopic B1.04 Bioscience and Engineering.

Innovations are sought in the following areas:

- Understanding the effects of microgravity on fluid behaviors.
- Using the mechanics of granular materials to determine how the reduced gravity environment affects transport and mixing of granular solids, with application to *in situ* resource utilization (ISRU) and more efficient terrestrial processes.
- Pool and flow boiling systems or subsystems that enable safe, efficient, and reliable heat transfer technologies for space application of advanced power and thermal control systems.
- Multiphase flow and fluid management to provide designers key information on controlling the location and dynamics of liquid–vapor interfaces in microgravity. This is needed for safe and reliable fluid handling and transport in microgravity.
- Innovative concepts for phase separation and condensation over a wide range of vapor content and gravity levels ranging from 0–1g.
- Measuring the residual accelerations on spacecraft or in ground-based low-gravity facilities. Emphasis is placed on MEMS or nanoscale devices capable of measuring quasi-steady (low frequency ~0–0.1 Hz) microgravity levels.
- Improving in-space system performance that relies on fluid or combustion phenomena, principally spacecraft fire safety, especially fire prevention, smoke, precursor, and fire detection and fire suppression.
- Characterization of ignitability, flame spread, and spacecraft material selection.

- Micropumps and microvalves, individual as well as simultaneous diagnostics for determining fluid movement through microscale devices for the aforementioned applications, and identifying specific chemical or biological elements of interest.
- Micropower systems for EVA operations, including power, heating, and cooling.
- Robust sensors for detection of hazards (fire, spills, leaks) in spacecraft, extraterrestrial habitats, and EVA systems.
- Partial and low-gravity compliant reactors for waste stabilization, as well as for oxygen and water recovery on extraterrestrial habitats.
- Understanding the effects of microgravity on combustion behaviors.
- Pollution reduction and improvement of the efficiency of liquid fueled combustors.
- Microfluidics for fuel cells and other power systems.

B1.02 Gravitational Effects on Biotechnology
Lead Center: MSFC
Participating Center(s): ARC

NASA is interested in the development of science and experiments that support strategic aspects of exploration, as well as develop the technologies to extend humanity's reach to the Moon, Mars, and beyond. Preparing for exploration and research will accelerate the development of technologies that are important to the economy and national security, as well as accelerate critical technologies such as biotechnology.

Plans are to support research and development to investigate the influence of the space environment, radiation, and reduced gravity on biotechnology processes, and human factors at the biomolecular level. Areas of interest include factors that influence bone and muscle biochemistry, protein crystal growth and structural analysis techniques, separation science and technology, and biomaterials. Examples of the types of research include but are not limited to:

- Technologies designed to improve our understanding of the effect of gravity on expression of biological macromolecules.
- Technologies to determine the relationships between material substrates, bone and muscle tissue and cell culture conditions, and subsequent cell protein expression and differentiation.
- Development of high-throughput technologies to determine gene and protein expression and differentiation.
- Biotechnology and instrumentation to help enable safe human exploration beyond Earth orbit for extended periods.
- Environmental monitoring and control for human life support.

B1.03 Materials Science for In-Space Fabrication and Radiation Protection
Lead Center: MSFC
Participating Center(s): ARC

Methods for conducting materials science and technology research required to enable humans to safely and effectively live and work in space are needed. Other areas of interest are the development of reduced gravity materials processing technology for in-space fabrication, repair, and resource development. Equipment that can operate with the limited resources of the Space Station Glovebox and in existing Space Station racks to perform demonstration experiments of strategic interest for in-space fabrication and repair, and for development of *in situ* resources, would also be of interest. Innovative developments are sought in the following research areas and their enabling technologies, including commercial applications on Earth.

In-Space Fabrication
NASA needs the development of techniques and processes that permit in-space fabrication of critical path components of future major projects. Developmental studies of materials and processes of direct strategic significance to the exploration of space are appropriate. In addition, the manufacture or repair of components during a mission is essential to human exploration and the development of space. Fabrication and repair beyond low-Earth orbit is

required to reduce resource requirements and spare parts inventory, and to enhance mission security. Also being sought are enabling technologies that can lead to materials and/or processes for the reduced gravity (micro-g, 1/6g, and 3/8g) in-space fabrication of *in situ* space resources. Of particular interest is the effect of reduced gravity and the space environment on these processes. Examples of the types of research include but are not limited to the following:

- Application of rapid prototyping technology to low gravity, 3/8 and 1/6 g level free-form fabrication of near-net shapes from metals, ceramics and polymers for fabricating spare parts and repairs.
- Development of space resources into raw materials and feedstock for use with rapid prototyping technology.
- Novel and innovative methods for processing materials in reduced gravity, in-space fabrication and repair including microwave processing, sintering, welding, and joining.
- Development of an improved lunar and Martian regolith simulant material more suitable for materials experiments with not just an average composition, but also the mineralogical analysis, particle shape, size, and distribution of the individual particle grains being more representative of actual lunar and Martian soils.
- Basic research, theoretical modeling, and experimental development of extractive and reactive processes, materials purification and characterization in a reduced gravity (3/8g and 1/6g) space environment and fundamental studies of in-space fabrication with *in situ* resources. For example: *in situ* fabrication of solar cells; metallic wire suitable for electrical conductors, antennas and rectifying-antennas; glass formation from *in situ* resources with minimal terrestrial components.

Radiation Protection Materials

NASA needs materials and novel concepts for effective radiation shielding in support of human exploration of space. These materials must be capable of attenuating exposure levels due to galactic cosmic rays and solar energetic particles, as well as their secondaries, to acceptable limits. Specific areas of interest include:

- Development of multi-functional and/or smart structural materials for radiation hardening/shielding;
- *In situ* regolith radiation shielding research;
- Development of light-weight, hydrogenated epoxy and preimpregnates (prepregs);
- Development of hydrogen filled, carbon nanostructures for both radiation shielding and as structural elements for spacecraft and habitat; and
- Methods for monitoring/dosimetry for space radiation.

B1.04 Bioscience and Engineering
Lead Center: GRC

NASA recognizes the critical role that fluid mechanics and transport processes, along with their supporting technologies, play in many biological and physiological events. A wide variety of fundamental problems in the categories of physiological systems, cellular systems, and biotechnology may be addressed. The objective of this research is to deliver new technology in the form of devices and instruments of use in microgravity missions to the Moon and Mars and/or for commercial application on Earth in the areas discussed below.

Micro-Optical Technology for Interdisciplinary and Biological Research

Technologies are sought for measuring and manipulating Space Station and long-duration mission experiments, and for monitoring and managing astronaut health and the health of structures and systems affecting astronauts' environments. Areas of innovative technology development include:

- Diagnostic methods to assess the performance of labs-on-a-chip, including detecting the presence of bubbles and particles and removing or characterizing them;
- Measurements for fluids including spatially and temporally resolved chemical composition and physical state variables;
- Optically-based biomimetics for self-aware, self-reconfiguring measurement systems;

- Measurement and micro-control technologies for health monitoring and health management of experiments, astronauts, and astronauts' environments;
- Optical quantum technologies for measurement systems including signal detection and transmission; and
- Technologies enabling optically-based mobile sensor platforms for detection and maintenance, using optical sensing, control, power, and/or communication.

Biological Fluid Mechanics (Biofluids)
Biofluids, an intersection of fluid physics and biology, is a new area of emphasis within NASA's Office of Biological and Physical Research (OBPR). Fluid mechanics and transport processes play a critical role in many biological and physiological systems and processes. An adequate understanding of the underlying fluid physics and transport phenomena can provide new insight and techniques for analyzing and designing systems that are critical to NASA's mission. The microgravity environment modifies vascular fluid distribution on a short time scale, because of the loss of hydrostatic pressure, and on a longer time scale, because of the shift of intercellular flows. This fluid shift could modify transport processes throughout the body. For example, modification of flow and resulting stresses within blood vessels could modify vascular endothelial cell structure and permeability, which may be detrimental in long-term inter-planetary space flight. Furthermore, reintroduction of gravity causes large-scale fluid shifts in the body, which can influence cardiac output and induce faintness. Studies of macro- and microscale biofluid mechanics of the vascular system in the microgravity environment may be important to understanding these physiological events. Innovations sought include but are not limited to the following:

- Studies of biological fluid mechanics that seek answers to questions related to effect of long-term exposure to microgravity on human physiology;
- Understanding the role of fluid physics and transport phenomena in the "fluid shift" observed in the human body when exposed to prolonged microgravity; and
- Understanding the role fluid physics plays in human physiological processes such as cardiovascular flows and its effect on arteriosclerosis, and pulmonary flows and asthma.

BioMicroFluidics
Many biotechnology applications need manipulation of fluids moving through micro channels. As a result, microfluidic devices are becoming increasingly useful for biological/biotechnological applications. Because capillary forces can have a significant effect on the flow at this scale, a strong similarity with microgravity flows exists. Innovations sought include but are not limited to the following:

- Understanding of fluid mechanics underlying the operations of microfluidic devices crucial to their successful operation and continued miniaturization; and
- Tools for prediction, measurement, and control of fluid flow in microchannels and microchannel network.

Models of Cellular Behavior
The simplest living cell is so complex that models may never be able to provide a perfect simulation of its behavior, however, even imperfect models could provide information that could shake the very foundations of biology. We are now at the point where we can consider models of molecular, cellular and developmental biological systems that, when coupled to experiments, result in an increased understanding of biology. Quantitative models of cellular processes require. Innovations sought include but are not limited to the following:

- New methods for better handling of large numbers of coupled reactions, increases in computing power, and the ability to transition among different levels of resolution associated with quantitative models of cellular processes; and
- Development of models to form the basis of tools to aid in optimization of existing biological systems and design of new ones, enabling engineers to evolve biological systems by rounds of variation and selection for any function they choose.

Functional Imagery
Research on-orbit has demonstrated that the microgravity environment affects the skeletal, cardiovascular, and immune systems of the body. Few of the investigations to date examined functional changes due to microgravity at either the cellular or molecular scale. NASA, therefore, seeks innovations that would lead to an enhanced capability

to image functioning biological systems at either length scale. All proposals should recognize the power, volume, and mass constraints of orbital facilities. Examples of possible innovations include but are not limited to the following:

- Development of novel fluorophores that tag proteins mediating cellular function, particularly those that can be excited using solid-state lasers;
- Systems that can simultaneously image multiple fluorophores following different processes at standard video frame rates;
- Devices that enable three-dimensional imagery of the sample; and
- Imaging hardware that can follow a metabolic process in a turbulent system.

Understanding Living Systems Through Microgravity Fluid Physics
Developing strategies for long-duration space flight requires an understanding of the effects of the microgravity environment on biological processes. Interdisciplinary fundamental and applied research is required in biology, physiology, and microbiology to human, and microbial systems from the standpoint of physics. Of particular interest are studies with technology development that develop theoretical, numerical, and/or experimental understanding of the effects of acceleration, and other factors in microgravity environments on these systems. Exploring the effects of Martian and lunar gravity and the quasi-steady, oscillatory, and transient accelerations that are typical of a space laboratory are of great interest, as well as fundamental studies with technology development of acceleration sensitivity. The knowledge obtained should contribute to related agency activities, such as the development of self-sustaining ecosystems and treatment of bacterial infection in space. Moreover, we expect that the knowledge and technologies derived will also provide ground-based economic and societal benefits. Major research disciplines include the fluid transport in microbiology, human physiology, hematology, and drug delivery systems. Innovations are sought in a number of areas.

Delineation of the effects of acceleration and environment at the macro- and microscale levels on processes such as bacterial growth, growth rates, resistance to antibiotics and disinfectants, interactions among microbes, microbial locomotion and interaction with the surrounding fluid or solid medium, transport through cell membranes, electro-osmotic flows, and cytoplasmic streaming, as well as quantification of metabolic processes and other phenomena that permit the examination of these problems:

- Effects of bulk fluid flows on biofilms and liposome formation.
- Transendothelial transport.
- Microscale modeling of fluid flows and mass transfer for drug delivery systems.

TOPIC B2 Fundamental Space Biology

The NASA mission to explore the universe and search for life includes the goal of exploring the principles of biology through research in the unique natural laboratory of space. Important is the biological and physical research organizing question which asks: How does life respond to gravity and space environments? It includes four sub-questions:

1. How do space environments affect life at molecular and cellular levels?
2. How do space environments affect organisms throughout their lives?
3. How do space environments influence interactions between organisms?
4. How can life be sustained and thrive in space across generations?

Fundamental space biology is NASA's agency-wide program for the study of fundamental biological processes through space flight as well as ground-based research that supports the NASA mission. Proposals are sought for research that:

1. Effectively make use of microgravity and other characteristics of space environments to enhance our understanding of fundamental biological processes;

2. Develop the scientific and technological foundations for a safe, productive human presence in space for extended periods and in preparation for exploration; and
3. Apply this knowledge and technology to improve our nation's competitiveness, education, and quality of life on Earth.

Ground-based and flight research is conducted on a broad spectrum of biological topics including cell and molecular biology, developmental and physiological biology, and how the space environment affects whole organisms and their interactions.

B2.01 Understanding and Utilizing Gravitational Effects on Plants and Animals
Lead Center: ARC
Participating Center(s): KSC

This subtopic area focuses on technologies that support the NASA Fundamental Biology Program in understanding the effects of gravity on plants and animals. The program supports investigations into the ways in which fundamental biological processes function in space, compared to their function on the ground. Given the Exploration Initiative newly assigned to NASA, this area of work and discovery is important to achieve the goals to explore the planets and allow plant, animal, and human habitation. To conduct these investigations, the program supports both ground and space flight research. The improved understanding of the role of gravity on plants requires innovative support equipment for observing, measuring, and manipulating the responses of plants to environmental variables. Areas of innovative technology development include:

- Measuring the atmospheric and radiation environment and optimizing the lighting and nutrient delivery systems for plants;
- Storage, transportation, maintenance, and *in situ* analyses of seeds and growing plants;
- Sensors with low power requirements and low mass to monitor the atmosphere and water (nutrient) environment, as well as automated control and data logging systems for the experiment containers to measure performance indicators, such as respiration (whole plant, shoot, root), evapotranspiration, photosynthesis, and other variables in plants;
- Data analysis and control;
- Modular seeding and/or planting units to minimize labor;
- Sensors for atmospheric, liquid, and solid analyses, including atmospheric and liquid contaminants, such as ethylene and other biogenic compounds, as well as analyses of hydroponic and solid media for N, P, K, Cu, Mg, and micronutrients;
- Remote sensors to identify biological stress; and
- Expert control systems for environmental chambers.

The improved understanding of the role of gravity on animals requires innovative instrumentation that tracks and analyzes from organism development, including gametogenesis through fertilization, embryonic development and maturation, through ecological system stability. Technologies may incorporate a variety of processes such as metabolism and metabolic control, through genetic expression and the control of development. Of particular interest are technologies that require minimal power and can noninvasively measure physical, chemical, metabolical, and developmental parameters. Such measurements will ultimately be made in environments at one or more of several gravity ranges, e.g., "microgravity" (.01 to .000001 g), "planetary" gravity (1 g [Earth]; 0.38 g [Mars] or 0.12 g [Moon]) or hypergravity (up to 2 g). Refined and stable measurements, however, are as important as gravity independence. Of interest are sustained instrument sensitivity, accuracy and stability, and reductions in the need for frequent measurement standardization. Parameters requiring measurement include pH, temperature, pressure, ionic strength, gas concentration (O_2, CO_2, CO, etc.), and solute concentration (e.g., Na^+, K^+, etc.). In the case of new techniques and instruments, a clear path toward miniaturization, reduction in power demands and increased space worthiness should be identified. Technologies applicable to plant, microorganism, and animal study applications include the following areas:

- Live support and energy management;
- Expert data management systems;
- Capabilities for specimen storage, manipulation and dissection;
- Video-image analysis for specimen (cell, animal, plant) health and maintenance;
- Sensors for primary environmental parameters and microbial organisms; and
- Electrophysiology sensors, biotelemetry systems and biological monitors carried on spacecraft.

B2.02 Biological Instrumentation
Lead Center: ARC
Participating Center(s): JPL

The Fundamental Biology (FB) Program is the Agency lead for biological research and biological instrumentation and technology development, and focuses on research designed to develop our understanding of the role of gravity in the evolution, development, and function of biological processes. Increasingly, the research thrusts are directed at incorporating the most advanced technologies from the fields of cell and molecular biology, genomics, and biotechnology, to provide researchers with the most up-to-date methods to conduct their biological research. For these requirements, the capability to perform autonomous, *in situ* acquisition, and preparation and analysis of samples to determine the presence and composition of biological components is a highly desired objective. As the size of flight payloads becomes increasingly smaller, and information technologies permit smarter and more independent payload and device control and management, the realization of completely autonomous *in situ* biological laboratories (ISBL) on spacecraft platforms and planetary surfaces will become more desirable.

Biological and biomolecular, microbiological, and genomic research is enabling unprecedented insight into the structure and function of cells, organisms, and subcellular components and elements, and a window into the inner workings and machinations of living things. Techniques and technologies, which have evolved from the microelectronics and biological revolutions, have permitted the emergence of a new class of instruments and devices. Many devices, techniques, and products are now available or emerging, which allow measurement, imaging, analysis, and interpretation of the biological composition at the molecular level, and which permit determination of DNA/RNA and other analytes of interest. Advances in information systems and technologies, and bioinformatics, provide the capability to understand, simulate, and interpret the large amounts of complex data being made available from these biological-physical hybrid systems. These synergistic relationships are facilitating the development of revolutionary technologies in many areas.

Biological instrumentation technologies to support FB objectives are grouped into the solicited categories below.

Biological Sample Management and Handling:
- Technologies for remote, automated biosample and biospecimen collection, handling, preservation/fixation, and processing; and
- Modular, embeddable systems and subsystems capable of supporting a variety of tissue, liquid, and/or cellular specimens, from a wide range of biological subjects, including cells, nematodes, plants, fish, avians, mice, rats, and humans.

***In situ* Measurement and Control:**
- Technology development for sensors, signal processors, biotelemetry systems, sample management and handling systems, and other instruments and platforms for real-time monitoring and characterization of biological and physiological phenomena.

Genomics Technologies:

- Technologies to enhance and augment research in genomics, proteomics, cell and molecular biology, including molecular and nanotechnologies, cDNA arrays, gene array technologies, and cell culture and related habitat systems.

Bio-Imaging Systems:

- Advanced, real-time capabilities for visualization, imaging, and optical characterization of biological systems. Technologies include multidimensional fluorescent microscopy, spectroscopy systems, and multi- and hyperspectral imaging.

Biological Information Processing

- Capability for automated acquisition, processing, analysis, communication, and archival and retrieval of biological data, and interface and transfer to advanced bioinformatics and biocomputation systems.

Integrated Biological Research Systems and Subsystems

- Integrated, experiment- and subject-specific biolaboratory modules and systems, providing complete flight prototype capability to support the above five categories.

B2.03 Understanding and Utilizing Gravitational Effects on Molecular Biology and for Medical Applications
Lead Center: JSC
Participating Center(s): ARC

Microgravity allows unique studies of the effects of gravitational effects on cell and tissue development and behavior. These studies use novel and advanced technologies to culture and nurture cells and tissues. Additionally, the ability to manipulate and/or exploit the form and function of living cells and tissues has significant potential to enhance the quality of life on Earth and in space through novel products and services, as well as through new science knowledge generated and communicated. This capability may lead to new products and services for medicine and biology. Current space research includes the development of space bioreactors for culturing fragile cells, which has applications in biomedical and cancer research; tissue engineering systems which take advantage of microgravity to grow 3-D tissue constructs; testing the effectiveness of drugs and biomodulators on growth and physiology of normal and transformed cells, and methods for measuring specific cellular and systemic immune functions of persons under physiological stress. Biotechnology research systems also are being developed for microgravity research on the International Space Station and future space-based laboratories. Studies of this nature are critical to our understanding of how the space environment affects astronaut health, and for maintaining a healthy environment for astronauts during missions of exploration.

Specific areas of interest are:

- New methods for culturing mammalian cells in bioreactors, including advanced bioreactor design and support systems; microprocessor controllers; and miniature sensors for measurement of pH, oxygen, carbon-dioxide, glucose, glutamine, and metabolites. Neural fuzzy logic network systems for the control of mammalian cell culture systems. Methods to minimize biofilm formation on fluid-handling components, sensors and bioreactors. Spectroscopic and biochemical analysis of biofilm formed in bioreactors. Micro-scale bioreactors for biomonitoring of radiation and other external stressors.
- Technologies that allow automated biosampling and bio-specimen collection, handling, preservation/fixation, and processing in cellular systems. Methods for separation and purification of living cells, proteins, and biomaterials, especially those using electrokinetic or magnetic fields that obviate thermal convection and sedimentation, enhance phase partitioning, or use laser light and other force fields to manipulate target cells or biomaterials.
- Techniques or apparatus for macro-molecular assembly of biological membranes, biopolymers, and molecular bio-processing systems; bio-compatible materials, devices, and sensors for implantable medical applications including molecular diagnostics, *in vivo* physiological monitoring and microprocessor control of prosthetic devices.

- Methods and apparatus that allow microscopic imaging including hyperspectral fluorescent, scattering and absorption imaging, and biophysical measurements of cell functions; effects of electric or magnetic fields, photoactivation, and testing of drugs or biocompatible polymers on live tissues. Integrated instrumentation for separation and purification of RNA, DNA, and proteins from cells and tissues.
- Quantitative applications of molecular biology, fluorescence imaging and flow cytometry, and new methods for measurement of cell metabolism, cytogenetics, immune cell functions, DNA, RNA, oligonucleotides, intracellular proteins, secretory products, and cytokine or other cell surface receptors. Small scale mass spectrometers. Means to enhance and augment genomics/proteomics techniques, including molecular and nano-scale tools. Development of novel fluorophores that tag proteins mediating cellular function, particularly those that can be excited using solid-state lasers.
- Micro-encapsulation of drugs, radiocontrast 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 to better understand and improve manufacturing processes on Earth.
- Miniature bioprocessing systems that allow for precise control of multiple environmental parameters such as low level fluid shear, thermal, pH, conductivity, external electromagnetic fields, and narrow-band light for fluorescence or photoactivation of biological systems.
- Novel low temperature sample storage methods (-80°C and -180°C) and biological sample preservation methods. Methods to reduce launch/return mass of biological samples and support reagents.
- DNA template for molecular wiring that permits macro- to nanoscale connectivity. Nanoscale electronics based on self-assembling protein-based molecular structures.
- Computer models and software that better handle large numbers of coupled reactions in cell science systems.
- Tools and techniques to study mechanical properties of the cell: subcellular rheology, cell adhesion, affect of shear flow, affects of direct mechanical perturbation. Tools and techniques to facilitate multiple simultaneous probing and analyzing of a cell or sub-cellular region (examples include atomic force microscope coupled with microelectrode or micro-Raman, Optical trap)
- Nanosensors for sub-cellular measurements: ultra-microelectrodes with less than 1μ diameter including cladding, nanoparticle reporters that provide spectroscopic information, and other novel intracellular sensor devices to provide spectroscopic data on intracellular processes.

TOPIC B3 Biomedical and Human Support Research

NASA has the enabling goal to extend the duration and boundaries of human space flight to create new opportunities for exploration and discovery. In order to reach this goal, the Biological and Physical Research (BPR) enterprise is seeking the answers to several “organizing” questions. Two of the questions related to biomedical and human support research are as follows: (1) How can we assure the survival of humans traveling far from Earth? and (2) What technologies must we create to enable the next explorers to go beyond where we have been? (More details on these questions can be found in the BPR Bioastronautics Strategy (http://spaceresearch.nasa.gov/) and the Bioastronautics Critical Path Roadmap (http://criticalpath.jsc.nasa.gov/CPR_RevD.pdf). Proposals are sought that support the objectives of the enabling goal including supporting the biomedical and human support research necessary to ensure the health, safety, and performance of humans living and working in space.

B3.01 Environmental Control of Spacecraft Cabin Atmosphere
Lead Center: JSC
Participating Center(s): ARC, GRC, KSC, MSFC

Advanced life support and thermal systems are essential to enable human planetary exploration. Requirements include safe operability in micro- and partial-gravity, ambient and reduced-pressure environments, high reliability, minimal use of expendables, ease of maintenance, and low-system volume, mass and power. Innovative, efficient, and practical concepts are needed for regenerative air revitalization, ventilation, temperature, and humidity control. Advanced active thermal control technologies in the areas of heat acquisition, transport, and rejection are also needed. In addition to long-duration space applications, innovative approaches that could have terrestrial application are encouraged. Proposals should include estimates for power, volume, mass, logistics, and crew time requirements as they relate to the technology concepts. More information on advanced life support systems can be found at http://advlifesupport.jsc.nasa.gov. Innovations are solicited in the areas that follow below.

Air Revitalization

Oxygen, carbon dioxide, water vapor, and trace gas contaminant concentration, separation, and control techniques for space vehicle applications (International Space Station, Moon, or Mars transit vehicle) and long-duration planetary mission applications.

- Separation of carbon dioxide from a mixture primarily of nitrogen, oxygen, and water vapor to maintain carbon dioxide concentrations below 0.3% by volume.
- The recovery of oxygen from carbon dioxide with some focus on an approach to deal with the by-products of the process, if any, keeping in mind the above mass, power, and expendables goals.
- Removal of trace contaminant gases from cabin air and/or a gas product stream from another system (e.g., water reclamation, waste management, etc.) using advanced regenerable sorbent materials, improved oxidation techniques, or other methods.
- Alternate methods of storage and delivery of atmospheric gases to reduce mass and volume and improve safety. [Compare to 4300 psia tank storage with a weight penalty of 0.56 lb of tank weight per lb of nitrogen gas stored.]
- Novel approaches to integrating atmosphere revitalization processes to achieve energy and logistics mass reductions.
- Alternate methods of atmospheric humidity control that do not use liquid-to-air heat exchanger technology (dependent on the spacecraft active thermal control system) or mechanical refrigeration technology. [Design metabolic latent load is 2.277 kg of water vapor per person per day].

Environmental Control and Thermal 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 thermal system technologies, which are highly reliable and possess low mass, size, and power requirements (i.e., reduced cost) for spacecraft cabin temperature and humidity control. Offerors should indicate explicitly how their research is expected to improve the mass, power, volume, safety, reliability, and/or design and analyses techniques for future thermal control systems for human space missions as compared to state-of-the-art technologies. Areas in which innovations are solicited include the following:

- Liquid-to-liquid heat exchangers that provide two physical barriers preventing interpath 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.
- 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. Devices would 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. Temperatures of -20°C, -40°C, -80°C or -180°C are desired.
- Highly accurate, remotely monitored, *in situ*, non-intrusive thermal instrumentation.

- Advanced analytical tools for thermal and fluid systems design and analyses, which are amenable to concurrent engineering processes.

Component Technologies
Energy efficient, low mass, low noise, low vibration or vibration isolating, fail-safe and reliable components for handling gases and fluids applicable to spacecraft environmental control and air revitalization, including actuators, fans, pumps, compressors, coolers, tubing, ducts, fittings, tanks, 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.

B3.02 Space Human Factors and Human Performance
Lead Center: JSC
Participating Center(s): ARC

The long-term goal for this subtopic is to enable planning, designing, and carrying out human space missions of up to 5 years with crew independence, without resupply 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 nonintrusively. 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. Technologies to track locations of individuals within habitats, and report on physiological or other state information. Methods and models for human performance prediction, including physical performance, as affected by encumbrances of clothing, space suits, etc.
- Predictive modeling of effects on the crew due to potential spacecraft environments and operational procedures. Develop computational models of the crew environment and of human performance and behavior to simulate the effects of factors that contribute to (or degrade) long-term performance capabilities. Such models of the environment, individual, and group behaviors and performance can be used to simulate and explore the conditions that influence human performance (e.g., fatigue, noise, CO_2, microgravity, group dynamics, etc.). Such capabilities would include digital models of human operators and routine and emergency tasks that interact in the context of the long-duration human exploration environment.
- 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.
- 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, 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.
- Rapid don/doff launch-and-entry and survival suit: a personal ambient environment and individual health and safety protective garment system with antigravity protection, metabolic-cooling and heating, breathing air, thermal protection, zero-atmospheric pressure protection, land and water survival gear, etc. An integrated suit (providing all desired protective functions), as well as a modular suit (allowing user to select ahead of time any of the array of required protection and survival subsystems) approach should be consid-

ered. The emphasis for this innovation should be to achieve the desired levels of protection for space travel, as well as for survival on Earth after landing at an unplanned site–all while affording rapid donning in microgravity through one-gravity (1g) environments on the order of 60 s and rapid doffing on the order of 300 s or less. Include accommodation for using the suit for ill, injured, or incapacitated crewmembers, meeting the don/doff goals while providing access for medical monitoring and ongoing treatment.

B3.03 Human Adaptation and Countermeasures
Lead Center: JSC
Participating Center(s): ARC

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 extraplanetary 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.

As launch costs relate directly to mass and volume, instruments and sensors must be small and lightweight with an emphasis on multi-functional capabilities. Low power consumption is a major factor, as are design enhancements to improve the operation, design reliability, and maintainability of these instruments in the environment of space and on planetary surfaces. As the efficient use of time is extremely important, innovative instrumentation setup, ease of usage, improved astronaut (patient) comfort, noninvasive sensors, and easy-to-read information displays are also very important considerations. Extended shelf-life and ambient storage conditions of consumables are also key necessities. Ability to operate in 0g, 1g, and 3/8g become more important as we push for future human Moon and Mars missions.

Immersive Virtual Scene Display System
Development of an immersive visual display system is required to be interfaced with treadmill exercise devices. This system would not be head-mounted but would 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 inflight or on-surface treadmill exercise. Ultra-long duration missions to the Moon or Mars will especially benefit from such technology that encourages crew to spend more time exercising by enriching the environment and contribute to psychological well being by mimicking the terrestrial exercise experience.

Measurement of Emboli in the Brain
A small Doppler ultrasound device (need not be oxygen compatible), emboli recognition system/software, and solid-state recorder of detected events. This would be worn in a fashion similar to a Holter monitor and help to monitor blood clots in the brain for those at risk for embolic stroke. This is especially valuable for ensuring the safety of Extra-Vehicular Activity (EVA) on planetary surfaces, as well as during orbital flight.

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 hypogravity environments, which may interfere with their activity by sensitizing or desensitizing the crew member or interfering in other ways with the desired physiological effect.

MEMS-Based Human Blood Cell Analyzer
Development of a small, automated, micro- and hypogravity capable, lightweight, low power instrument that will analyze a small sample (microliter 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 microfluidics, micromechanics, micro-optics, microelectronics, and data telemetry capabilities in an integrated handheld package with a simple, user-friendly operator interface. Such technologies will be critical to the implementation of future missions beyond low-Earth orbit to the Moon or Mars. Proper medical care and valuable research contributions will be dependent on such technologies in these exploration class missions.

Human-Worn Whole Body Biomechanical and Movement Analysis Suit

A whole-body suit and analysis system worn by human subjects is needed, which records and measures biomechanical movements and biomechanical characteristics in order to provide an assessment of total body physical activity during human space missions, especially missions to hypogravity environments such as the Moon or Mars. Measurements to be made and recorded would include upper and lower limb segment displacements along with related joint angular velocities and accelerations. The system would allow entry of limb segment and trunk mass and center-of-mass data specific to the individual wearing the suit and then would provide data analysis related to work and power across different body segments and for the whole body based on analytical algorithms. Other capabilities include storage of raw data and the ability to download the data to other computer-based storage and data analysis systems through either hardwired connections or via telemetry. Many differences may be noted in the way humans move in micro- and hypogravity environments. These differences may suggest better ways to perform work or to design tools, workstations, or procedures for accomplishing critical tasks in the future beyond low-Earth orbit missions.

Body Composition Hardware for Spaceflight

Development of on-orbit instrumentation for determining body composition. Specific parameters of interest include lean body mass, total fat mass, and total body water. Validation data will be required using the current gold-standard techniques in this field. This information will be used in conjunction with nutritional status protocols to assess crew health. The effects of the hypogravity environment of planetary surfaces on body composition are not known. Any future mission to the Moon or Mars will certainly measure these changes to detect and combat potential adverse changes. Such an instrument must work in 0g, 1/6g, and 3/8g environments.

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.

B3.04 Food and Galley
Lead Center: JSC

As NASA begins to look beyond low-Earth orbit and to plan for future exploration missions, such as to the Moon or Mars, new food science technologies will be needed. The impossibility of regularly resupplying a Mars crew means that the prepackaged shelf-stable food, ingredients, and equipment to provide a complete diet for six crewmembers for more than three years will have to be carried with them. As the crew remains on the Moon or Mars surface, crops will be grown to supplement the crew's diet, using plants to revitalize the air and water supply. Methods are needed, therefore, for processing potential food crops. Areas in which innovations are solicited follow below.

Long-Duration, Shelf-Stable Food

An initial trip to the Moon or Mars will require a stored food system that is nutritious, palatable, and provides a sufficient variety of foods to support significant crew activities on a mission of at least three years duration. Development of highly acceptable, shelf-stable food items that use high-quality ingredients is important to maintaining a healthy diet. Foods should maintain safety, acceptability, and nutrition, for the entire shelf life of 3–5 years. Shelf-life extension may be attained through new food preservation methods and/or packaging. Once on the lunar or planetary surface, it may be possible to use bulk packaging of meals or snack items. These food products will require specialized processing conditions and packaging materials.

Advanced Packaging

The current food packaging technologies represent a potentially significant trash-management problem for exploration-class missions to the Moon or Mars. New food packaging technology is needed that minimizes waste by using packaging with less mass and volume and/or by using packaging that is biodegradable or recyclable. Another opportunity would be development of a packaging material that can readily be reused by the crew to make objects of value to the space flight mission.

Food Processing

Advanced life-support systems, which use chemical, physical, and biological processes, are being developed to support future human planetary exploration. One such system might grow crops hydroponically and then process them into edible food ingredients or table-ready products. Variations in crop quality, crop yield, and nutrient content may occur over the course of long-duration missions, posing further requirements to the food processing and storage system. Such variations might affect the shelf stability and functional properties of the bulk ingredients and ultimately, the quality of the final food products.

Equipment to process crops on missions to the Moon and Mars should be highly reliable, safe, automated, and should minimize crew time, power, water, mass, and volume. 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. Some potential crops for advanced life-support systems include minimally processed crops such as lettuce, spinach, carrots, tomatoes, onions, cabbage, bell peppers, strawberries, fresh herbs, and radishes. Other baseline crops that require processing would be wheat, soybeans, white potatoes, sweet potatoes, peanuts, dried beans, rice, and tomatoes. There is a need to develop one or more pieces of food processing equipment for each of these crops.

Food Safety

Assurances of food quality and food safety are essential components in the maintenance of crew health and well-being. Food quality and safety efforts should be focused on monitoring the shelf stability of processed food ingredients and on identification and control of microbial agents of food spoilage, including the development of countermeasures to ameliorate their effects. Determination of radiation on crop functionality and the stored food system shelf life is also needed in the development of the food system. For all food production and processing procedures, Hazard Analysis Critical Control Points (HACCP) must be established.

B3.05 Biomedical R&D of Noninvasive, Unobtrusive Medical Devices for Future Flight Crews
Lead Center: GRC

Human presence in space requires an understanding of the effects of the space environment on the physiological systems of the body. The objective of this subtopic is to sponsor applied research leading to the development of noninvasive, unobtrusive medical devices that will mitigate crew health, safety, and performance risks during future flight missions to the Moon and Mars. Medical diagnostic 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, and power consumption, and capable of multiple functions. Design enhancements that improve the operation, design reliability, and maintainability of medical devices in the space environment are also sought. Of additional consideration are innovative instrumentation automation, ease of use, improved astronaut comfort, and easy-to-read information displays.

Major research disciplines include endocrinology, hematology, microbiology, muscle physiology, pharmacology, drug delivery systems, and mechanistic changes in neurovestibular physiology.

Innovations in the following areas are sought:

- Biomedical monitoring, sensing, and analysis (including the acquisition, processing, communication, and display) of electrical, physical, or chemical aspects of a human's health or physiological state.
- Instrumentation to be used for in-flight and ground-based studies for reliable and accurate noninvasive monitoring of human physiological functions such as the musculoskeletal, neurological, gastrointestinal, and hematological systems.
- Noninvasive biosensors for real-time monitoring of blood and urine chemistry including gases, calcium ions, electrolytes, proteins, lipids, and hormones.
- In-flight specimen analysis to evaluate physiological, metabolic, and pharmacological responses of astronauts.
- Instrumentation to provide quantitative data to establish the effectiveness of an exercise regimen in ground-based research, and to measure bone strain in the hip, heel, and lumbar spine during exercise.
- Assessment of gas bubble formation or growth in the body after in-flight or ground-based decompression, and to prevent or minimize associated decompression sickness.
- In-flight assessment of the metabolism of proteins, carbohydrates, lipids, vitamins, and minerals.
- Smart sensors capable of sensor data processing and sensor reconfiguration.
- Small, portable, medical imaging diagnostic instrumentation.

B3.06 Waste and Water Processing for Spacecraft Advanced Life Support
Lead Center: JSC
Participating Center(s): ARC, GRC, KSC, MSFC

Regenerative closed-loop life-support systems will be essential to enable human planetary exploration. Efforts are currently focused on missions ranging from a return to the Moon and through an initial Mars mission, including using the International Space Station as a test bed for research and technology validation. These future life-support systems must provide additional mass balance closure to further reduce logistics requirements and to promote self-sufficiency. Requirements include safe operability in micro- and partial-gravity, ambient and reduced-pressure environments, high reliability, minimal use of expendables, ease of maintenance, and low-system volume, mass, and power. Recovery of useful resources from liquid and solid wastes will be essential. Innovative, efficient, practical concepts are needed in all areas of resource recovery processes, providing the basic life-support functions of water reclamation and waste management. In addition to these long-duration space applications, innovative regenerative life-support approaches that could have terrestrial application are encouraged. Phase-I proof of concept should lead to Phase-II hardware development that could be integrated into a life-support system test bed. Proposals should include estimates for power, volume, mass, logistics, and crew time requirements as they relate to the technology concepts. More information on advanced life support systems can be found at http://advlifesupport.jsc.nasa.gov. Areas in which innovations are solicited in the following areas:

Water Reclamation

Efficient, direct treatment of wastewater consisting of urine, wash water, and condensates, to produce potable and hygienic waters.

- Physicochemical methods for primary treatment to reduce the total organic carbon concentration of the wastewater from 1000 mg/L to less than 50 mg/L and/or the 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 treatment of brine solutions including water recovery.
- Methods to eliminate or manage solids precipitation in wastewater lines.

- Disinfection technologies, both for potable water storage and point-of-use. Development of residual disinfectants that can be consumed by crewpersons. Techniques to minimize or eliminate biofilm or microbial contamination from potable water systems and water treatment systems, including fluid handling components such as pipes, tanks, flow meters, check valves, regulators, etc.

Solid Waste Management

Concepts and methods to safely and effectively manage wastes for all future human space missions are required to perform the following functions: acceptance/collection, transport, storage, processing, disposal, and associated monitoring and control. Actual types and quantities of wastes generated during missions are highly mission dependent. For sizing purposes, however, the "maximum" waste streams have been estimated as follows, based on a 6-person crew: trash (0.56 kg/day), food packaging (7.91 kg/day), human fecal wastes (0.72 kg/day dry, 3.0 kg/day wet), inedible plant biomass (2.25 kg/day), paper (1.16 kg/day), tape (0.25 kg/day), filters (0.33 kg/day), water recovery brine concentrates (3.54 kg/day), clothing (3.6 kg/day), and hygiene wipes (1.0 kg/day). Wastes can also be assumed to be source-separated because this requirement has been identified for a majority of waste processing equipment:

- Microgravity- and hypogravity-compatible solid waste management technologies;
- Volume reduction of wet and dry solid wastes;
- Small and compact fecal treatment and/or collection system;
- 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 associated with waste;
- Storage devices needed for the containment of solid waste that incorporates an odor abatement technology.
- Microgravity-compatible technologies for the jettison of solid wastes in space; and
- Other novel waste management technologies for storage, transport, processing, resource recovery, and disposal that satisfy a critical need for the referenced missions (e.g., recovery of critical resources).

Component Technologies

Energy efficient, low mass, low noise, low vibration or vibration isolating, fail-safe and reliable components for handling fluids, slurries and/or solids applicable to wastewater treatment and solid waste management. Components include actuators, pumps, conveyors, compressors, coolers, tubing, tanks, bins, fittings, couplings, quick disconnects, and valves which 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.

B3.07 Biomass Production for Planetary Missions
Lead Center: KSC
Participating Center(s): ARC, JSC

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 Moon 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. Innovations are solicited in the following areas:

Crop Lighting

- Sources for plant lighting such as, but not limited to, light emitting diodes, high-efficiency lamps or solar collectors suitable for orbital space, interplanetary space, lunar or Martian surface;
- Transmission and distribution systems for plant lighting including, but not limited to, luminaries, light pipes, fiber optics, and optical filters; and
- Heat removal techniques for the plant growth lighting such as, but not limited to, water-jackets, water barriers, and wavelength-specific filters and reflectors.

Water and Nutrient Management Systems

- Technologies for production of crops using hydroponics or solid substrates suitable for orbital space, interplanetary space, lunar or Martian surface;
- Water and nutrient delivery systems;
- Regenerable media for seed germination plant support; and
- Separation and recovery of usable minerals from wastewater and solid waste products for use as a source of mineral nutrients for plant growth.

Environmental Monitoring and Control

Innovations in monitoring and control approaches for plant-production environments, including temperature, humidity, gas composition, and pressure. Gases of interest could include carbon dioxide, oxygen, nitrogen, water vapor, and ethylene. Development of autonomous control systems integrated with predictive modeling for crop production optimization.

Mechanization and Automation

Innovations in propagation, seeding, and plant biomass processing. Plant biomass processing includes harvesting, separation of inedibles from edibles, cleaning and storage of edibles (seed, vegetable, and tubers) and removal of inedibles for resource-recovery processing.

Facility or System Sanitation

Methods or technologies to identify and prevent excessive build-up of microorganisms within closed plant production systems with emphasis on nutrient delivery systems. Processes to insure pathogen free products through HACCP food safety protocols.

Health Measurement

Remote, direct, and indirect methods of measuring plant health and development using canopy (leaf) spectral signatures or fluorescence to quantify parameters such as rate of photosynthesis, transpiration, respiration, and nutrient uptake. Data acquisition should be noninvasive or remotely sensed using spectral, spatial, and image analysis. System modeling and decision making algorithms may be included.

Sensor Technologies

Innovations are required for development of sensors using miniature, micro- and nanotechnologies for evaluation of the physical and biological parameters in all phases of biomass production. Such sensor arrays include wide-ranging applications of gas and liquid sensors, as well as photo sensors and microbiological community indicators. Innovations are required in all phases of sensor development, including biomass fouling, miniaturization, wireless transmission, multiple-phase and multiple-tasking sensors, and interface with artificial intelligence (AI) data collection systems.

Flight Equipment Support

Innovative hardware and components developed to support life support and biological research in the Space Shuttle, on board the International Space Station, and exploration missions to the Moon, Mars, and beyond. Biomass production investigations using flight-support equipment will be required to meet the demanding requirements for space flight operations, meet the rigorous scientific data collection standards, and produce plants in a controlled environment for research purposes and food. Innovative methods to perform in-flight biomass analyses, including equipment miniaturization, are requested in order to perform remote analyses and to minimize requirements to return in-flight samples. Innovations in whole-package design and in component designs will be required.

Structures

Innovative concepts and designs for autonomous or human tended plant production structures that might be deployed in space habitats, including flight, planetary transit, or planetary surfaces systems. Systems would need to accommodate the capture and distribution of solar light or generated light (e.g., electric lamps) and meet the mass and stowage challenges for spaceflight delivery.

B3.08 Software Architectures and Integrated Control Strategies for Advanced Life Support Systems
Lead Center: JSC
Participating Center(s): ARC, JPL, KSC

The purpose of this subtopic is to develop advanced control system technologies that can support an integrated approach to the command and control of Advanced Life Support (ALS) for future long-duration human space missions, including a permanent human presence on the Moon and Mars. The control strategies for ALS systems must deal with continuous and discrete processes and with dynamic interactions between subsystems such as air revitalization, water recovery, food production, solids processing, and the crew. The goal of autonomously controlling an ALS system 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 control systems. These various technology areas must eventually be integrated into a coherent system that runs day after day for years and that can effectively interact with crewmembers who place their lives in its hands. The control strategy must be able to reach "across" the system and "down" into its parts to gather all data necessary to achieve its control objectives. Interfaces to crew, ground control, and other spacecraft systems must allow for insight into control strategies, choices, and pending actions and allow for manual control at any level.

The challenges of controlling regenerative life support for an enclosed crew environment involve the ALS goals to minimize expendables, to minimize crew and ground involvement, and to incorporate biological systems for recycling air, water and solids. The interdependence of environmental processing systems, and the need for reducing operations support costs are included. There is a need for the development and evaluation of control architectures and strategies which meet these challenges, both by building on current advances in distributed, modular, object-based protocols, and by new advances in integration of agent technology, planning, and resource management across heterogeneous systems. This includes:

New Control Strategies for Closed-Loop Systems
Advanced Life Support consists of a combination of physico-chemical systems with biological systems to recycle air, water, solid waste, plants, and food. The system is closed with respect to hydrogen, oxygen, and carbon in order to reduce the amount of consumable air water and food necessary for extended human presence on other planets. Closed systems and biological systems have different constraints and control paradigms than conventional processes. There is a need for new control algorithms, analyses, strategies, and techniques that can accommodate this architecture.

Distributed Network Protocols, Including Support for Fieldbus and Intelligent Controllers
The robustness of the control and data paths for equipment and subsystems is determined by the fieldbus protocols that connect them. Fieldbus protocols have been developed for the special needs of the aerospace and process control industries. There is a need for investigation and adaptation of these protocols, and the development of new protocols to support the type of distributed intelligent systems and networks envisioned for human exploration missions. These protocols need to be robust and fault-tolerant, and to support a large number of heterogeneous systems. Ideally, these protocols should support both local and interplanetary connectivity.

Development of Ontologies for Communication Among Autonomous Systems or Control Agents
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 taxonomy or common ontology needs to be developed for the types of control problems associated with integrated control of advanced life support systems.

Software Development Methodologies for Autonomous Systems
This includes requirements management, testing, performance metrics, and long-term maintenance support, including development for growth and support for model-based simulations. There is a need for new tools to support the development of distributed autonomous 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.

Approaches for Integration of New Controls Technology (both hardware and software) with Existing Legacy Systems
Some space technologies are relatively mature. New controls technology must be compatible with legacy fieldbuses and operations concepts in addition to providing new functionality. There is a need for tools and development methodologies that can accommodate growth in system functionality.

Fault Detection, Isolation and Recovery (FDIR) Across Multiple Systems; Sharing of Parameters and Data Between Heterogeneous Systems
The majority of FDIR approaches focuses on single subsystems and depend on a homogeneous platform and software architecture, often using a blackboard or shared memory model to share data between modules. There is a need to perform FDIR across multiple heterogeneous systems across networks. Ideally, FDIR should support cooperative efforts between group operations and planetary systems.

Control System Failure Tolerance
Critical systems provide functional redundancy in the case of failure or performance degradation. There is a need for new approaches to providing failure tolerance for both hardware and software components of the control systems. Of particular importance is the reduction of crew time for maintenance, and reduction of dependence on re-supplying hardware, as these are the most expensive constraints on these systems.

Planning and Scheduling
This includes reactions to system faults, supporting adjustments to operations, inventory, and logistics because of planned and unplanned maintenance. There is a need for tools to support development and deployment of applications that support planning and scheduling. Developed applications should support the integration of both planet-side and Earth-side activities.

Development and Integration of Autonomous System and Intersystem Control with Crew and Ground Operations
There is a need for tools, architectures, and technology that can support integration of operations between crew, ground operators, ground applications, and onboard applications.

Development of Architectures that Support a Range of Autonomy, from Fully Autonomous to Fully Manual, with the Corresponding Range of Support for Human Interaction
Autonomous systems for human exploration missions must provide visibility, situational awareness, and an ability to change the level of autonomy based on both situation and human input. As unexpected situations arise that are outside the scope of design, autonomous control systems must interact with crew and ground operators at varying levels of transparency. Unlike Earth-based systems, the planet-side crew will not be subsystem experts and may be isolated from ground support. Local systems must safely and robustly aid the crew in both troubleshooting and nominal operations. There is a need for software architectures and development methodologies, including system and crew modeling, to provide such capabilities.

B3.09 Radiation Shielding to Protect Humans
Lead Center: LaRC

Revolutionary advances in radiation shielding technology are needed to protect humans from the hazards of space-radiation during NASA missions. All space-radiation environments in which humans may travel in the foreseeable future are considered, including low-Earth orbit, geosynchronous orbit, Moon, Mars, etc. All radiations are considered, including particulate radiation (electrons; protons; neutrons; alpha; light-to-heavy ions, with particular emphasis on ions up to iron; mesons; etc.) and including electromagnetic radiation (ultraviolet, x-rays, gamma rays, etc.). Technologies of specific interest include, but are not limited to, the following:

- Advanced computer codes are needed to model and predict the transport of radiation through materials.
- Advanced computer codes are needed to model and predict the effects of radiation on the physiological performance, health, and well-being of humans in space radiation environments.
- Innovative lightweight radiation shielding materials are needed to shield humans in aerospace transportation vehicles, large space structures such as space stations, orbiters, landers, rovers, habitats, space suits, etc. The materials emphasis should be on non-parasitic radiation shielding materials, or multifunctional materials, where one of the functions is radiation shielding.
- Non-materials and "out-of-the-box" radiation shielding technologies are also of interest.
- Laboratory and space flight data are needed to validate the accuracy of radiation transport codes.
- Laboratory and space flight data are needed to validate the effectiveness of radiation-shielding materials and non-materials solutions.
- Comprehensive radiation-shielding databases and design tools are also sought to enable designers to incorporate and optimize radiation shielding into space systems during the initial design phases.
- Accurate and reliable theoretical and phenomenological models are needed for the collision of radiation ions to generate the input database for transport phenomena. The models that give comprehensive results in a fast manner for broader (preferably whole) ranges of colliding ions, for ion energies from a few mega-electron volts to a few giga-electron volts are desirable. The information needed is as follows:
  - Total, elastic, absorption, and fragmentation cross sections
  - Spectral and angular distributions of producing particles
  - Multiparticle fragmentations
  - Cluster effects
  - Meson production

B3.10 Sensors for Advanced Human Support Technology
Lead Center: JPL
Participating Center(s): ARC, GRC, JSC, KSC, MSFC

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

Significant improvements are sought in miniaturization, accuracy, precision, and operational reliability, as well as long life, real-time multiple measurement functions, in-line operation, self-calibration, reduction of expendables, low energy consumption, and minimal operator time/maintenance for monitoring and controlling the life-support processes.

- For water monitoring, sensitive, fast response, online analytical sensors to monitor suspended liquid droplets, dispersed gas bubbles, and water quality, particularly total organic carbon.
- Other species of interest include dissolved gases and ions, and polar organic compounds such as methanol, ethanol, isopropanol, butanol, and acetone in water reclamation processes; and particulate matter, major constituents (such as oxygen, carbon dioxide, and water vapor) and trace gas contaminants (such as ammonia, formaldehyde, ethylene) in air revitalization processes. Both invasive and noninvasive techniques will be considered.
- Monitoring of microbial species, especially pathogens, primarily in water, is important. Enabling technologies may include proper sample preparation and handling, with minimal operator effort and minimal or no reagent usage.
- Significant mass savings and ease of use may be enabled by approaches that detect more than one species at a time. Proposals that seek to develop new technologies or combine existing technologies to simultaneously monitor several major constituents and/or trace constituents are of interest.

TOPIC B4 Partnerships and Market Driven Research

NASA's Space Product Development (SPD) division supports the strategic missions to understand and protect our home planet and to explore the universe and search for life. It also seeks to find answers to the biological and physical research organizing sub-question that asks: How can research partnerships—both market driven and interagency—support our national goals, such as contributing to economic growth and sustaining human capital in science and technology? Innovative proposals are sought for market driven technologies and processes that will support NASA's goals and include dual-use market needs on Earth. There are four initiative areas where NASA space research has strong potential for dual market use on Earth:

1. Self-calibrating and self-repairing bio-MEMS devices for such uses as monitoring crew health in space along with dual applications on Earth for monitoring biological/physical interfaces;
2. Space resource utilization techniques that enable the use of *in situ* planetary resources along with dual applications on Earth that create products by combustion synthesis of materials, extraction of volatiles, separation of solids;
3. Spacecraft technologies that enhance spacecraft inspections, robotic processing, or Free Flyer experiments with dual applications on Earth, such as high density video and advanced sensor networks;
4. Life support technologies that enable health monitoring, provide functional foods and nutraceuticals and environmentally clean habitats with dual applications on Earth, such as high-resolution wireless ultrasound for patient monitoring, improved crop productions, and new forms of drug delivery. Small business applicants must have strong intentions of becoming a part of NASA's Research Partnering Center initiatives leading to partnered Phase III contracts for products to be used in space and on the Earth.

B4.01 Space Market Driven Research
Lead Center: MSFC

The commercial development of space offers enabling benefits to space exploration for NASA. In accordance with the Space Act, as amended, to "seek and encourage to the maximum extent possible the fullest commercial use of space," NASA facilitates the use of space and microgravity for the development of commercial products and services The products may use information from in-space activities to enhance an Earth-based effort, or may require in-space use. This subtopic has three goals. The first goal is the commercial demonstration of pivotal technologies or processes, for example, self-calibrating and self-repairing bio-MEMS devices for such uses as monitoring crew health in space along with dual applications on Earth for monitoring biological-physical interfaces. The second goal is the development of associated infrastructure equipment for commercial experimentation and operations in space, or the transfer of these technologies to industry in space or on Earth. An example of this is the automated processes and hardware (robotics), which will reduce crew exposure and time, and which are a priority. The third goal is the commercial research and technologies pursued and developed in the program often have direct applicability to NASA priority mission areas. This dual-use strategy for research and technology has the potential to greatly expand what the NASA scientific and engineering communities can do in advancing exploration mission requirements. All Agency activity in microgravity, including those in life science and microgravity sciences, which lead to commercial products and services as well as benefits to the mission requirements of exploration objectives, are of interest. Below are some specific areas for which proposals are sought.

Biotechnology
This category comprises biotechnology, biomedical, and agricultural instrumentation or techniques that exploit space-derived capabilities or data to support the commercial development of space by the agricultural, medical, or pharmaceutical industry.

- Portable biological sensors: The need for sensing devices that can detect and identify biological pathogens (airborne or *in vivo*) is desired to support NASA's mission for a permanent presence of man in space.
- Development of noninvasive health monitoring systems and models: Application to NASA's crew health program for extended duration missions. For example, (1) novel *in vitro* cell-matrix models for studying the

effects of microgravity on human tissue repair and wound healing, (2) novel orga-notypic skin models that simulate physiological changes found in humans under a microgravity environment, and (3) functional models for delineating the MG-inducible or MG-responsive pathways of human tissue angiogenesis (new blood vessel formation).

- Physiological measurement in microgravity of bone growth and the immune system in microgravity.
- Innovative research in plant-derived pharmaceuticals using microgravity.
- Agricultural research, i.e., genetic manipulation of plants using microgravity.
- Instrumentation or technology to explore the use of microgravity in genetic assay, analysis, and manipulation.
- Instrumentation to analyze cell reactor systems and characterize cell structure in microgravity in order to develop enhanced drug therapies that can also be applied to pharmaceutical development and commercialization.
- Innovative techniques for dynamic control and cryogenic preservation of protein crystals.
- Innovations in preparation of protein crystals for x-ray diffraction experiments without the use of frangible materials.
- Innovation of low-technology temperature control chambers requiring little or no power for bringing temperature sensitive experiments up to, or back from, the International Space Station.

Materials Science

Areas in which Materials Science innovations are sought include the following:

- Applications using space-grown semiconductor crystals, including epitaxially grown materials for commercial electronic devices. The applications will also attempt to use the knowledge of the space-grown material behavior to enhance ground processing of the materials to achieve equivalent performance of space-grown materials in electronic circuitry.
- Applications using space-grown optical electronic materials such as fluoride glasses and nonlinear optical compounds for commercial optical electronic devices and to achieve equivalent performance of space-grown materials in ground processing.
- Innovations using nonlinear optical material to be processed in space.
- Innovations for new space-processed glasses for optical electronic applications.

B4.02 Market Driven Space Exploration Payloads
Lead Center: MSFC

NASA has an interest in the development of science and experiments that support strategic aspects of exploration, as well as the development of technologies to extend humanity's reach to the Moon, Mars, and beyond. This includes designing exploration microgravity payloads. For example, life support technologies that enable health monitoring, provide functional foods and nutraceuticals, and environmentally clean habitats with dual applications on Earth such as high-resolution wireless ultrasound for patient monitoring, improved crop productions, and new forms of drug delivery. Preparing for exploration and research will accelerate the development of technologies that are important to the economy and national security as well as accelerate critical technologies.

Microgravity Payloads

- Design and develop microgravity payloads for space station applications that lead to commercial products or services.
- Enabling commercial technologies that promote the human exploration and development of space.
- Enabling commercial technologies through the use of ISS as a commercial test bed for hardware, products, or processes.
- Enabling technology designed to reduce crew work loads and/or facilitate commercial investigations or processing through automation, robotics, or nanotechnology.

Combustion Science
Innovative applications in combustion research that will lead to developing commercial products or improved processes through the unique properties of space or through enhanced or innovative techniques on the ground.

Food Technology
Innovative applications of space research in food technology that will lead to developing commercial food products or improved food processes through the unique properties of space or through enhanced or innovative techniques on the ground.

Biomedical Materials
Innovative materials where microgravity promotes structures such as biodegradable polymers for use in wound healing and orthopedic applications.

Entertainment Value Missions
Innovative approaches for commercial economic benefit from space research involving broadcasting, e-business, or other activities that have entertainment value.

B4.03 Market Driven Space Infrastructure
Lead Center: MSFC

In accordance with the Space Act, as amended, to "seek and encourage to the maximum extent possible the fullest commercial use of space," NASA facilitates the use of space for commercial products and services. For example, space resource utilization techniques that enable the use of *in situ* planetary resources along with dual applications on Earth that create products by combustion synthesis of materials, extraction of volatiles, and separation of solids; also, spacecraft technologies that enhance spacecraft inspections, robotic processing or Free Flyer experiments with dual applications on Earth, such as high density video and advanced sensor networks. The products may use information from in-space activities to enhance an Earth-based effort or may require in-space manufacturing. This subtopic's goal is the development of infrastructure technology that will enable or enhance commercial space operations. Processes and hardware that have a clear utilization plan are a priority. All space activities that lead to commercial use in space are of interest. Some specific areas for which proposals are sought include the following:

Power and Thermal Management
Power and thermal management technologies that enable or enhance commercial satellites or space systems are sought.

Communications
Broadband, data compression, and imaging that can enable or enhance commercial operations in space or commercial satellites. This includes use of hyperspectral imagery and remote sensing.

Space Vehicles and Platforms
Improved technologies are sought for autonomous commercial vehicles and platforms. These technologies include autonomous rendezvous and docking, structures, and avionics.

Space Resources Utilization
Advanced commercial space activities will benefit from using nonterrestrial resources. These resources include propellants, power, and structural materials.

B4.04 Partnering Innovations for Security and Safety
Lead Center: MSFC

NASA also has the goal to protect its assets, on Earth and in space, as well as our home planet and better understand the use of technologies that improve the quality of life in space and on Earth. By investing in space research and by collaborating with other agencies, industry, and academia, NASA has the opportunity to contribute to the creation of a more secure environment in space and on Earth. By leveraging resources in support of research in the unique environment of space, NASA goals and national priorities, such as security, as well as market needs, may be achieved. This dual use with good potential for commercial product development is strongly encouraged. Following are some example areas for which proposals are sought:

- Sensors and detection systems to improve processes and operations in support of NASA space research and exploration goals, national security, and industrial processes.
- Improved communication systems to effectively and efficiently gather information from space-based research and provide better communication capabilities in support of NASA; its space and ground-based research and exploration goals are a priority. These systems could also be used to disseminate warnings and other critical information, in the event of a national disaster.
- Innovative devices and procedures for the use of technologies to protect NASA's personnel and assets as well as citizens from various threats to their personal security and/or property. These devices and procedures for the use of technologies would also provide protection to personnel carrying out NASA space research and exploration operations, both in space and on Earth.
- Countermeasure systems and/or devices to better effect rescue, recovery, treatment, and environmental safety during and after the occurrence of a disaster or a related accident.

TOPIC B5 Flight Payload Technologies and Outreach

The Biological and Physical Research enterprise (BPR) has two organizing questions that can benefit from advanced sensors and devices: (1) How can we assure the survival of humans traveling far from Earth? and, (2) How does life respond to gravity and space environments? Proposals are sought in areas of nanotechnology, information technology, and biotechnology that are likely to help answer both questions. It is important for BPR to assure that its missions and experiments use new technologies, tools, models, and procedures that improve experiment integration and mission flight support. Proposals are sought for innovative ideas for experimental use of the Space Shuttle, International Space Station, and Free Flyers. Proposals are also sought for payload technologies that will support planned human exploration missions to the Moon and Mars. BPR has the need to educate and inspire the next generation to take the journey. The objective is to improve science literacy by engaging the public in missions and discoveries associated with BPR. Proposals are sought for innovative methods for analysis, metrics development audience assessment, and outreach product development.

B5.01 Telescience and Flight Payload Operations
Lead Center: MSFC
Participating Center(s): ARC

NASA has interest in the development of science and experiments that support strategic aspects of exploration, as well as to develop the technologies to extend humanity's reach to the Moon, Mars, and beyond. Preparing for exploration and research will require the acceleration of the development of new technologies that will be imperative to future telescience and payload operations. It is important that the space missions and experiments for biological and physical research be managed using new tools, models, and procedures that improve telescience and flight payload operations. In addition, NASA wants to make available data and information associated with microgravity research investigations and results.

The ability for developers to access existing and new tools and collaborate in the design, simulation, modeling, building, and testing will be crucial to the success of NASA's new initiative. New methods of computing, accessing disparate data spread over wide geographical areas will require new approaches to computing, data storage and communications.

There are many potential users for NASA services and data located throughout the U.S. There are three general types of users of these services and data. The first type is the principal investigator (PI)/payload developer (PD) who is responsible for the payload, experiment, and attendant science, and who commands the payload or experiment. The second type is the secondary investigator(s) who participates in analysis of the science and its control, but does not send commands. The third type is the educational user, from secondary school students up to graduate students. These users will receive either data processed by the PI or unprocessed data. Commercial investigations require the ability to receive, process, and display telemetry, view video from science sources, including the ISS, and interact with NASA concerning the science and operations. To conduct or be involved in general science activities, including the ISS science operations, a user will require various services from the Payload Operations Integration Center (POIC) located at the Marshall Space Flight Center near Huntsville, Alabama, or from other control centers located at various NASA facilities. These services are required to enable the experiment to be controlled using the inputs from various video sources, telemetry, and the crew. The input allows the experimenter to send to his/her payload or experiment commands to change various experiment operations. Before an experiment can get underway, an experimenter must participate in the payload planning process to schedule onboard services such as power, crew time, and cryogenics. This planning process is integral to the entire payload/carrier operation and requires the PI/PD or his/her representatives to participate via voice or video teleconferencing. To enable a user to operate from his/her home base, whether located in a laboratory, office, or home; these services (commensurate to the level of operation) must be provided at the user's location at a reasonable cost. Costs include both the platform upon which these services will run, and the communications required to provide these services to the experimenter's location.

Proposals are sought for innovative ideas and efficiencies for systems to better effect communication and handling of data and information for scientific and commercial research on the International Space Station payloads and on manned exploration missions, and at the same time, for general use as applicable.

B5.02 Flight Payload Logistics, Integration, Processing, and Crew Activities
Lead Center: MSFC

In preparation for future human exploration, we must advance our ability to live and work safely in space, and at the same time, develop technologies to reach the Moon, Mars, and other planets. These new technologies will improve the Nation's other space activities and may provide applications that could be used to address problems on Earth. The objective of this subtopic is to introduce new technology in the form of new tools, models, and procedures. It is important that the space missions and experiments for biological and physical research be managed using new tools, models, and procedures that improve flight payload integration and associated activities. Proposals are sought for more effective and efficient flight payload logistics, integration, processing, and crew activities. As experiment hardware is developed, concurrent planning for logistics, processing, and for both analytical and physical payload integration must take place. One objective is to minimize crew time required for experiment handling, transfer, installation, and operation through automation, procedural efficiencies, and other means. Some potential areas for payload improvements include, but are not limited to, the following:

- Acoustics, i.e., noise level reduction
- Power requirement reduction
- Electro Magnetic Interference/Electro Magnetic Compatibility (EMI/EMC) reduction
- Thermal control
- Materials usage
- Data control/handling
- Safety
- Test and checkout

- Systems integration
- Logistics
- Automation, robotics, and nanotechnology
- Training

B5.03 Development of Improved Outreach Planning and Implementation Products
Lead Center: MSFC

U.S. achievements in space have lead to the development of technologies that have widespread applications to address problems on Earth, as well as in space. In preparation for future human exploration of space, we must advance our ability to live and work safely in space and at the same time develop technologies to extend our reach to the Moon, Mars, and beyond. Outreach is a critical part of this process. This subtopic places emphasis on the effective implementation and analysis of outreach activities.

The Biological and Physical Research enterprise (BPR) seeks to use its research activities to encourage educational excellence and to improve scientific literacy from elementary school through the university level and beyond. The Enterprise delivers value to the American people by facilitating access to the experience and excitement of space research. NASA wants to provide access to information and data about microgravity research experiments and commercial investigations to schools, industry, and the general public.

Proposals are sought that provide a system, or systems, based on commercial solutions to develop outreach products for the improvement of education and public outreach planning and implementation. These systems should allow outreach participation in NASA programs, including the science and operational levels. Systems could provide for the general public and the educational community access to NASA and commercial science activities and operations through low-cost technologies, and outreach and education activities. The systems should be capable of facilitating secondary and college-level students' access to, and the ability to participate in, science activities. Similarly, the systems should be able to accommodate institutions and organizations that promote the use of science and technologies, e.g., museums and space camps. Examples of potential outreach activities include, but are not limited to the following:

- Exhibits and educational/informational material for conferences, workshops, and schools.
- Development and distribution of outreach brochures, newsletters to the general public, and student flight experiment programs.
- Adult Ambassador Program, e.g., advocacy speakers for community education and outreach events, alliance with Collegiate Alumni Learning Weekend Programs, development of a partnership with retirement organizations for the planning and implementation of a program with appropriate learning experiences, development and implementation of "learning laboratories" for science centers and museums, publication of articles in general interest periodicals, publication of articles and reports in scientific journals, multimedia outreach products, outreach Web sites, education briefs, fact sheets, and press releases.
- In addition to the development of new tools for planning and implementation, BPR seeks to evaluate the effectiveness of outreach activities. Systems are sought to assess and analyze the implementation and effectiveness of education and outreach activities and goals associated with BPR research. Assessment of available learning venues for varied age groups and priority order of attendance would be valuable in helping to formulate which venues and audiences to target.

This page has intentionally been left blank.

9.1.3 EARTH SCIENCE

NASA's goal in Earth Science is to observe, understand, and model the earth system to discover how it is changing, to better predict change, and to understand the consequences for life on earth. Earth Science Enterprise (ESE) does so by characterizing, understanding, and predicting change in major Earth System processes and linking models of these processes together in an increasingly integrated way. Earth Science is divided in two themes: Earth System Science and Earth Science Applications theme. Earth System Science theme comprises the Enterprise's Research, Observation and Information Management, and Advanced Technology programs. Earth System Science's Research is focused into six science areas: 1) Climate Variability and Change, 2) Atmospheric Composition, 3) Carbon Cycle, Ecosystems, and Biogeochemistry, 4) Water and Energy Cycle, 5) Weather, and 6) Earth Surface and Interior. The ESE's Advanced Technology Program is designed to foster the creation and infusion of new technologies into Enterprise missions in order to enable new science observations or reduce the cost of current observations. Requirements for advanced technology development are based on requirements articulated in ESE's Research Plan. The *Earth Science Enterprise Strategy* discusses ESE's approach to these great endeavors and outlines the key program components of the Earth Science Enterprise. Three subordinate documents, the *Earth Science Enterprise Research Plan*, the *Technology Plan*, and the *Applications Plan*, provide more detail in these important areas. These documents are located at:

http://www.earth.nasa.gov

TOPIC E1 Instruments for Earth Science Measurements 100

E1.01 Passive Optics 100
E1.02 Lidar Remote Sensing 101
E1.03 *In Situ* Sensors 102
E1.04 Passive Microwave 103
E1.05 Active Microwave 105
E1.06 Passive Infrared - Submillimeter 107
E1.07 Thermal Control for Instruments 108

TOPIC E2 Platform Technologies for Earth Science 109

E2.01 Guidance, Navigation and Control 109
E2.02 Command and Data Handling 110
E2.03 Advanced Communication Technologies for Near-Earth Missions 111
E2.04 Onboard Propulsion 112
E2.05 Energy Storage Technologies 112
E2.06 Energy Conversion for Space Applications 113
E2.07 Platform Power Management and Distribution 114

TOPIC E3 Advanced Information Systems Technology For Earth Science 115

E3.01 Automation and Planning 115
E3.02 Distributed Information Systems and Numerical Simulation 116
E3.03 Geospatial Data Analysis Processing and Visualization Technologies 116
E3.04 Data Management and Visualization 117
E3.05 Onboard Science for Decisions and Actions 117

TOPIC E4 Applying Earth Science Measurements 118

E4.01 Innovative Tools and Techniques Supporting the Practical Uses of Earth Science Observations 118
E4.02 Advanced Educational Processes and Tools 119
E4.03 Wireless Technologies for Spatial Data, Input, Manipulation and Distribution 120

TOPIC E1 Instruments for Earth Science Measurements

NASA's Earth Science Enterprise (ESE) is studying how our global environment is changing. Using the unique perspective available from space 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 the ESE 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 the Instruments for Earth Science Measurements 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 enable new Earth observation measurements. The following subtopics are concomitant with this objective and are organized by measurement technique.

E1.01 Passive Optics
Lead Center: LaRC
Participating Center(s): ARC, GSFC

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, and responses are solicited for these topics.

1) Stiff actuator technology designed to produce precisely controlled motion of large (> 1.0 cm diameter) optical elements intended for use in tunable Fabry-Perot and Fourier Transform Spectrometer (FTS) instruments. Motion ranges of particular interest include 20–60 µm, 1–2 mm, and 3–5 cm. Techniques applicable to very cold temperature (<150 K) and vacuum operation of optical components equipped with these actuators are especially desired. Devices and components with low mass and requiring low power are preferred.

2) 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.

3) 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.

4) High performance four-band two-dimensional (2-D) 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.

E1.02 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 techniques, components, and instrument concepts 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, subsystems, and complete instrument packages addressing the following specific measurement needs:

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

In addition to instrument systems, innovative component technologies that directly address the measurement needs above will be considered. Technical and scientific leads at NASA have given careful consideration to the component technologies described below, and responses are solicited for these technology areas.

1. Novel laser materials and components for high efficiency solid state lasers operating at 1 and 2 µm wavelength regions. The laser components include:
   - Rugged, compact fiber lasers and fiber amplifiers for use at 1.5 and 1 µm;
   - Low voltage (<1 kV) electro-optic q-switch for use at 1 µm;
   - Efficient and reliable high power, quasi-CW, pump diodes operating at 792 nm and 808 nm in fiber-coupled or free-space configuration; and
   - Laser crystals for generating 2 µm radiation with high thermal conductivity and small variation of the index of refraction with temperature.

2. High damage-resistant, efficient, inorganic and birefringent nonlinear optical materials for generation of ultra-violet and mid-infrared radiation.

3. Thermally efficient conductively-cooled head for solid-state lasers with side-pumped rod configuration, and thermally and mechanically stable optical bench.

4. Frequency-agile, semiconductor lasers operating in 1 to 2 µm wavelength region with spectral linewidth less than 200 kHz over 1 ms and optical power greater than 20 mW.

5. Scanning or scanable lightweight telescopes with an optical quality better than 1/6 wave at 632 nm, mass density less than 12 kg/m^2, and aperture diameters from 0.5–1.0 m.

6. Laser beam steering and scanning technologies operating at 0.355, 1.06, or 2.05 µm with 5–25 cm aperture diameter for airborne and 0.5–1.0 m for spaceborne instruments, meeting the following minimum requirements:
   - 60° field of regard
   - 90% optical throughput
   - wave single pass optical quality at 632 nm

7. 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 aberra-

tions 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.

8. High gain, low noise photon counting detectors that operate without the use of cryogens are needed. Other desirable properties are linearity over a large dynamic range, saturation count rates over 100 MHz, reasonable active area size (>200 μm), 250–2200 nm response wavelengths, and high clocking and readout rates with low read noise. High-speed (500 Msamples per second or greater) waveform digitizers are also of interest for operation with integrated pulse-finding capability suitable for continuous operation and capable of locating more than 200,000 individual pulses per second.

9. Narrow band optical filters with <0.1 nm FWHM and >75% throughput, with minimum 1 inch clear aperture.

E1.03 *In Situ* Sensors
Lead Center: GSFC
Participating Center(s): ARC, JPL

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 short-wave 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.

E1.04 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, NO_X, 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 multispectral 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 an important element of competitive proposals under this solicitation.

Specific technology innovation areas include:

- Imaging radiometers, receivers or receiver arrays on a chip, and flux radiometers.
- Large aperture, deployable antenna systems suitable for highly reliable space deployment with root mean square (RMS) surface accuracy approaching 1/50th wavelength. Such large apertures can be real or synthetic apertures. Of key importance is the ability for a highly compact launch configuration, followed by a highly reliable erection and resultant surface configuration.
- Focal plane array modules for large-aperture passive microwave imaging applications.
- Wideband and ultra-wideband sensors with >15dB cross-pole isolation across the bandwidth.
- Sensors with low surface currents enabling scanning up to +/-50° without grating lobes, and collimation in one direction with low side lobes for 1-D aperture synthesis.
- Bi-static GPS receiving systems for application as altimeters and scatterometers.
- Enhanced onboard data processing capabilities that enable real-time, reconfigurable computational approaches which enhance research flexibility. Such approaches should improve image reconstruction, enable high compression ratios, improve atmospheric corrections, and the geolocation and geometric correction of digital image data.
- Techniques for the detection and removal of Radio Frequency Interference (RFI) in microwave radiometers are desired. Microwave radiometer measurements can be contaminated by RFI that is within or near the reception band of the radiometer. Electronic design approaches and subsystems are desired that can be incorporated into microwave radiometers to detect and suppress RFI, thus insuring higher data quality.
- New technology calibration reference sources for microwave radiometers that provide greatly improved reference measurement accuracy. High emissivity (near-black-body) surfaces are often used as onboard calibration targets for many microwave radiometers. NASA seeks ways to significantly reduce the weight of aluminum core target designs, while reliably improving the uniformity and knowledge of the calibration target temperature. NASA seeks 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.
- New approaches, concepts and techniques are sought for microwave radiometer system calibration over or within the 1–300 GHz frequency band, which provide end-to-end calibration to better than 0.1Ø°, including corrections for temperature changes and other potential sources of instrumental measurement drift and error.

- Microwave and millimeter wave frequency sources are sought as an alternative to Gunn diode oscillators. Compact (<10 cm^3) self contained oscillators with output frequency between 40 GHz and 120 GHz, low phase noise <125 dBc/Hz at 1kHz, and high output power (>100 mW) are needed.
- Low noise (<1000 K) with low conversion loss (< 6 dB), compactly designed (< 8 cm^3) heterodyne mixers requiring low local oscillator drive power (<2 mW) are needed over the frequency range between 100 GHz and 1 THz. Multigigahertz, low power, 4-bit undersampling analog-to-digital converters, and associated digital signal processing logic circuits are also needed.
- Low power lightweight microwave radiometers are desired which are able to operate stably over long periods, with DC power consumption of less than 2 W and preferably less than 1 W, not including any mechanisms.
- Monolithic microwave integrated circuit (MMIC) low noise amplifier (LNA) for space-borne microwave radiometers, covering the frequency range of 165 to 193 GHz, having a noise figure of 6.0 dB or better (and with low 1/f noise).

NASA is developing satellite systems that will use passive and active microwave sensing at L-band and other frequencies to measure sea surface salinity, and soil moisture to a depth of ~10 cm. In support of these global research efforts, the following ancillary measurement systems are required:

- Inexpensive approaches to ground sensors are desired that are capable of measuring areas at least 100,000 km^2, with a spatial resolution of 20 km. These ground sensors will be needed to validate those space-borne measurements. Measurement of ground-wave propagation characteristics of radio signals from commercial sources may satisfy that need. Although absolute values of soil moisture are desirable, they are not required if the technique can be calibrated frequently at suitable sites. Cost per covered area, autonomous operation, anticipated accuracy, and depth resolution of the soil moisture measurement will be considerations for selection.
- Autonomous GPS-located ocean platforms are needed which can measure upper ocean and lower atmosphere properties including temperature, salinity, momentum, light, precipitation, and biology, and can communicate the resultant data and computational or configuration instructions to and from remote terminals. Similar sensor packages are desired for use onboard ships while under way. This includes the development of intelligent platforms that can change measurement strategy upon receipt of a message from a command center.
- Autonomous low-cost systems are desired that can measure Earth and ocean surface and lower atmospheric parameters including soil moisture, precipitation, temperature, wind speed, sea surface salinity, surface irradiance, and humidity.
- Novel approaches to beam steering for these very large aperture antenna systems are also desired: 1)lightweight, electronically steerable, dual-polarized, phased-array antennas; 2) shared aperture, multi-frequency antennas; 3) high-efficiency, high power, low-cost, lightweight, phase-stable transmit/receive modules; 4) advanced antenna array architectures including scalable, reconfigurable and autonomous antennas; 5) sparse arrays, digital beamforming techniques, time domain techniques, phase correction techniques; 6) distributed digital beamforming and onboard processing technologies; and 7) brightness temperature/scatter co-registration data processing algorithms, data reduction, and merging techniques.

Ground-based microwave radiometer instrumentation, subsystems, and techniques for validating space-borne precipitation measurements. Passive microwave instrumentation, or subsystems, capable of ground-based retrievals of precipitation. The instrumentation, or subsystems, shall operate in inclement weather conditions without the interfering affects of liquid water accumulation on the aperture or field-of-view obstructions. Capabilities for volumetric scanning of the atmosphere and autonomous operation are of great interest.

E1.05 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 and soil moisture mapping, accurate global wind retrieval and snow inundation mapping, global 3-D 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 & Ka-band interferometers for snow cover measurement over land (Ku-band) and 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 3-D rain mapping.
- Lightweight, low-cost, Ku/Ka band radar system for ground-based rain measurements.
- High power, low sidelobe (better than -30 dB) scanning phase array flat plate antenna (X, Ku, Ka, or W-band) for high altitude operation (65,000 feet).

E1.06 Passive Infrared - Submillimeter
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; (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.
- Calibrated radiometer systems that can achieve accuracy and stability of 0.1 K.
- Astrophysics receiver-detector technology proposals are also solicited, specifically under topic S2.01, Sensors and Detectors for Astrophysics.

E1.07 Thermal Control for Instruments
Lead Center: GSFC
Participating Center(s): ARC, JPL, MSFC

Future instruments and platforms for NASA's Earth Science Enterprises will require increasingly sophisticated thermal control technology.

1. Instrument optical alignment needs, lasers, and detectors require tight temperature control, often to better than +/- 1°C.
2. Heat flux levels from lasers and other high power devices are increasing, with some projected to go as high as 100 W/cm^2.
3. Cryogenic applications are becoming more common. Large, distributed structures, such as mirrors and antennae, will require creative techniques to integrate thermal control functions and minimize weight.
4. The push for miniaturization also drives the need for new thermal technologies towards the micro-electromechanical system (MEMS) level.
5. The drive towards 'off-the-shelf' commercial spacecraft, and reconfigurable spacecraft presents engineering challenges for instruments, which must become more self-sufficient.

Innovative proposals for thermal control technologies are sought in the following areas:

- Miniaturized heat transport devices, especially those suitable for cooling small sensors, devices, and electronics.
- Highly reliable, miniaturized Loop Heat Pipes and Capillary Pumped Loops that allow multiple heat load sources and multiple sinks.
- Advanced thermoelectric coolers capable of providing cooling at ambient and cryogenic temperatures.
- Inexpensive passive radiative coolers for low Earth orbit.
- Technologies for cooling very high flux (>100 W/cm^2) heat sources, including spray and jet impingement cooling.
- Advanced thermal control coatings, such as variable emittance surfaces and coatings with a high emissivity at ambient and cryogenic temperatures.
- High conductivity materials to:
    - Minimize temperature gradients, especially for optical benches and structures,
    - Provide jitter isolation links between cryocoolers and sensors, and
    - Provide high efficiency light-weight radiators.
- Advanced analytical techniques for thermal modeling, focusing on techniques that can be easily integrated into existing codes.

- Thermal control systems that actively maintain optical alignment for very large structures at both ambient and cryogenic temperatures.
- Single and two-phase pumped fluid loop systems, which accommodate multiple heat sources and sinks.
- Long life, lightweight pumps for single and two-phase fluid loop systems.
- Efficient, lightweight vapor compression systems for cooling up to 2 kW.

TOPIC E2 Platform Technologies for Earth Science

NASA is fostering innovations that support implementation of the Earth Science (ES) Enterprise program, an integrated international undertaking to study the Earth system. ES uses the unique perspective available from orbit to study land cover and land use changes, short and long term climate variability, natural hazards, and environmental changes. Additionally, ES uses terrestrial and airborne measurements to complement those acquired from Earth orbit. ES has a parallel development effort to these platforms that includes the largest ground and data system ever undertaken, which will provide the facility for command and control of flight segments and for data processing, distribution, storage, and archival of vast amounts of Earth science research data. The Earth Science Program defines platforms as the host systems for ES instruments, i.e., 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. 'Platform,' however, 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, and drop sondes), terrestrial platforms, sea surface and subsurface platforms, and even surface penetrators. These application examples are given to illustrate the wide diversity of possibilities for acquiring ES data consistent with the future vision of the Earth Science Program and indicate types of platforms for which technology development is required.

E2.01 Guidance, Navigation and Control
Lead Center: GSFC
Participating Center(s): JPL

Future ES architectures will include platforms of varying size and complexity in a number of mission trajectories and orbits. These platforms will include spacecraft, sounding rockets, balloons, and Unmanned Aerial Vehicles (UAVs). 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, and volume resource constraints. A vigorous effort is needed to develop guidance, navigation and control methodologies, algorithms, and sensor–actuator technologies to enable revolutionary Earth science missions. Of particular interest are highly innovative GN&C technology proposals directed towards enabling ES 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 ES spacecraft and/or the management of large fleets of heterogeneous and/or homogeneous ES assets are desired. Specific areas of research include:

GN&C System Technologies
Innovative GN&C solutions for ES instrument pointing and stabilization. Advanced GN&C solutions for the Microsat attitude determination and control problem. Of special interest are low cost (at high production volumes) and highly integrated Microsat GN&C subsystems suitable for enabling both spin stabilized and three-axis stabilized Microsats. GN&C proposals that exploit and combine recent advances in miniature spacecraft subsystem architectures, spacecraft attitude determination and control theory, advanced electro-mechanical packaging, MEMS technology, ultra-low power microelectronics are encouraged. Proposals of special interest are ones that address the technologies needed to implement closed-loop spacecraft control system architectures which provide the "Drag-Free" precision orbit determination and maintenance capabilities needed for future ES Low Earth Orbit (LEO) formation-flying applications. Technology solutions are encouraged rhat employ Drag-Free sensors (similar to

accelerometers), high specific impulse (Isp) thrusters, and low-cost processors with appropriate closed-loop filtering and control algorithms to implement a complete Drag-Free spacecraft control system module.

Vision-based GN&C system concepts, subsystems, hardware components, and supporting algorithms/flight software. Applications of interest are of high performance video image processing 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 proximity operations.

Advanced GN&C solutions for balloon-borne stratospheric science payloads, including sub-arc second pointing control, sub-arcsecond attitude knowledge determination and trajectory guidance for individual balloon-borne payloads. Innovative techniques are of interest for modeling, simulating, and analyzing the inherent dynamics and control of balloon-borne payloads. Also of interest are innovative concepts, strategies, techniques, and methods for modeling, simulating, and analyzing formations, constellations, and/or networks of multiple balloon-borne stratospheric science payloads.

GN&C Sensors and Actuators
Advanced sensors and actuators with enhanced capabilities and performance, as well as reduced cost, mass, power, volume, and reduced complexity for all spacecraft GN&C system elements. Emphasis is placed on improved stability, accuracy, and noise performance. Nontraditional multifunctional sensor/actuator technology proposals 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 navigations functions.

E2.02 Command and Data Handling
Lead Center: GSFC

Advancing science with reduced levels of mission funding, shorter mission development schedules and reduced availability of flight electronic components creates new requirements for spacecraft Command and Data Handling (C&DH) systems. There are specific areas for which proposals are being sought.

Onboard Processing
- General purpose data processing: higher levels of spacecraft autonomy require higher levels of general purpose CISC (Complex Instruction Set Computer) and RISC (Reduced Instruction Set Computer) processing with fault tolerance and error correction (system and application).
- Special purpose data processing: higher levels of automated onboard science data processing to complement the data gathering capabilities of future instruments. Reduce the processed data volume to remain within the limits of spacecraft to Earth communications.
- Reconfigurable computing hardware: achieving pure hardware processing capabilities with the flexibility of reprogrammability to allow different science objectives to be met with the same hardware platform. Development of technologies such as radiation hardened Field Programmable Gate Arrays (FPGAs) and similar components for data communications and processing.
- Low-power electronics: in order to provide higher capabilities on smaller and/or less expensive spacecraft. Electronics that consume less power decrease overall thermal load, and decrease battery size and solar panel size.

Command and Data Transfer

- Subsystem data transfer: communications between various spacecraft subsystems in order to realize higher autonomy. Development of technologies and architectures that increase the rate of data transfer above 20 Mbits/s are necessary to achieve the self-diagnosis, autonomous control, and science data transfer requirements.
- Intra-system data transfer: communications within the spacecraft subsystem, between cards within a box to replace the conventional passive backplanes.

Protocols and Architectures

- Internet-based protocol modules and extensions that will support seamless connectivity between terrestrial and aerospace platforms by mitigating variable latencies and bit error rates among distributed air and spacecraft to terrestrial gateways.
- Novel methodologies for performing medium to large-scale simulations of space Internet architectures, protocols, and applications.
- Network security technologies to assure integrity and authentication of data from the public Internet to protected space-based networks.
- Ad hoc and innovative, lightweight networking protocols to support spacecraft constellation, formation flying, satellite clusters, proximity, and sensor based networks.

E2.03 Advanced Communication Technologies for Near-Earth Missions
Lead Center: GSFC
Participating Center(s): GRC

Programmable Analog Devices
A technology is desired to provide a software programmable analog component. This “programmable analog array” would consist of basic elements including filters, amplifiers, couplers and mixers whose frequency of operation, bandwidths and gains can be changed by software command. The signal flow in the component itself will be reconfigurable by software and firmware loads in a manner similar to that of Field Programmable Gate-Array (FPGA) digital devices. Desired components will be capable of operating in the S- and Ku-bands. Maximum flexibility in configuration is also desired with the goal of producing a generic “sea of elements” rather than an integrated system on a chip.

Low-Overhead Software-Defined Radio (SDR) Implementations
NASA is interested in SDR architectures and implementations that optimize flexibility and interoperability between different SDRs, but are based on extremely efficient core architectures and low processor overheads. Algorithms that can be implemented in current space flight capable hardware are especially encouraged.

RF Component Technology
A wide variety of general advances in component, material and manufacturing technologies are required to support future NASA mission requirements. These technologies include innovative approaches to enable higher frequency, miniature, power efficient Traveling Wave Tube Amplifiers (TWTAs) operating at millimeter wave frequencies and at data rates of 10 Gbps or higher. Wide band-gap semiconductor (WBGS) based devices for high power, high efficiency microwave and millimeter wave solid-state power amplifiers (SSPAs), as well as low noise amplifiers in the same ranges. MEMS-based RF switches are needed for use in reconfigurable antennas, phase shifters, amplifiers, oscillators and in-flight reconfigurable filters. Frequencies of interest include S-, Ku-, Ka-, and V-band (60 GHz).

Bandwidth Efficient Channel Coding
To support extremely high data rates in a limited frequency spectrum, bandwidth-efficient channel coding is required. NASA is interested in algorithms that provide lossless data compression and efficient error correction at data rates greater than 1 Gbps for links between Earth orbit and Earth ground stations.

RF Materials and Structures

NASA is interested in materials that can be efficiently manufactured and effectively used in the construction and deployment of thin-film based RF antenna systems. Methods for deploying very large, lightweight, aperture structures on-orbit are needed. Inflatable structures, as well as "shape memory" alloy-based implementations, capable of withstanding launch and deployment forces are encouraged.

E2.04 Onboard Propulsion
Lead Center: GRC
Participating Center(s): GSFC, JSC, MSFC

This subtopic seeks technologies that will significantly increase capabilities and reduce costs for Earth science spacecraft. Propulsion functions include orbit insertion, orbit maintenance, constellation maintenance, precision positioning, in-space maneuvering, and de-orbit. Propulsion technologies are sought that will provide platforms with larger scientific payloads, longer-life missions, and increased operational flexibility during missions. To accomplish these goals, innovations are needed in low-thrust chemical and low-power electric propulsion technology, including thruster components, advanced propellants, power processing units, and feed system components. Of particular interest are innovations in propulsion technology that lead to smaller-sized, integrated, autonomous spacecraft. The following specific areas are of interest:

Miniature and Precision Propulsion

Propulsion technologies for miniature (less than 10 kg) spacecraft and for high-precision (impulse bit <–100mN s) station keeping and attitude control are sought. This includes concepts with fundamentally different approaches to propulsion than for larger scale spacecraft, accounting for the unique physics occurring in physically small propulsion devices. These technologies could leverage micro-electromechanical system (MEMS) fabrication techniques, though more robust substrate materials are also sought.

Thruster Technology

Electric and chemical propulsion technologies that provide increased capability (mass and volume) and/or flexibility (duty cycle and life) for small, power-limited spacecraft, including:

- Electrostatic and electromagnetic propulsion technologies;
- High-performance (specific impulse > 250 s), high-density monopropellant thruster technology;
- High-performance (specific impulse > 350 s), space storable bipropellant thruster technology; and
- Propellant gelation technology.

Propulsion System Components

Innovative electric and chemical propulsion system components for small spacecraft are sought including:

- Materials compatible with high-temperature, oxidizing, and reactive environments;
- Components for fluid isolation, pressure and mass flow regulation, relief quick disconnect, and flow control;
- Technologies for metering, injection, and ignition of fluids in combustion devices;
- Gaseous storage and pressurization system; and
- Components for xenon storage and flow control.

E2.05 Energy Storage Technologies
Lead Center: GRC
Participating Center(s): GSFC, JPL, JSC, MSFC

Advanced energy storage technologies are required for Earth science observation platforms. These platforms are defined as host systems that include traditional spacecraft, airborne platforms, such as piloted and unpiloted aircraft and balloons, terrestrial platforms, micro-spacecraft, and surface penetrators.

The energy storage technologies solicited include both primary and secondary batteries, primary and regenerative fuel cells, and flywheels. The desired technology advances common to all of the storage devices of interest include the following elements:

- Improvements in energy density and specific energy;
- Improvement in cycle life, run time, and calendar life;
- Performance over a wide temperature range;
- Reduction in device size, to the micro-scale;
- Reduction in system complexity; and
- Integration into, and with, other spacecraft structures.

A vigorous effort is needed to develop energy storage technologies that will enable the revolutionary ES missions.

Specific technology advances that contribute to achieving the following performance goals are of interest.

Advanced Battery Technology

- Specific energy: >150 Wh/kg for secondary batteries >400 Wh/kg for primary batteries
- Low-Earth-Orbit (LEO) cycle life >60,000 cycles for secondary batteries
- Calendar life >15 years
- Operating temperature range -100°C to 100°C
  - Systems capable of delivering 30–50% of the capacity available at ambient temperatures at temperatures as low as -100°C

Primary and rechargeable lithium-based batteries with advanced anode and cathode materials and advanced liquid and polymer electrolytes are of particular interest. Proposals addressing structural and microbatteries are sought.

Fuel cell (FC) and Regenerative Fuel Cell (RFC) Technologies

- Specific energy: FC >1500 W/kg, RFC >600 Wh/kg
- Efficiency: FC>70% at 1500 W/kg, RFC >60% at 600 Wh/kg
- Life FC >10,000 hours, RFC > 1500 cycles

Advances to PEM, Direct methanol and solid oxide fuel cell systems are of particular interest.

Flywheel Energy Storage

- Specific energy > 100 Wh/kg
- LEO cycle life > 60,000 cycles

Micro-flywheels with a high number of watt hours per kilogram and highly integrated components are of particular interest.

E2.06 Energy Conversion for Space Applications
Lead Center: GRC
Participating Center(s): GSFC

Earth science observation missions will employ spacecraft, balloons, sounding rockets, surface assets, and piloted and robotic 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 characteristic of the technological challenges to be faced and are representative of the type of developments required beyond the current state-of-the-art.

The energy conversion technologies solicited include photovoltaics, Brayton, Rankine, Stirling, and thermophotovoltaic, as well as related technologies such as concentrators and thermal technologies. Specific areas of interest follow.

- Photovoltaic cell and array technologies with significant improvements in efficiencies, cost, radiation resistance, and wide operating conditions are solicited. Potential concepts include rigid arrays, concentrator configurations, and ultra-lightweight array technologies that exploit the properties of lightweight, flexible thin-film photovoltaic cells. Photovoltaic cell and array technologies for extreme environments such as high- or low-temperature operation are solicited. Technologies for electrostatically-clean spacecraft solar arrays are also of interest.
- Future micro-spacecraft require distributed power sources that are integrated with microelectronics devices/instruments. These microelectronic devices/instruments integrate energy conversion and storage into a hybrid structure.
- Thermal power conversion technologies for Earth orbiting spacecraft and/or orbit transfer vehicles are sought.
- Advances may be in solar concentrators (rigid or inflatable, primary or secondary) and receivers to improve specific power and reduce mass.
- Topics of interest in power conversion include heat cycles (Brayton, Rankine, and Stirling), compact heat exchangers, advanced materials and fabrication techniques, and control methods, as they relate to life, reliability and manufacturability.
- 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.

E2.07 Platform Power Management and Distribution
Lead Center: GRC
Participating Center(s): GSFC, JPL

Earth science missions employ spacecraft, balloons, sounding rockets, surface assets, aircraft, and marine craft as observation platforms. Advanced 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 materials, devices, components, packaging, and coatings.

Power Electronic Materials and Components
Advanced magnetic, dielectric, semiconductor, and superconductor materials, devices, and circuits are of interest. Proposals must address improvements in energy density, speed, or efficiency. Candidate devices and applications include transformers, inductors, semiconductor switches and diodes, electrostatic capacitors, current sensors, and cables.

Power Conversion, Protection, and Distribution
Technologies that provide significant improvements in mass, size, power quality, reliability, or efficiency in electrical power conversion and protective switchgear components are of interest. Candidate applications include solar array regulators, battery charge and discharge regulators, power conversion, power distribution, and fault protection.

Environmentally Durable Technologies
Technologies that enable materials, surfaces, coatings, and components to be durable in a space environment, in atomic oxygen, soft x-ray, electron, proton, ultraviolet radiation, and thermal cycling environments are of interest to NASA. Environmentally durable coatings for radiators and lightweight electromagnetic shielding are sought.

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 E3 Advanced Information Systems Technology For Earth Science

The objectives of the Advanced Information System Technology (AIST) Topic are to develop innovative technologies that enable new, or enhance existing, mission and science measurement capabilities for problems closely aligned to the NASA Earth Science Enterprise and, upon completion, provide these capabilities to the broadest set of NASA missions across the agency. The Earth Science Enterprise acquires, processes and delivers very large (gigabyte to terabyte) volumes of remote sensing and related data to public and government entities that apply this information to understand and solve problems in Earth Science. Currently, NASA's Earth Science Enterprise (ESE) operates 18 orbiting platforms with 80 sensors making scientific measurements of the complex Earth system. Information technology is currently employed throughout ESE's space and ground systems and the AIST Topic is soliciting technologies that apply to the end-to-end system functions. Target capabilities fall into five major themes: Data Collection and Handling, Transmission and Dissemination, Search, Access, Analysis and Display, and Systems Management.

Results from the AIST Topic will:
- Reduce the risk, cost, size, and development time of NASA's ESE space-based and ground-based information systems,
- Increase the accessibility and utility of Earth science data,
- Enable new Earth observation measurements and information products, and
- Develop information technologies that enable planetary scale observing systems in support of NASA's exploration and discovery vision.

E3.01 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. 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 processing large volumes of data (commonly available on the Internet) into useful information; 3) intelligent search 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;
- 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;
- Control of Field Programmable Gate-Arrays (FPGA) to provide real-time products.

E3.02 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 (which may be based on Open Grid Service Infrastructure [OGSI]) 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.
- Higher level services, including those for job management, resource brokering, workflow management, portlet (i.e., application-specific graphical user interface [GUI]) building, and collaboration. 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.
- Tools for rapidly porting and hosting science applications in a distributed environment. These applications were 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.
- Novel supercomputing approaches using FPGAs, graphics processors, and other novel architectures and technologies.

E3.03 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 application of ESE and other remote sensing data. Focus areas are to provide tools for processing, analysis, interpretation, and visualization of remotely sensed data sets. ESE benchmarks practical uses 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://earth.nasa.gov/eseapps/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 databases.

E3.04 Data Management and Visualization
Lead Center: GSFC

This subtopic focuses on innovative approaches to managing and visualizing large collections of Earth science data in a highly distributed and networked environment.

- Develop technologies that support long term data management, storage, search, and retrieval of very large, distributed, geospatial Earth science data sets, including the development of object based storage devices, file systems that promote long term data maintenance and recovery from user errors, and global compression techniques that optimize data backup operations.
- Develop techniques to manage and locate data in a distributed metadata catalog environment and provide tools to create, use, and then tear down wide area high speed Storage Area Network (SAN) access to remote data sets.
- Develop tools and techniques that enable high bandwidth scientific collaboration in a distributed environment, and allow data viewing, real-time data browse, and general purpose rendering of multivariate geospatial scientific data sets using georectification, data overlays, data reduction, and data encoding across widely differing data types and formats.
- Design and implement 3-D virtual reality environments for scientific data visualization that will enable users to 'fly' through the data space to locate specific areas of interest, and make use of novel 3-D presentation techniques which minimize or eliminate the need for special user devices such as goggles or helmets.

E3.05 Onboard Science for Decisions and Actions
Lead Center: ARC

Current sensors can collect more data than is possible to transmit to the ground for analysis. One solution is to incorporate intelligence in the sensor or platform to prioritize or summarize the data and send down high priority or synoptic 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 two 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 retargeting of sensors in response to user demand or significant events. Also included in this category is onboard processing of sensor data through the use of processing architectures and 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.

TOPIC E4 Applying Earth Science Measurements

The Earth Science Enterprise (ESE) continues to strive to better understand how the global environment is changing, predict change and understand how these changes affect the human and economic condition. In this Topic, the ESE wants innovative companies to propose technology and techniques to accomplish two goals.

1. Goal 1: Accelerate the deployment of NASA science data and understanding into existing decision support tools used by managers concerned with stewardship of the Earth's resources. This goal addresses the development of innovative technology solutions that 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 the management of land and biota, air, water, education, and emergency issues.
2. Goal 2: Inspire and motivate students to pursue careers in science, technology, engineering, and mathematics.

E4.01 Innovative Tools and Techniques Supporting the Practical Uses of Earth Science Observations
Lead Center: SSC
Participating Center(s): MSFC

Technical innovation 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://gaia.hq.nasa.gov/ese_missions/). 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 Earth Science Applications Directorate may be found at http://www.esa.ssc.nasa.gov. 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.

E4.02 Advanced Educational Processes and Tools
Lead Center: GSFC

This subtopic focuses on innovation in effective applications related to classroom- or museum-ready software tools for display and/or analysis of Earth science information for learners in both formal and informal settings, and tools for organization and dissemination of NASA's Earth science educational materials to a wide array of educational audiences. The Earth science educational program covers a wide range of audiences from students to adults in both classroom settings, such as public schools or continuing education venues, to all matter of informal learning settings such as radio, television, museums, parks, scouts, and the Internet. In these venues, the learning focuses on the scientific discoveries by the ESE, the technology innovations and the applied use of these discoveries and technologies for improved decision making by all.

The areas of interest (described below) cross-cut the three programmatic areas within the ESE program (formal, informal, and professional development) and hence, are anticipated to have utility in at least two of these areas and most likely in all three areas.

The first area of interest focuses on innovation in the application of digital library technologies to educational materials and audiences. NASA's Earth Science Education Program currently collaborates with the Digital Library for Earth System Education (DLESE). The successful proposal must be able to integrate with, or be integrated into, existing educational digital library efforts within NASA and/or make contributions to DLESE. These proposals will advance the use and usability of globally distributed, networked information resources, and encourage existing and new communities to focus on innovative applications areas. Collaboration between Earth scientists, formal or informal education community professionals, and computer scientists is required for these proposals to demonstrate useful results. Areas of interest include:

- Extend the current Joined Digital Library (JOIN) effort by developing additional Jini applications. (JOIN is a collection of tools based on Sun's Jini technology used to implement efficient, decentralized, and distributed computing systems and follows "the network is the computer" philosophy.)
- Development of formal and informal education audience-specific interfaces (e.g., specific interfaces for students, park interpreters, TV producers, curriculum developers, etc.).
- Development of interfaces to promote diversity within educational audiences (e.g., age, ethnicity, cultural, urban/rural, etc.).
- Development of accessibility tools for disabled users to interact and search digital libraries.
- Development and access to educational materials including new resources for science, mathematics, and engineering education at all levels.
- Development of interoperability tools to integrate dissimilar library archives.
- Development of tools to administer and manage end-user expectations and satisfaction.
- Develop applications that enhance the general functionality of existing digital libraries by providing new general-purpose tools for archive management, metadata ingestion, intelligent search, and retrieval.
- Tools to support online community interaction, which could include new means for gathering, interacting, and communicating with other library users.

The second area of interest focuses on innovation in effective software and related development techniques, and in highly practical methods for maintaining and disseminating software for use by educational audiences engaged in teaching or learning about Earth science. The specific areas of greatest interest are highly-portable, classroom-ready software for analysis, visualization, and processing of Earth science satellite data, and methods to provide long-term support and viability for educational software. Collaboration between Earth scientists, educators, computer scientists, and "business" model experts is required for these proposals to demonstrate useful results. Areas of interest include:

- Extend the current Image 2000 effort by developing additional plug-in applications and modifying core software if necessary. Image 2000 is a Java/Java Advanced Imaging (JAI)-based image processing package being developed at GSFC.
- User-friendly, extensible, Earth science satellite image processing software for multiple operating systems, for educational use in K–12, undergraduate and continuing education venues.
- Techniques and software for integrating vector and raster data for the visualization and analysis of geospatial Earth science data.
- Tutorials geared toward the use of image processing software for visualization and analysis of Earth science related satellite imagery.
- Infrastructure and startup of an Internet based user-supported support and development network, in the spirit of "Open-Source," to ensure continued maintenance and development of Earth science satellite image processing software and tutorials for educational audiences.

E4.03 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 technologies' 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.

9.1.4 EXPLORATION SYSTEMS

With the announcement of the Vision for U.S. Space Exploration in January 2004, NASA has formed a new Exploration Systems Enterprise that is charged with the development of systems to be used in the exploration of the Moon, Mars, and other destinations. The Exploration Systems Enterprise is responsible for developing and demonstrating the strategies and systems that will allow human and advanced robotic exploration of other worlds through the use of innovative approaches, new vehicles, and breakthrough technologies. Consistent with the National Space Exploration Policy, the NASA Strategic Plan, and the Vision for Space Exploration, the Exploration Systems Enterprise will:

Support Research at Key Research Destinations: The development of exploration strategies, systems, and technologies will be guided by requirements for conducting research at key destinations in the search for habitable environments and life. These destinations include, but are not limited to, the Moon, Mars, the moons of Jupiter and other outer planets, and deep space telescopes that will search for planets outside our solar system.

Enable Sustainable Exploration: Exploration architectures and vehicles will be developed with the goal of enabling sustainable, affordable, and flexible exploration of the solar system.

Employ Humans and Robots: Exploration Systems will design architectures and missions that use humans and robots in partnership, using the capabilities of each where most useful.

Use the Moon as a Testing Ground for Mars and Beyond: The Exploration Systems Enterprise, working with the Lunar Exploration and Mars Exploration Themes, will use robotic and human missions to further science, and to develop and test new approaches, technologies, and systems, including the use of lunar and other space resources, to support sustained human space exploration of Mars and other destinations.

The Exploration Systems Enterprise is guided by a philosophy that ensures that operators and technologists work together to enable the usage of technology research and development. Technology will be matured prior to development through performance demonstration.

http://www.nasa.gov/missions/solarsystem/explore_main.html

TOPIC X1 Self-Sufficient Space Systems 123

X1.01 *In Situ* Manufacturing 123
X1.02 *In Situ* Resource Excavation and Separation 124
X1.03 *In Situ* Resource Processing and Refining 125

TOPIC X2 Space Utilities and Power 126

X2.01 Photovoltaic Solar Power Generation 126
X2.02 Nuclear Power Generation 127
X2.03 Wireless Power Transmission 127
X2.04 Cryogenic Propellant Depots 128
X2.05 Power Management for Space Utilities 130
X2.06 Thermal Materials and Management 130
X2.07 Space Environmental Effects 131
X2.08 Energy Conversion Technologies 132

TOPIC X3 Habitation, Bioastronautics, and EVA 134

X3.01 Extravehicular Activity Systems 134
X3.02 Habitats, Habitability, and Human Factors 135

TOPIC X4 Space Assembly, Maintenance, and Servicing 137

X4.01 In-Space Assembly and Construction 137
X4.02 Self-Assembling Systems 139
X4.03 Inspection and Diagnostics 140
X4.04 Servicing, Maintenance, and Repair 141

TOPIC X5 Surface Exploration and Expeditions 142

X5.01 Mobile Surface Systems 143
X5.02 Virtual Exploration 144

TOPIC X6 Space Transportation 144

X6.01 Earth-to-Orbit Propulsion 145
X6.02 Vehicle Airframe Structures 145
X6.03 Atmospheric Maneuver and Precision Landing 147
X6.04 Vehicle Subsystems 148
X6.05 In-Space Propulsion (Chemical and Thermal) 149
X6.06 In-Space Propulsion (Electric and Magnetic) 151
X6.07 In-Space Propulsion (Nuclear) 152
X6.08 Launch Infrastructure and Operations 153
X6.09 Space Transportation Test Requirements and Instrumentation 155

TOPIC X7 Information and Communication 157

X7.01 Radio Frequency (RF) Telecommunications Systems 157
X7.02 Intelligent Onboard Systems 158
X7.03 Mission Training Systems 160
X7.04 Human Surface Systems Electronics and Communications 161

TOPIC X8 Systems Integration, Analysis, Concepts and Modeling 163

X8.01 Technology-Systems Analysis and Infrastructure Modeling 163
X8.02 Design Technologies for Entry Vehicles 164

TOPIC X1 Self-Sufficient Space Systems

The goal of this topic is to drive down the cost of human and robotic exploration missions and campaigns. This includes supporting improved health and safety for human explorers beyond Earth orbit. It also includes working with the space science community to test concepts and technologies. Specific objectives of this topic include:

1. Developing and validating the technology to use local resources, such as regolith and minerals, ices and atmosphere–in order to produce, process, and deliver consumables, including propellants–storable and cryogenic; life support and other gases; and water;
2. Fabricate key physical structural systems and elements from local materials, including radiation shielding; structural elements (e.g., trusses, panels, etc.); and mechanical spares for mission system elements;
3. Enable local fabrication of selected "finished products" and/or "end-items," including photovoltaic cells and solar arrays, wires, tubes, connectors, etc., and pressurized volumes;
4. Testing key technologies and demonstrating innovative new systems concepts in space; and
5. Establishing a foundation for profitable commercial development of space applications of these technologies in the mid- to far-term.

X1.01 *In Situ* Manufacturing
Lead Center: JSC
Participating Center(s): ARC, KSC, MSFC

The Russian Mir space station and the current International Space Station have many lessons learned that can be applied to NASA's new human exploration vision. There are two lessons, however, that cannot be ignored: launching everything you need from Earth is expensive, and no matter how much you try, things break. The purpose of this subtopic is to identify and experimentally validate *In Situ Manufacturing* capabilities that include production of sub-element and replacement components, complex products, and assemblies and machines to reduce launch costs, reduce logistics and spares concerns, and enable self-sufficiency and infrastructure growth. *In Situ Manufacturing* can use either *in situ* or Earth supplied feedstock, however the long-term goal is to exclusively use *in situ* processed feedstock. *In situ* produced feedstock will be provided by processes developed in the SBIR subtopic, X1.03 *In Situ Resource Processing & Refining*. Technical areas included in the subtopic are:

- Metallic Parts Manufacturing
- Polymer/Plastic/Composite Parts Manufacturing
- Ceramic Parts Manufacturing
- Manufacturing Support Processes

To be able to make replacement or spare parts, structures, and complex assemblies and machines, manufacturing and assembly processes are required for the different materials parts and assemblies will be made from (metal, polymer, ceramic, and composites). Non-destructive evaluation (NDE) processes are also required to verify that the parts and assemblies manufactured have the required properties, and internal quality. Metrology processes will be required to ensure that parts meet dimensional and surface finish requirements. For *in situ* manufacturing and evaluation processes to be beneficial, compared to bringing everything from Earth, it must be capable of producing 100s to 1000s of times their own mass of product in their useful lifetimes, with reasonable quality, and be able to make a wide variety of parts and assemblies of different shapes and sizes for the feedstock material selected. Proposed manufacturing and assembly processes must also be easily transportable, require the minimum of power and Earth supplied processing consumables needed to perform its function, operate in microgravity or partial-gravity environments, and require the minimum of maintenance, human supervision, crew operation, and crew training.

X1.02 *In Situ* Resource Excavation and Separation
Lead Center: JSC
Participating Center(s): ARC, KSC, MSFC

The goal of using the 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, is to achieve a reduction in launch and delivered mass for exploration missions, a reduction in mission risk and cost, and to expand the human presence in space. The purpose of this subtopic is to identify and investigate *In Situ Resource Excavation and Separation* capabilities that include resource characterization and prospecting, excavation and delivery to resource processing units, and simple extraction and separation of desired resources from the bulk resource. Extracted and separated resources from *In Situ Resource Excavation and Separation* processes are to be delivered and used in SBIR subtopic X1.03, *In Situ Resource Processing and Refining*. To be successfully implemented, *In Situ Resource Excavation and Separation* proposals must minimize the mass which must be brought from the Earth, 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 microgravity (asteroids, comets, Mars, moons, etc.) or partial-gravity (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. Technical areas included in the subtopic follow:

- Resource Assessment. This includes mineral and resource characterization, material property characterization, and physical property characterization; evaluation metrics include accuracy of element and mineral characterization and number of elements and minerals characterized.
- Lunar and Mars Regolith Excavation. Evaluation metrics include mass of resource excavated per mass of excavator, mass excavated per hour, mass excavated per power consumed, and projected Mean Time Between Repairs (MTBR).
- Hard Material and Ore Excavation. Evaluation metrics include kilograms of resource excavated per kilograms of excavator, mass excavated per hour, mass excavated per power consumed, and projected MTBR.
- Subsurface Resource Excavation. Evaluation metrics include mass of resource excavated per mass of excavator, mass excavated per hour, and projected MTBR.
- Material Surface Transport. Evaluation metrics include distance traveled per hour, mass transported versus mass of transporter, and mass transported per hour.
- Physical and Mechanical Separation Processing. Evaluation metrics include mass resource separated per day, mass separated per mass of separator, and Watts per mass of resource separated.
- Electro-Thermal Separation Processing. Evaluation metrics include mass resource separated per day, mass separated per mass of separator, and Watts per mass of resource separated.
- Mars Atmospheric or Regolith Volatile Separation & Collection. Evaluation metrics include mass resource separated per day, mass separated per mass of separator, and Watts per mass of resource separated.

Proposals of interest include:

(1) Developing 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 *in situ* manufacturing (X1.01) or *in situ* processing (X1.03).

(2) Developing 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 and volatiles, or feedstock for *in situ* processing (X1.03).

For processing concepts that can be used on robotic precursor missions, payload masses (including rovers) are typically below 300 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 and separation 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 300–2000 kg of propellant depending on the size of the same and whether the mission is a Mars orbit rendezvous or direct Earth return mission. Mars mission surface durations are 30–90 days for opposition class missions and 450–600 days for conjunction class missions. Mars human ascent vehicles typically require 20,000–30,000 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 500 W to 1 kW of power/hour, unpressurized rovers can require 3–6 kW of power/hour and pressurized rovers can require 10 kW/hour and above.

X1.03 *In Situ* Resource Processing and Refining
Lead Center: JSC
Participating Center(s): ARC, KSC, MSFC

The goal of *In Situ* Resource Utilization (ISRU) is to utilize resources that are available at the site of exploration, pursuing the philosophy of "make what you need where you need it" instead of bringing it all the way from Earth, with the intent of achieving a reduction of mass requirements for exploration missions, a reduction in mission risk and cost, and expanded human presence in space. The purpose of this subtopic is to identify and experimentally validate single and multistep *In Situ Resource Processing and Refining* processes that have the potential for achieving the goal of ISRU. Such processes may include thermal, chemical, and electrical processing of extracted resources into useful products. *In Situ Resource Processing and Refining* includes efficient and economical production of propellants, mission critical consumables, life support gases and water, and feedstock (such as silicon, aluminum, iron, and polymers) for use in *In Situ Manufacturing* (X1.01), from resources that have been extracted and separated using processes defined and developed under *In Situ Resource Excavation & Separation* (X1.02). To be successfully implemented, *In Situ Resource Processing & 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. In addition, the maintenance, human supervision, crew operation, and crew training required for process operation must be minimal and affordable. Technical areas included in the subtopic are:

- Mineral Processing To Extract Oxygen and Feedstock For *In Situ* Manufacturing
- Water and Carbon Dioxide Processing To Produce Oxygen and Fuels
- Hydrocarbon, Plastic, and Polymer Production
- *In Situ* Bio-Support Processing, including agricultural chemical, mineral extraction for fertilizer products, processed regolith for plant soil, food supplements, etc.

Process evaluation metrics include mass of product made per hour, final mass of product per mass of processor, Watts per mass of resource processed per hour, percentage conversion of resources into product in a single pass, and mass of Earth consumables used per mass of *in situ* product made.

Proposals of interest include:

(1) Developing 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; and

(2) Developing 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.

For processing concepts that can be used on robotic precursor missions, payload masses (including rovers) are typically below 300 kg. Robotic precursor concepts must demonstrate critical functions and must be scalable to human mission needs. Mars sample return missions that incorporate *in situ* propellant production require 300–2000 kg of propellant depending on the size of the same 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/hr in habitats and 0.1 kg/person/hr for Extra-Vehicular Activities (EVAs). Early human lunar mission surface durations may vary from 3–45 days and can include from 2–6 crewmembers. Lunar human landers require approximately 5000–8000 kg of propellant for ascent and approximately 15,000–25,000 kg for landing and ascent combined. Mars mission surface durations are 30–90 days for opposition class missions and 450–600 days for conjunction class missions. Mars human ascent vehicles typically require 20,000–30,000 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 3–6 kW of power/hour and pressurized rovers can require 10 kW/hour and above.

TOPIC X2 Space Utilities and Power

This topic covers utilities and power for space vehicles and off-Earth surface sites. NASA is planning robotic exploration of the moon with a return of humans between 2015-2020. The human return does not mean the robotic effort comes to a halt, but, instead, robotic interfaces will further evolve with the additional need for the utilities and power elements to suit people. The objectives of this topic is to identify and develop breakthrough technologies that have broad potential across many types of systems, to provide increased scientific return at lower cost, and to enable missions and capabilities beyond current horizons.

X2.01 Photovoltaic Solar Power Generation
Lead Center: GRC

Research and technology development and/or demonstrations are needed that lead to significant improvements in performance over current photovoltaic systems or enable new operational capabilities for exploration missions. Examples of such include, but are not limited to, dramatic increases in array specific power, operational array voltages approaching 1000V, arrays capable of long-term operation in high radiation environments, arrays having very small stowed volume, surface array concepts using automated deployment systems, and arrays capable of sustained operation under various planetary surface environments. Concepts are sought with power levels in the 10–100 kW range, which could be available for use within 10 years. Research and technology developments are also needed that involve nanostructures for photovoltaics (inorganic/organic, III-V, thin film, thermo-photovoltaics including uses of carbon nanotubes, quantum dots, microcrystalline interfaces, etc.).

Proposal efforts for photovoltaic cells and solar arrays could include technology development, validation, and demonstrations in the areas of innovative solar cells with efficiencies above 35%, photovoltaic devices capable of sustained operation under various environmental extremes (high and low temperatures, high radiation environments, space plasma environments that could lead to arcing, high dust environments, etc.), solar array blanket technology, and unique array designs and deployment schemes. Cell and blanket technology should have the potential for significant cost reduction compared to state-of-the-art space-qualified arrays. Other areas include demonstration of high efficiency, lightweight concentrator cell and array designs, advanced concentrator concepts (up to 100 times concentration), multiquantum well and multiquantum dot devices, and advanced multiband gap schemes.

X2.02 Nuclear Power Generation
Lead Center: GRC

NASA is interested in the development of highly advanced systems, subsystems, and components for use with both nuclear reactors and radioisotopes for future lunar and Mars robotic and manned missions. Anticipated power levels range from 100s of watts to multi-megawatts.

In-space applications include power for primary electric propulsion, crew planetary transfer habitation module, vehicle housekeeping, cryogenic propellant maintenance, orbiting power station, and science payloads. For planetary surface applications, habitats; resource processing and propellant production, liquefaction and maintenance; surface mobility for both robotic and piloted rovers; excavating and mining equipment; atmospheric mobility (airplanes, blimps, etc.) are needed. For science applications, deep drilling, resource production demos, rovers, weather stations, etc. are needed; and for surface robotic outpost as a precursor to human exploration and extended stay human bases (50–500 days).

Major technologies being pursued are:

- High efficiency power conversion >20%, 2 kWe to MWe unit size;
- Low mass thermal management (radiators)< 6 kg/m^2; and
- Electrical power management, control and distribution. >1000 V, in the kWe to multi-megawatt range.

Supporting technology includes:

- High temperature materials and coatings >1300 K;
- Deployment systems for radiators, surface mobility for remote emplacement of power systems (teleoperated, telesupervised or autonomous);
- Systems and technologies to mitigate planetary surface environments–dust accumulation, wind, planetary atmospheres, (CO_2, corrosive agents, etc.);
- Power system design considerations for long life (> 10 years), autonomous control, and operation; and
- Radiation tolerant systems and materials.

In addition to reducing overall system mass, volume and cost, increased safety and reliability are of extreme importance. It is envisioned that these technologies will be used on robotic and human missions and it is to NASA's advantage to develop those technologies that transcend robotic to human mission requirements with a minimum of redesign. Technologies that enable challenging missions such as, electric power production for bimodal nuclear thermal propulsion, nuclear electric propulsion, planetary surface power, 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.

X2.03 Wireless Power Transmission
Lead Center: MSFC

The focus of this activity is to conduct research for Space Solar Power (SSP) 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. Within the roadmap of SSP WPT 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 program 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.

Innovative concepts for integrated power and communication transmission in space are also solicited. Concepts that use a single laser beam to carry both high power and information packets are of interest. Challenges include separation of unmodulated power from modulated power, bandwidth issues, pulsed versus continuous power beaming, etc. Configurations of interest include space-based laser transmitters that operate simultaneously for both power and communications using the same system, or are highly integrated into units suitable for space testing and use. Dual-use configurations of receiver systems for both power and communications are also of interest.

Innovative technology elements of interest include the following:

- High-efficiency WPT transmitting elements or “beamers” that could include microwave converters which are greater than 85% efficient and lasers that are greater than 65% efficient;
- High-efficiency WPT receivers that could include band gap matched photovoltaics which are greater than 65% efficient or rectenna EMC filters with less than 0.25 dB insertion loss;
- Efficient and low mass retrodirective laser or microwave systems;
- Lightweight and long-lifetime thermal control architectures for transmitting and receiving elements;
- High efficiency conversion of RF-to-DC or light-to-DC;
- Array of laser diodes fed through fiber optics (phased array) to effect beam pointing and focusing without additional losses;
- Fiber lasers in wavelengths to allow improvements in efficiency;
- Laser technology scalable to high power in an affordable robust low mass structure suitable for the space environment;
- Innovative alternative concepts such as solar pumped lasers and reflectors;
- Beamed power safety systems;
- Concentration of incident sunlight in space to 104–106 Suns;
- Relay stations, if any;
- Receiving stations;
- Distribution systems;
- Thermal management;
- Interference;
- Power management and distribution;
- Laser design;
- Laser beam director;
- Laser pointing and tracking;
- Laser adaptive optics; and
- Systems integration.

X2.04 Cryogenic Propellant Depots
Lead Center: MSFC
Participating Center(s): GRC, JSC, KSC

The focus of this subtopic is to develop and advance enabling technologies required to build and operate an in-space cryogenic propellant depot with the capability to preposition, store, manufacture, and later use the propellants for Earth–Neighborhood campaigns and beyond. In-Space cryogenic or gel propellant production and/or storage technology is quite unique in that it has been studied in detail but little research has been accomplished in space, where the effects of low gravity come into play. The in-space propellant depot will provide affordable propellants and similar consumables to support the development of sustainable and affordable exploration strategies as well as commercial space activities. An in-space propellant depot not only requires technology development in key areas such as cryogenic or gel storage, electrolysis, and fluid transfer, but in other areas such as lightweight structures, highly reliable connectors, and autonomous operations. These technologies can be applicable to a broad range of propellant depot concepts or specific to a certain design. In addition, these technologies are required for spacecraft and orbit transfer vehicle propulsion and power systems, and space station life support. Generally, applications of this technology require long-term storage (>30 days), on-orbit fluid transfer and supply, cryogenic propellant production from water, and unique instrumentation. Components or concept proposals for intelligent modular systems are being solicited to improve the performance, operating efficiency, safety and reliability of cryogenic fluid production, storage, transfer, and handling in a low gravity (10^{-6} g to 10^{-2} g) environment. Specific areas of interest include the following:

- Electrolysis system that manufactures cryogenic propellants from water or ice in a low gravity environment. This system should incorporate innovative techniques and components to provide an automated, safe, and highly reliable process.
- Water storage and transfer interface such as a bladder positive-expulsion system or other innovative techniques.
- Innovative techniques for cryogen storage and transfer.
- Reliable and safe cryogenic storage for extended periods of time. This includes zero boil-off systems, advanced insulations, and thermal control techniques such as vapor cooled shielding, systems using the boil-off for drag make-up and innovative tank designs.
- Automated assembly, operations, and maintenance. This includes cryogenic connects, disconnects and couplings; robotic assembly and repair; docking of large components; and health monitoring and smart systems.
- Lightweight structures including inflatables, deployables, and advanced composites.
- Suitability of propellant gelation to enhance propellant depot operations.
- Micrometeoroid and space debris protection schemes and associated technologies including advanced lightweight materials, self-healing, integration with other structures and tankage, and possible avoidance techniques.
- Associated propellant tank-set technologies including fluid slosh and orientation in low gravity environments, tank support structure dynamic interaction in orbit, support struts thermal performance, integrated insulation, instrumentation and plumbing penetrations, and coating degradation.
- Schemes for warm tank chill-down including spray nozzle configurations, liquid flow rate and duration, number of gas venting steps, and performance in a low gravity environment.
- Stratification and hot spot management including mixing needs, mixing strategies and performance determination in low gravity environments.
- Low gravity performance and operating life determination of key components such as the liquid pumps, condensers, pressurization, liquid acquisition device, refrigerator, and mass gauging instrumentation.
- Low heat leak valves and lines that are highly reliable with long life.
- Connects and disconnects with small or no fluid and heat leakage. The connects and disconnects should also have small pressure drops, small force and alignment requirements, and long life with high reliability.
- Procedure for the capability for a no-vent fill with consideration given to microgravity condensation and fluid mixing.
- Devices for vapor free acquisition of cryogenic liquids or liquid free venting in a microgravity environment.
- Cryocooler systems with cooling capacity greater than 10 W in the 10–40K range.
- Small and medium scale tank pressure control and/or tank boil-off control technologies for long-term storage of liquid hydrogen in space.
- Instrumentation for monitoring cryogens in low gravity including mass gauging, liquid-vapor sensing, and free surface imaging.

Several options are available to test the technology needed for propellant depots. Technologies can be tested in the laboratory, on Expendable Launch Vehicles, the Space Shuttle, the ISS, a Small Scale Depot, or a Full Scale Depot. Laboratory testing can use sub- or full-scale tank sets for tests carried out on components, subsystems, and integrated systems on the ground. Identified improvements can be incorporated into subsequent tank sets, which may be used on the ground or in orbital tests. In some cases, a "proto-flight" approach may be used, where the original ground-test tank set can potentially be modified for subsequent testing on-orbit. For example, test requirements may be addressed by building a subscale experiment, which simulates the hydrogen fluid systems of the storage facility, evaluating their performance in a vacuum chamber, and then demonstrating microgravity fluid transfer by performing an orbital experiment.

X2.05 Power Management for Space Utilities
Lead Center: GRC
Participating Center(s): GSFC, JSC

Advanced power management and distribution technologies are required for manned and unmanned space exploration vehicles, orbiting assets, and surface platforms. Technologies are sought that improve the size, mass, capacity, durability, reliability, modularity, and costs of the electrical power distribution system. Advancements are sought in three areas: advanced materials and devices, modular power electronic components and systems, and intelligent power systems.

Power Electronic Materials and Devices
Advancements are sought that improve the performance of power electronic devices in applications exceeding 100V. Improvements in performance are especially sought in high operating temperatures (over 200°C) and radiation tolerance (>200 krad total dose and >50 MeV LET). Proposals should focus research on developing new materials, devices, manufacturing, and/or packaging technologies to meet these requirements. Candidate applications include transformers, inductors, motors, semiconductor switches and diodes, electrostatic capacitors, current sensors, or cables.

Modular Power Electronic Components and Systems
Technologies are sought that will enable power electronic components to function as building block modules and operate in a variety of applications and missions. Candidate applications include energy source regulation, energy storage regulation, power conversion, motor drives, and protective switchgear for power systems above 100 V (AC or DC distribution) and power levels above 1 kW. Proposals should focus research on developing modular interfaces between components, including electrical interfaces, mechanical interfaces, control, and/or communications. Examples of modular technologies include series operation for increased voltage, parallel operation for increased current, efficiency optimization, active health management, and modular packaging that enables "hot-swap" maintenance. It is greatly desired that proposed technologies be entirely free of any centralized controller or sensor for increased fault tolerance.

Modular power system technologies are also sought which enable large power systems to be built from smaller, independent power systems. Of particular interest are proposals that research highly fault-tolerant distribution architectures, structural cables and connectors, and technologies that allow multiple power systems to collaborate and share resources.

Intelligent Power Systems
Technologies that improve the reliability and safety of electrical power systems are sought. To increase the reliability of long duration manned missions, technologies that enable space power systems to autonomously reconfigure following a failure, or in response to degraded system performance, are sought. Technologies that can detect 95% of hidden electrical faults (arcing, leakage, and/or corona) are desired to improve system safety. Finally, technologies and methods for detecting power electronic degradation and determining component and system health are required.

X2.06 Thermal Materials and Management
Lead Center: JSC
Participating Center(s): ARC, GSFC, KSC, MSFC

Advanced thermal materials and thermal management techniques are needed in a wide range of operating conditions that may be addressed across the low, intermediate, and high temperature regimes. Metals, ceramics, polymers, and composites can be synthesized to address a variety of needs: thermal protection system (TPS) materials for reentry, coatings for on-orbit thermal control, improved thermal interfaces, high thermal conductivity fabrics, and methods to enhance active thermal control systems' heat acquisition, transport, and rejection. By increasing efficiency and reducing the complexity of thermal control systems, dramatic reductions in vehicle mass can be achieved.

Proposals should be particularly innovative, advance the state-of-the-art, and demonstrate a high degree of maturity in consideration of materials characterization, testing, and reliability. Materials proposed should be designed to significantly outperform existing materials systems. Materials developed for high temperature applications should show realistic promise for resilience and durability that such materials are likely to experience in reentry environments. Special consideration will be given to proposals that take a nanoscale approach to developing these materials.

A primary goal of this subtopic is to provide advanced thermal system technologies, which are highly reliable and possess low mass, size, and power requirements (i.e., reduced cost). In addition to those mentioned above, innovations are solicited in the thermal control field. Areas of interest in passive thermal control include heat pipes or thermally conductive fabrics using high thermal conductivity fibers or nanofibers. Innovations are sought in active thermal control in the areas of heat pumps capable of acquiring waste heat at near 273 K and rejecting the heat above 300 K, cabin dehumidification and temperature control technology, multifluid evaporative heat rejection devices, and robust quick disconnect fittings. Radiator designs are also sought for orbital vehicles that will survive the high temperatures of re-entry (~200–600°F). Innovations may include high temperature materials, high temperature or easily reapplied coatings, and thermal diodes to prevent fluid overpressure.

X2.07 Space Environmental Effects
Lead Center: KSC
Participating Center(s): ARC, GSFC

This subtopic is soliciting proposals for space environmental effects with emphasis on the development of materials and equipment for spacecraft and space habitats either robotic or human. Space Environmental Effects encompasses all effects of the Space Environment on spacecraft design, performance, launch, and operation. Among the environments considered are meteoroids and debris, ionizing radiation, spacecraft charging and plasma interactions, material interactions, dusty planetary surfaces, and Low Earth Orbit (LEO)-specific environments (such as atomic oxygen and atmospheric drag), as well as the synergistic effects of the different environments. We are looking for radiation protection to 200 krads total dose and operation in environments ranging from 1×10^{-12} torr to 7-torr dusty CO_2 atmospheres with dust particle sizes in the 1–10 µm range and particle velocities reaching 30 m/s. We are interested in materials and equipment that are able to withstand temperatures ranging from -193°C to 130°C, collisions with micrometer-to-millimeter size micrometeorites and fragmented space debris moving at velocities from 5–70 km/s. Full sun effects are expected to last for 17 day and night cycles.

We are interested in theoretical models, tools, ground-based environmental simulations, and space flight experiments to determine the effects of space environments on spacecraft flying through them. From these models, we should be able to derive effects on semiconductors, material degradation, and shielding effectiveness. We are looking for proposals that will develop proof-of-concept demonstrations of mitigation techniques of the deleterious effects of the space environment, such as special coatings, processes, designs, or materials hardened-by-design.

We are looking for proposals to develop screening, shielding concepts, component selection techniques, and/or manufacturing processes that will make it possible to cope with the radiation effects in the space environment.

We are looking for proposals for the development of clear antistatic coatings that can withstand exposure to the rigors of the space environment as well as for the development of adhesives which would allow the application of these coatings to flexible and rigid materials used in space suits, planetary landers and rovers, and in the instrumentation on board these craft.

We are looking for proposals that will develop techniques to modify the electrostatic properties of several polymers used in space applications that have long charge decay times. The modifications should result in charge dissipation times short enough to enable the reclassification of these polymers as statically dissipative instead of electrically insulating. These modifications should not change the physical and chemical properties that make these polymers usable for space applications. Proposals for the development of instrumentation or techniques to monitor electro-static fields remotely are also needed. These instruments should operate inside spacecraft and space habitats at distances ranging from a few centimeters to several meters and work at relative humidities ranging from 0%–70%. Similar instruments that operate outside closed environments on planetary surfaces, at larger distances (in the meter to kilometer range) are desired.

We are looking for proposals that will develop techniques to prevent the accumulation of dust on surfaces of structures, spacesuits, landers, rovers, and habitats exposed to the dusty environments of Mars and the Moon. These techniques should require low power and be lightweight.

X2.08 Energy Conversion Technologies
Lead Center: GRC
Participating Center(s): GSFC

Over the next three decades, NASA will send robotic probes to explore our solar system, including the Moon, Mars, the moons of Jupiter and other outer planets, and will launch new space telescopes to search for planets beyond our solar system. To support these missions, a number of key building blocks are necessary. One of these building blocks includes new capabilities in power, power management and distribution, and related thermal management. A vigorous effort is needed to develop revolutionary energy conversion technologies that will enable the Agency's "Vision For Space Exploration." Technological challenges to be faced include:

- Exploiting innovative technological opportunities;
- Developing power systems for adverse environments, i.e., high radiation (Electrons from 100 KeV to 500 MeV and protons from 100 KeV to 1000 MeV at fluencies appropriate for Earth and Jupiter), UV and VUV radiation, and high, wide, and low temperature swings (40–500K) depending on flight path; and
- Implementing system wide techniques that maximize efficiency, power density, reliability, safety, lifetime, operating temperature range, and radiation hardness, while minimizing mass, volume, cost, deployment complexity and thermal requirements.

These characteristics are representative of the type of developments required beyond the current state-of-the-art. The energy conversion technologies solicited apply to solar and nuclear sources with application to space transportation vehicles, planetary orbiting satellites, and planetary surface systems including probes, rovers, and stationary systems.

The energy conversion technologies solicited include the following:

Thermoelectric Conversion
Thermal-to-electric conversion is Carnot limited but considering the large temperature gradients typically available for space power systems, theory predicts that conversion efficiencies > 50% should be achievable. Efficient power generation (>20%) using thermoelectrics requires revolutionary advances in materials to achieve ZT values (the thermoelectric figure of merit) larger than 2 over a wide temperature range. Advances in bulk and thin-film complex engineered material structures which can eventually be applied to practical, scalable, and efficient devices are actively sought.

Acousto-Electric Conversion
Technology developments are needed that would convert acoustical or vibrational energy to usable electrical power for local activation of sensors, data processing, and telemetry circuits or devices.

MHD and Related Conversion
Development of technology that would provide electrical power from MHD, and/or provide super-conductor magnetic energy storage and/or flywheel (mechanical energy storage) for lunar systems in the 5000 W range for 120–336 hours (5–14 Earth days). Also being sought are hybrid energy storage systems with multifunctional capability or with reusable capability from spacecraft to depot to buoy to rover.

Conductors and Converters
This area seeks the development of innovative conductor technologies including power in structure, programmable/reconfigurable power and structure, and connector technology to accommodate reconfigurable power in structure implementations. This topic also includes the development of smart connector and wire technologies to detect and mitigate potential problems with mechanical continuity, corona onset, etc. Converter technologies include the development of wide temperature power processors using unique materials to accommodate harsh environments such as high radiation, high and low temperatures, etc.

Thermodynamic Conversion
This area seeks technology development for thermodynamic energy conversion to supply useable electric power for a range of applications that could include local power for small sensors, or higher power for distribution. The power range of interest is from single watts to thousands of watts. Of particular interest is the low mass, high efficiency, wide operating range, and other features that have a positive impact on system level performance.

Electrochemical Conversion
This area seeks revolutionary ultra-capacitor developments and/or applications for board level integration to provide added control redundancy and communications and locations power for rovers and fixed buoy applications. This includes microbattery power supplies and converter technologies.

Bio-Chemical Conversion
This area seeks revolutionary research and technology developments that provide advanced systems for conversion of bio-fuels or bio-wastes into energy and useful products, e.g., water, fuel, oxygen, and plant nutrients. Technologies can involve biological, thermo-chemical, or hybrid systems. Inherent system reliability, low maintenance, and limited waste (including heat) rejection are system parameters that should be considered in the technology design.

Micro- and Meso-Thermal/Chemical Process Technologies
This area seeks revolutionary research and technology developments that will enable thermal and chemical processes necessary for energy conversion to occur at micro- and meso-scales compared to today's technology.

Thermal and Chemical Modeling and Tools
This area encompasses a number of different thrusts related to developing state-of-the-art tools for evaluating performance and capabilities of not only advanced power systems, but also other passive and active thermal/fluid/chemical transport applications. Two specific needs include the following: (1) develop an innovative thermodynamic properties model that focuses on multiple phases (gas, liquid, solid, etc.) of metals for the purpose of transport modeling of advanced liquid-metal-based power conversion cycles and propulsion concepts; and (2) develop an integrated computational fluid dynamic analysis computer program composed of a system level network thermo-fluid analysis program and a Navier-Stokes based CFD program to combine the strengths of both in order to analyze complex flow phenomena over a number of components integrated into a system model.

In addition, electrical and structural effects are important and technology that includes the interplay among thermal/chemical/electrical/structural disciplines is highly desired.

Responses to this solicitation should address the current state-of-the-art showing the relative revolutionary improvements and capabilities of the proposed technologies.

TOPIC X3 Habitation, Bioastronautics, and EVA

The goal of this topic is to assure robust and reliable capabilities to support the health and safety of human explorers during long-duration space missions. In addition, it is the goal of this topic to drive down the cost of human exploration missions and campaigns beyond Earth orbit and to develop and demonstrate critically-needed capabilities for human activities in space. Some selected objectives of this topic include 1) developing innovative, affordable, and highly operable new technologies for extravehicular activity (EVA) systems and advanced space habitation systems; and 2) establishing a foundation for profitable commercial development of space applications of these technologies in the mid- to long-term.

X3.01 Extravehicular Activity Systems
Lead Center: JSC

Advanced extravehicular activity (EVA) systems are necessary for the successful support of future human space missions. 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, and operating lifetime (before resupply, recharge and maintenance, or replacement is necessary); reduced hardware and software costs; increased human comfort; and less-restrictive work performance capability in the space environment, in hazardous ground-level contaminated atmospheres, or in extreme ambient thermal environments. All proposed Phase I research must lead to specific Phase-II experimental development that could be integrated into a functional EVA system. Additional design information on advanced EVA systems can be found in the EVA Technology Roadmap of the EVA Project Plan. Areas in which innovations are solicited include the following:

Environmental Protection
- Radiation protection technologies that protect the suited crewmember from radiation particles;
- Puncture protection technologies that provide self-sealing capabilities when a puncture occurs and minimizes punctures and cuts from sharp objects;
- Dust and abrasion protection materials to exclude dust and withstand abrasion; and
- Thermal insulation suitable for use in vacuum and low ambient pressure.

EVA Mobility
- Space suit low profile bearings that maximizes rotation which is necessary for partial gravity mobility requirements and is also lightweight and low cost.

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;
- Convection and freezable radiators that will be low cost and weight for thermal control;
- Innovative garments that provide direct thermal control to crewmember;
- High reliability pumps and fans that will 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 conductance flexible suit garment that can function as a radiator for high metabolic loads and as an insulator for low metabolic loads.

Sensors, Communications, and Cameras

- Space suit mounted displays for use both inside and outside the space suit–outside mounted displays will be compatible with space;
- CO_2, bio-med, and core temperature sensors with reduced size, lightweight, increased reliability, and packaging flexibility;
- Visual camera that provides excellent environment awareness for crewmembers and the public and are integratable into a spacesuit that is lightweight and low power;
- Minimass spectrometer that detects N_2, CO_2, NH_4, O_2, and hydrazine partial pressures; and
- Radio and laser communications that provides good communications among the crew and the base that is lightweight and low power.

Integration

- Robotics interfaces that permit autonomous robot control by voice control via EVA;
- Minimum gas loss airlock 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 and extensions.

X3.02 Habitats, Habitability, and Human Factors
Lead Center: JSC

Advanced Habitation Systems

Advanced habitation systems include the overall habitat system and its crew supporting habitability functions within. Habitability systems technologies are being sought to enable Human Exploration and Development of Space Enterprise future orbital, planetary, and deep space applications. Space Station and planetary habitation and habitability systems in areas such as crew work, food, hygiene, rest, logistics, maintenance, and repair systems are being sought out for innovative solutions with regard to reliability, durability, repairability, radiation protection, packaging efficiency, and life-cycle cost effectiveness. Integration of workstations, integrated sensors, circuitry, automated components, integrated outfitting and advanced work station evolution to aid and enable the crew to work autonomously are considered necessary for advanced habitation. Development in crew food systems in the areas of foot heating, preparation, dining, water heating, chilling and dispensing, and trash management enable a cohesive habitable environment for the crew. Technology development in crew hygiene systems such as waste collection, personal hygiene, multi-use equipment, and hygiene evolution enables a habitable environment for the crew.

The Space Station and Crew Exploration Vehicle are of most interest and consideration of flight-testing in space should be considered. Exploration missions such as the Moon, Mars, and planetary transit are of particular interest. Areas in which advanced habitability system innovations are solicited include the following technologies for use in space (zero gravity) and/or planetary surfaces:

Advanced Habitability Systems

Crew Food Systems: Create food systems to package, preserve quality food and lightweight, low power, food preparation systems to support on-orbit crew meal storage, preparation, and dining activities.

Food Heating Systems: Create low power food heating systems to support crew food preparation activities; conduction, convection, microwave, or advanced heating technologies may be considered.

Water Dispensing Systems: Create low power systems that chill, heat, and dispense potable water, which support crew food preparation activities.

Wardroom: Create a wardroom system using deployable or erectable systems, which support crew rest-and-relaxation activities.

Trash Management Systems: Recycling technologies, and dual use technologies.

Crew Hygiene Systems: Create crew hygiene systems that are lightweight, low power, low volume systems to support on-orbit and planetary crew waste and hygiene activities. Create lightweight, low power and low volume technologies for waste collection, gas and liquid separation and urine separation. Create new and/or advanced technologies for crew hygiene, no-rinse hygiene products, and non-foaming gas/liquid separation (technologies which handle soaps). Integrated systems and outfitting: Create new and/or advanced approaches to integrating crew hygiene systems and products into the Space Station, crew exploration vehicle, and planetary vehicles and facilities. Create new approaches to outfitting the Space Station, crew exploration vehicle, and planetary vehicles to accommodate crew hygiene.

Crew Rest Systems: Create crew rest systems that are lightweight, low power, low volume systems to support orbit and planetary sleeping and privacy activities. Create new technologies and/or approaches with regard to the design and implementation of crew quarters, radiation protection, acoustic and noise control, quiet air ventilation, crew relaxation and recreation, and interactive audiovisual systems. Integrated systems and outfitting: Create new technologies and/or approaches to integrating crew rest systems into the Space Station, crew exploration vehicle, and planetary vehicles and facilities. Create new approaches to outfitting the Space Station, crew exploration vehicle, and planetary vehicles to accommodate crew rest and privacy.

Airlock Systems
Create airlock systems that are low power and minimum gas loss during operations. Create new technologies with regard to long life and replaceable seals. Create new technologies with regard to low power, long life, and replaceable pumps. Create new approaches to hatch mechanisms for minimum effect to airlock volume during opening and closing.

Tools for Integrated Testing for Human Exploration Missions
Future human exploration missions in space will be increasingly complex. In order to carry out these challenging missions, systems engineering and integration activities must be efficient and demonstrated. It will, therefore, be necessary to perform large-scale integrated tests on the ground before undertaking the actual missions.

Integrated ground tests for human exploration missions will provide a test bed not only for hardware, but also for development of requirements, hardware acquisition strategies, novel system concepts, and management. These must all result in systems that are increasingly self-sufficient and sustainable in order to leave Earth for longer periods of time. This subtopic focuses on tools that help technology developers, mission planners, and eventually astronauts to accomplish their various tasks in more efficient and synergistic ways. By developing these tools and using them in ground test beds, they will then be ready for use in the complex human exploration missions of the future.

Specific items solicited for integrated testing of human missions include:

- Tools which help develop, flow down, and verify mission requirements at various levels;
- Novel hardware acquisition strategies for incremental missions;
- Techniques that improve real-time analysis and help minimize the time between integrated tests;
- Novel system concepts for highly integrated systems that result in much lower mass, power, and volume of hardware and consumables;
- Sustainability technologies that capitalize on terrestrial dual-use of the technology to improve development time and support for research and development;
- Novel management techniques for planning, scheduling, and conducting complex integrated mission simulations;

- Tools to develop system level mathematical models of missions and tests that are more intuitive and easier to use than existing ones;
- Computer-based tools that can be used to perform real-time test or mission analysis;
- Systems engineering and analysis tools that make mission architecture studies faster to perform and easier to conduct and communicate; and
- Tools that improve the efficiency and cost effectiveness of integrated testing with humans.

TOPIC X4 Space Assembly, Maintenance, and Servicing

The goal of the space assembly, maintenance and servicing topic is to enable a much more robust set of options for affordable implementation of ambitious new modular space exploration systems and missions, and means to drive down the cost of human exploration missions and campaigns beyond low Earth orbit. The objectives of this topic include:

1. Developing and validating technologies for the space assembly of large systems – including both science mission systems (e.g., observatories) and human operational systems;
2. Enabling autonomous and/or telepresence systems inspection;
3. Advancing remote or shared control of these capabilities in near-Earth and interplanetary space;
4. Developing and validating the capability to extend the life and reduce the costs if a new generation of space systems through repair, refueling, upgrades and re-use of components from one system to another;
5. Minimizing the effect of space system failures by enabling easy access for repair – thus reducing system-level functional redundancy (and associated costs);
6. Enabling a reduction in the total mass launched to orbit for given mission architectures;
7. Increasing the performance, autonomy, reliability and reduce the cost of performing Guidance, Navigation and Control (GN&C) for space missions; and
8. Establishing a foundation for profitable commercial development of space applications of these technologies in the mid- to long-term.

The space program can enrich society by directly enhancing the quality of education and providing many tangible benefits for Americans, as well as benefiting people the world over in their everyday lives. A goal of NASA is, therefore, to share the experience, the excitement of discovery, and the benefits of human space flight with all.

X4.01 In-Space Assembly and Construction
Lead Center: JSC
Participating Center(s): ARC

This subtopic seeks innovative technologies that improve robotic joints, actuators, end-effectors, mobility devices and mechanisms for on-orbit aid to human explorers. Proposals should address how to resolve issues associated with:

- Material and component compatibility within the intended operating environment
- Reduction in mass without compromising material strength
- Design modularity to accommodate multiple tasks
- Design flexibility to assure extended useful lifetime through mechanism upgrades
- Design simplicity to facilitate easy repair

Specific areas of interest include the following:

1. Technologies or systems that provide a reduction to the weight and or volume of robotic systems such as:
   - Reduced scale (<50 in^3) high power-to-weight ratio (actuator output force >25:1) gripping actuators.

- Miniaturized (<0.1 in^3) actuator control and drive electronics.
- Miniaturized (<0.025 in^3) sensing systems for manipulator position, rate, acceleration, force, and torque.

2. Robotic systems that can grapple, manipulate, and operate existing Extra-Vehicular Activity (EVA) tools while maintaining a small, human-sized form factor.

3. Compact (<4 ft^3), low power (<1 kW peak draw and < 500 W average continuous draw) devices for site setup and preparation for human presence on orbit. Examples include site clearing and setup devices, equipment deployment and retrieval devices, and the actuation components for these devices.

Proposals are solicited for innovative, integrated, sensor concepts that serve to maximize functionality, minimize weight, size, cost and failure probability, or increase mission performance or versatility of Extra-Vehicular Robots (EVR). Categories of EVR include, but are not limited to, free-flyers for external inspection of manned spacecraft and humanoid robots for external servicing of manned spacecraft.

A free-flying, remotely controlled imaging platform capable of transmitting images to its operator could provide images on demand of the exterior of the Space Shuttle, the International Space Station (ISS) or a future Space Solar Power (SSP) Satellite to inspect for damage, plan or supervise repair work, etc. Technology needs include:

- Model-based landmark navigation to allow a free-flying camera platform to find its way around the outside of the ISS without requiring expensive external beacons, including the ability to update the model (space station for example) as it changes.
- Machine vision techniques, including construction of image mosaics, for detection of unspecified changes in objects being inspected under diverse or changing lighting or viewing conditions.
- Sensing to minimize the risk of collision between the imaging vehicle and target vehicles, such as:
    - Small (<0.2 in^3 volume), lower power (<0.05 W), range/range-rate sensor
    - Small (<0.2 in^3 volume), lower power (<0.1 W) "ranging" sensor that produces a depth map of the scene
- System on a Chip (SOC) imager that captures infrared (IR) images of a scene

A humanoid robot designed to have the dexterity of a space-suited astronaut would be capable of operating tools and performing repairs on a manned spacecraft that was originally designed for human operation. Specific technology needs include:

- Miniature (<0.05 in^2 sensor area) robust sensor material for measuring position or strain.
- Sensors with integrated multiplexing to reduce wire count.
- Sensor material must be space qualifiable for temperature extremes and outgassing.

An effective human/robotic interface enables humans and computers to seamlessly control anthropomorphic robotic systems. Proposals are sought that improve the robotic teleoperator's efficiency through advanced display systems, haptic feedback systems and telepresence control interfaces. Specific technology requirements include the following:

- Unencumbering, lightweight (<5 lbs) teleoperator-worn tactile and force feedback devices that provide operator awareness of manipulator and payload inertia, gripping force, and forces and moments due to the robot's contact with external objects.
- Innovative miniaturized display hardware for use with Helmet Mounted Display (HMD) systems that project data in a Heads Up Display (HUD) format. Emphasis is placed on compact (<0.3 in^3 volume), low mass (<2 oz) hardware that can be used with HMD displays and efficiently display data (graphical and alphanumeric) without detracting from the HMD displayed video.
- Virtual reality interfaces that make it practical for an Intra-Vehicular Activity (IVA) astronaut or a suited EVA astronaut to operate on-orbit free-flyer camera platforms and planetary robotic camera platforms.

- Innovative systems that permit control of a robotic system through a combination of gesture and voice commands. Innovative concepts include machine vision, artificial intelligence based systems (with provision for crew oversight), as well as other nonvision forms of sensing and perception that provide command input to the robot.
- Miniaturized High Definition Television (HDTV) video cameras for use in capture of live video. Cameras should not exceed 2 inches in width and 2 inches in height with respect to the optical plane and should not exceed 4 inches in depth along the optical axis. An integrated zoom lens and an external sync capability is highly desirable. In addition, the camera shutter should operate on a global basis, i.e., all pixels on the imager should be exposed simultaneously instead of exposing one row of pixels at a time.
- A Helmet Mounted Display (HMD) that uses the HDTV format. Emphasis is placed on minimizing the weight (<3 lbs) of the HMD. Wide horizontal field of view (>150°) and high resolution (<2 arcminutes per pixel) are key objectives of this technology.

X4.02 Self-Assembling Systems
Lead Center: JSC
Participating Center(s): ARC, MSFC

In support of future robotic and human missions, the need for additional automation in rendezvous and docking has been identified. This subtopic addresses hardware and software technologies necessary to develop a robust automated guidance, navigation, and control (GN&C) capability bringing together to mate two vehicles from initially large distances (> 1000 km). The "target" vehicle may be orbiting the planet or Moon for several years prior to the rendezvous. The "chaser" vehicle may begin the rendezvous after launch from the planet or Moon's surface. Because of intended use for future human missions, the rendezvous and docking capability must be low risk ensuring a very high level of mission success. The proposed system should be modular and adaptable to smaller robotic missions in order to validate the technology and spread the investment and experience base.

For the purposes of this solicitation, the target vehicle is in the vicinity of the Moon, either orbiting the Moon at low altitudes or at the Earth–Moon L1 libration point. The chaser can be launched from the Earth or the Moon's surface. The proposed system may include active components on the target vehicle if a high level of mission success can be ensured over long timeframes. Preferred solutions support rendezvous operations with nonfunctioning target spacecraft at least in a contingency sense.

Innovations are currently sought to solve the following specific technology challenges (single sensor navigation solutions to address both items below are preferred):

- Definition and development of a small lightweight relative navigation system addressing spacecraft-to-spacecraft ranges of 100 km to less than 100 m. This system should provide precision relative-state position and velocity data needed for trajectory control and be capable of supporting trajectory operations for various rendezvous and proximity operations mission profiles, including circumnavigation of the target, and final separation and departure operations.
- Definition and development of a small, lightweight relative navigation system providing position and velocity trajectory control and relative attitude control during the final 100 m of the approach through mating.

X4.03 Inspection and Diagnostics
Lead Center: LaRC
Participating Center(s): ARC, JSC, KSC

Innovative and commercially viable concepts are being sought for the development of resilient space qualified non-destructive evaluation (NDE) and health-monitoring technologies for in-flight and on-orbit inspection and maintenance of space transportation systems. Emphasis is focused on highly miniaturized, lightweight, and compact systems that deliver accurate assessment of structural integrity. NDE systems that provide the greatest improvement in structural defect detection with minimum weight penalty will be given the highest priority. Structural applications to be considered for NDE and health monitoring development include but are not limited to:

- High stress and hostile aerodynamic, thermal, and chemical service environments projected for complex structural space vehicle systems; and
- Autonomous, non-contacting, remote, rapid, and less geometry-sensitive technologies that reduce weight and acquisition costs or improve system sensitivity, stability, and operational costs.

Evaluation sciences include ultrasonics, laser ultrasonics, optics and fiber optics, shearography, video optics and metrology, thermography, electromagnetics, acoustic emission, and x-rays. Innovative and novel evaluation approaches are sought for the following material and structural systems:

- Adhesives, sealants, bearings, coatings, glasses, alloys, laminates, monolithics, material blends, wire insulating materials, and weldments;
- Thermal protection systems;
- Complex composite and hybrid structural systems;
- Low density and high temperature materials; and
- Aging wiring.

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, corrosion, and disbands;
- Detection of cracks under bolts;
- Real-time and *in situ* monitoring, reporting, and damage characterization for structural durability and life prediction;
- Repair certification;
- Environmental sensing;
- Planetary entry aeroshell validation;
- Micrometeor impact damage assessment;
- Electronic system and 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 include, but are not limited to:

- Advancements in integrated multifunctional sensor systems;
- Autonomous inspection approaches;
- Distributed and embedded sensors;

- Roaming inspectors;
- Shape adaptive sensors;
- Concepts in computational models for signal processing and data interpretation to establish quantitative characterization and event determination;
- Advanced techniques for management and analysis of digital NDE data for health assessment and lifetime prediction;
- Biomimetic, and nanoscale sensing approaches for structural health monitoring that meet size and weight limitations for long duration space flight.

X4.04 Servicing, Maintenance, and Repair
Lead Center: KSC

The purpose and scope of the subtopic is to develop technologies and concepts for servicing, maintenance, and repair of space exploration systems. These systems include crew living quarters, laboratories, airlocks, ground transportation systems, and space transportation systems. The related support systems include environmental control systems, waste collection and processing systems, food storage and preparation systems, power systems, pneumatic systems, fluids systems, computer systems, communications systems, instrumentation systems, various structures and mechanisms, and other tools and equipment. Commodities may include gaseous and liquid nitrogen, oxygen, hydrogen, methane, carbon dioxide, and water. Operational environments include micro- and partial-gravity, possible corrosive reactivity, thermal extremes, possible low visibility, high potential for static discharge, possible cosmic radiation, and extensive permeation of dust-like materials. Requirements include safe operation, high reliability, ease of use, multiple uses, low-system volume, and low power. Operational concepts include limited direction from Earth-based mission control teams, minimized crew times in performance of these activities, optimal system autonomy, and optimal system readiness. In addition, all failure scenarios are expected to be designed to be “fail operational–fail safe.” NASA seeks highly innovative technologies and concepts to address efficient, accurate and cost-effective servicing, maintenance, and repair of space exploration systems. Specific technical areas include the following.

Upgradeable and Reconfigurable Systems Concepts
Support systems for the space exploration systems need to be developed which provide for a “Zero Outage” environment. Support systems must have the capability to be upgradeable through incremental component level upgrades. Support systems must also have the capability to be reconfigurable through the use of subsystems, components and connections that are multi-use, multi-commodity, and used in multiple environments. These reconfigurations must also have the capability of being performed autonomously to restore critical functionality. Expected products include concept papers, and subsystem or component level prototype demonstrations.

Standards, Interfaces, and Architectures
Standards, Interfaces, and Architectures need to be developed that support common and abstract definitions of both physical and behavioral characteristics, as well as shield internal technology-specific details from external system elements. The goal is to develop truly modular components that provide “Plug and Play” functionality between spacecraft and spaceport, between spacecraft elements, and between spacecraft and in-space or surface elements. Expected products include concept papers, and subsystem or component level prototype demonstrations.

Modular Orbital Replacement Units
It is expected that certain maintenance and repair actions will be performed by astronauts during Extra-Vehicular Activities (EVA). Astronauts will remove, replace, and retest units having characteristics of multiple functionality, integrated intelligence, adaptive interfaces, and interconnections. In addition, development of the associated equipment, tools and procedures, will be required to ensure a successful recovery from a system-level failure. Expected products include concept papers and prototype demonstrations.

Modular Component Replacement Units
It is expected that certain maintenance and repair actions will be performed by astronauts in a laboratory setting. Astronauts will remove, replace, and retest components contained within higher level units. Characteristics to be addressed include component mating surface preparations such as cleaning and polishing, electrical component contact soldering or annealing, and multiple functionality of the spare components. In addition, development of the associated equipment, tools, and procedures will be required to ensure a successful recovery from a component level failure. Expected products include concept papers and component level prototype demonstrations.

Propulsion System Refurbishment and Repair
The goal is to develop propulsion system component level technologies that support in-space modular replacement, commodity servicing, and in-place diagnostic and health determination. Capabilities need to be developed for remote and NDE inspection and testing of system components. The capability to repair or replace fluid lines either by human EVA or robotically operated tools will need to be developed. In addition, development of capabilities to safely isolate, inert and disengage fluid, mechanical and electrical interconnects will need to be developed. Expected products include concept papers and subsystem or component level prototype demonstrations.

Refueling and Fluids Resupply Support Systems
Multiple elements will have interfaces that will require the transfer of commodities between them to allow for integrated systems operations. These commodities will typically be electrical power, data, communication, pneumatics, coolant fluids, cryogenic fuel and oxidizer, and other systems related commodities as required. Umbilicals are mechanisms that enable these connections between multiple elements and can be manually operated or autonomous. Depending on the specific operation, both manual and automated umbilicals will be required to enable deployment and operation of space-based equipment, facilities and habitation modules. It is expected that these umbilicals will have leak detection capability, remote sensing, use self-healing characteristics and low-maintenance sealing technologies. In addition, the systems being serviced must have advanced volume-gauging systems. These servicing systems must also demonstrate safe and secure operation. Expected products include concept papers and subsystem or component level prototype demonstrations.

Structural Materials-Level Repair Systems
Develop in-space capabilities and technologies for material repair both via human EVA and robotically operated disassembly, welding, bonding, insulation application and reassembly. It is also highly desirable to develop technologies for polymeric and composite materials that mimic the self-healing repair processes of biological systems. Applications for self-healing processes of inanimate materials can be found in areas where failures could result in catastrophic consequences. Examples include: failure of structural members, failure of electrical wire insulation materials or failure of polymeric membranes used in critical life support systems for separations of gaseous and liquid commodities. Expected products include: concept papers and laboratory demonstrations.

TOPIC X5 Surface Exploration and Expeditions

The goals of this topic include working collaboratively with technology developments in the Space Science Enterprise (and other organizations) to enable future human exploration missions to effectively address – and at a fundamental level – the "grand" science challenges facing NASA, driving down the cost of human exploration missions and campaigns beyond Earth orbit, and sharing the experience of exploration with the public. In pursuing these goals, the objectives under this topic include:

1. Developing and validating the capability for human explorers to gain deep lunar and planetary subsurface knowledge and access – both remotely and through sampling – ranging down to 1000s of meters;
2. Enabling cost effective access of human explorers to lunar, planetary, and other deep space locations;
3. Providing hardware and systems required to support manned surface operations;
4. Enabling safe and affordable human exploration of other planetary surfaces – locally but over global distances involving traverses of up to 1000s of kilometers;

5. Integrating and validating the technologies needed to revolutionize public engagement in "virtual exploration" – ranging from higher rate communications, to the creation of virtual reality simulations, to innovative human-machine interfaces; and
6. Establishing a foundation for profitable commercial development of space applications of these technologies in the mid- to long-term.

X5.01 Mobile Surface Systems
Lead Center: JPL
Participating Center(s): ARC, JSC

This subtopic seeks innovative technologies that enable safe, efficient, and highly capable human-robot teams, whether these teams work jointly in the same environment or include remote and local partners. Such teams will prepare lunar or planetary bases for human arrival, support and maintain these human bases, and/or explore lunar or planetary surfaces.

Crew Mobility Systems
One specific research area of interest is mobility systems for crew and/or cargo. This could include local unpressurized transports, long-distance pressurized transports, mobile "habitats," mobile ISRU "plants," or other concepts. Proposals addressing this area should focus on space-relevant hardware, mobility options, logistical issues such as ingress/egress and loading/unloading, and/or functional requirements. Crew transports must also take into account handling rough terrain while carrying suited crew members.

Another area of interest is robotic field assistants that provide various levels of assistance to humans during EVAs, including possibly mobility or transport. Proposals addressing this area should focus on types and levels of assistance and/or space-relevant hardware and interfaces. For instance, robotic field assistants will need space-relevant means to accurately localize themselves with respect to moving crew members, the habitat, and other objects or areas of interest.

Proposals may also address communication between team members, whether between humans and robots, or between multiple robots. The specific focus of such proposals should be interface needs, interface methods, interface reliability, and/or ensuring appropriate communication is sent to all team members.

Proposals may focus on flexibility in switching between modes: autonomous, remote tele-operation, local astronaut-control, and joint control modes; local versus long-distance traverse modes; or behavioral modes. Any given mobile surface system may have multiple modes and multiple tasks. The system itself may need to know when to switch between modes or tasks, and be able to do so cleanly. Human-controlled mode switches also need to be handled smoothly.

A final area of interest is supervised and/or autonomous robotic outpost elements such as communication relays, ISRU devices, or data collectors. Such outposts could involve remote wireless data transfers or periodic transfers of data and/or collected resources to other mobile robotic or human agents. Integration with a robotic field assistant is one useful option. Autonomously or semi-autonomously deploying and maintaining such outposts needs to be addressed, including providing for power and communication needs.

Precursor Mobility Systems
Mobile Surface Systems addresses mid-term development of mobility platforms for precursor missions and robotic systems supporting human-robot mission operations. Work includes the formulation of system concepts, development of enabling technologies, integration of these technologies within an appropriate software and hardware framework, and testing, verification and validation of such system prototypes in representative laboratory and field environments. The applicable technologies and design concepts span the full range of autonomous and telerobotic mobility platforms including high dexterity robotic field assistants, robotic scouts, and robotic systems (in-space and planetary/lunar) for structural inspection and structural repair.

In this year, this subtopic requests proposals specific to the following areas:

- Modular robotic systems (mechanical and electrical);
- Assembly and control of modular systems; and
- Alternative mobility systems (vs. wheels) such as inflatable systems or walking systems.

X5.02 Virtual Exploration
Lead Center: ARC
Participating Center(s): JSC

Future NASA Exploration Systems will require humans to effectively interface very large sets of both software and physical data. This demands significant advances in human–machine interfaces that will incorporate 2- and 3-D multimodal displays, which will be supported on the back end by high-end computing and sophisticated data management, data fusion, and data mining algorithms. Such interfaces are required for accessing physical spaces, as in teleoperation for robotic exploration, for accessing data repositories, as in ultralarge immersive data sets, and for accessing data that augments human models, as in immersive model exploration and sensory augmentation. The purpose of this call is to catalyze the creation of specific software products and interface design case studies that will enable NASA individuals to explore physical- and software-based data sets as outlined above.

Innovative proposals are sought in the following areas:

- Technologies supporting telerobotics, particularly in the presence of multisecond communications delays, including:
    - Predictive interfaces
    - Force feedback systems
    - Multisensorial displays
- Interfaces for analysis of large heterogeneous databases, including:
    - Interactive 2- and 3-D environments, including but not limited to, real-time exploration of these models
    - Multimodal displays
- Multisensor data fusion for purposes of both data analysis and situational awareness (e.g., for mission operations and/or telerobotics)
- Data management and data archiving for large data sets (tera to peta bytes)
- Data mining, data compression, and data processing for analysis of large data sets
- Human sensory augmentation for real-time exploration

TOPIC X6 Space Transportation

Space Transportation is critical to future Space Exploration. To achieve the ambitious goals of the Nation's Exploration Vision, capabilities must be developed to provide both "Earth escape" and "in-space" transport, as well as descent, landing, and return capabilities. Technologies necessary to provide transportation systems that are effective, affordable, safe, and reliable are sought. Large payload masses will be required to meet human exploration requirements with the associated attention to safety and reliability. High performance propulsion will also be required to manage vehicle size and propellant mass. Interest is highest in capabilities that can be matured in time to meet the timeline milestones set out in the President's Vision to return to the moon in the 2015–2020 timeframe. Consideration will also be given to capabilities that may be incorporated into "spiral development" opportunities for enhancing initial capabilities at subsequent intervals.

X6.01 Earth-to-Orbit Propulsion
Lead Center: MSFC
Participating Center(s): GRC, KSC

NASA is interested in innovative Earth-to-Orbit (ETO) propulsion systems and component technologies, as well as design and analysis tools used to support the assessment of the technical viability of those systems. Next generation launch technologies will require high overall vehicle payload mass-to-liftoff mass ratios, propulsion systems that deliver higher thrust-to-engine weight ratios, increased trajectory averaged specific impulse, reliable overall vehicle systems performance, and other innovations required to achieve cost and crew safety goals.

Proposals should address technical issues related to Earth-to-Orbit (ETO) LH2/LOX and LOX/Hydrocarbon engines including engine and main propulsion systems design and integration, turbomachinery, combustion devices, valves, actuators, ducts, and overall propulsion systems integration. Proposals may also address enhancing technologies for solid propellant and hybrid motors for ETO applications.

Specific areas of interest for technology advancement and innovations include the following:

- Technologies and design and analysis tools applicable to assessment of ETO propulsion systems including engine systems, turbomachinery, and combustion device concepts. Of particular interest are design and analysis tools that provide improved understanding and quantification of component, subsystem, and system operating environments and that significantly enhance the overall systems engineering evaluation of potential ETO propulsion concepts such as tools for component and parameter sensitivity analysis, quantification of system benefits to changes, the operability of the overall propulsion system concept, "bottoms up" weight estimating, cost estimating, and reliability prediction of propulsion systems.
- Technologies that improve performance, reduce cost, reduce weight or improve reliability of ETO engine systems, turbomachinery, and combustion device concepts.
- Manufacturing techniques that will allow for significant reduction in the cost and schedule required to fabricate engine and main propulsion system components for candidate ETO engine systems. 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.
- Health monitoring systems and sensor technology that can improve capability to assess the system health.

X6.02 Vehicle Airframe Structures
Lead Center: LaRC
Participating Center(s): MSFC

The Exploration Systems Enterprise has adopted a two-part approach for maturing the technologies in this subtopic. Near term, evolutionary advances in the state-of-the-art (SOA) are required to enable new options for future Earth-to-Orbit (ETO) Transportation with specific emphasis on advances in onboard primary propulsion. This strategy will meet ambitious Lunar and Earth Neighborhood missions in the 2010 timeframe which provide safe, affordable and effective transportation of crews, mission systems, cargo and consumables (including propellants) from Earth to low Earth orbit (LEO) and beyond. Far term, truly transformational advances are sought to enable the ambitious campaigns of Mars Exploration by human and robotic missions in the 2020 timeframe that provide transport, including precise and reliable access to and from the global Mars surface, and to and from the Mars Neighborhood comparable to Earth Neighborhood missions.

Proposals addressing near term evolutionary advance must address how their proposal will advance the SOA from an existing Technology Readiness Level (TRL) of 3 to a TRL of 6 at the completion of a SBIR Phase II award.

Proposals addressing farther term focus on truly transformational advances must address the required technology maturation process to advance the SOA to at least a TRL of 3.0 at the completion of a SBIR Phase II award.

Because of the large number of proposals anticipated within this subtopic, proposing organizations must identify the single, specific category (e.g., 1.1 or 3.1) against which their proposal will be evaluated. Proposals not identifying the specific category will not be evaluated.

This subtopic seeks innovations that resolve the conflicting requirements of low cost and safety with the need for performance. The following categories identify both near-term and long-term performance goals as appropriate for each.

1.0 Primary Vehicle Structures

1.1 Near Term
Current capabilities are limited to expendable vehicle structures that result in unacceptable life cycle costs and limit flexibility in operational scenarios. Innovations are sought that include, but are not limited to the following areas:
- Robust, reliable, and high strength-to-weight vehicle airframe and structures concepts and material systems to reduce the high cost of ETO transport;
- Integrated thermal structures that have the atmospheric entry thermal protection system closely integrated with the structures;
- Specialized modeling, analysis, and design tools for integrated aerothermal, thermal, thermal-structural responses; and
- Novel methods for predicting and testing structural durability and damage tolerance, with emphasis on environmental degradation, combined thermal-mechanical loads, and operation beyond nominal design conditions; and related methods to repair damaged structures.

1.2 Long Term
Innovative concepts include but are not limited to:
- Reusable “hot structures,” i.e., structures that can function without requiring any atmospheric entry thermal protection system for wings and fins, thrust structures, fairings, control surfaces, and leading edges; and
- Adaptive structural capability, i.e., smart structures.

2.0 Pressurized Structures (Tankage)

2.1 Near Term
Innovative concepts include, but are not limited to:
- Advanced design tools;
- Zero boiloff long-term storage capability;
- Composite interfaces and feedlines systems; and
- Innovative measurement and test methods for design validation of hot aerosurfaces and integrated thermal-structural concepts for tanks.

2.2 Long Term
Innovative concepts include, but are not limited to:
- Reusable “Hot structures” for, but not limited to, integral cryogenic tanks and intertanks.

3.0 Structural Interfaces

3.1 Long Term
Innovative concepts include, but are not limited to:
- Adaptive modular designs; and
- Integral intelligent vehicle health management.

4.0 Materials: Usage and Compatibility

4.1 Near Term
Innovative concepts include, but are not limited to:

- Materials technology systems focused on advanced, high-temperature materials compatible with cryogenic and gaseous hydrogen and oxygen, and high-temperature products of combustions such as water vapor;
- Advanced high temperature material systems and their related processing into useful product forms for fabrication vehicle structures and tankage that include, but are not limited to, nickel, iron and titanium alloys;
- Material property data for probabilistic design;
- End of life property prediction tools; and
- Usage/compatibility testing for reusability.

4.2 Long Term
Innovative concepts include, but are not limited to:

- Advanced high temperature material systems and their related processing into useful product forms for fabrication of vehicle structures, tankage, and secondary structures and appendages that include, but are not limited to, intermetallics, refractory metals, ceramic matrix composites, and metal matrix composites.

X6.03 Atmospheric Maneuver and Precision Landing
Lead Center: ARC
Participating Center(s): GRC, JSC, LaRC, MSFC

Highly reliable, exceptionally safe (where humans and nuclear reactor cores are involved), highly effective, and increasingly affordable Atmospheric Maneuvering and Precision Landing capabilities are enabling and enhancing technologies for future human or robotic exploration missions. Atmospheric maneuvering is essential for Martian entry and return to Earth entry— crews, samples, or nuclear reactor cores. Pinpoint Landing is critical for humans or cargo landing on the Moon, Mars, or Earth. This subtopic solicits systems-level innovations and high-leverage technologies, derived from clear concepts of operations, including aero-assist maneuvers.

Conceptual Designs
Solicitations for the development of innovative conceptual designs of entry vehicles are requested. Proposed vehicle designs must either accommodate increased cargo masses and volumes compared to current vehicles for robotic missions or be capable of treating the extremely large masses and volumes required for future human and cargo missions to Mars and the Moon. Innovative entry vehicle designs for missions requiring precision landing are solicited that have increased L/D (i.e., > 0.30) while maintaining vehicle operational viability. Vehicle designs are also sought that can demonstrate increased aerodynamic lift, provide lift modulation needed for precision trajectory control, provide efficient deceleration to minimize the aerodynamic heating environment, integrate innovative lower mass fraction thermal protection systems, provide the capability to meet terminal descent objectives for Mars landers and for Earth landers, and are compatible with launch systems. In conjunction with conceptual entry vehicle design, innovative conceptual design concepts are solicited for aero-assist deceleration systems, such as trailing ballutes, inflatable aeroshells, attached afterbodies, inflatable ellipsleds, and steerable parachute systems.

Thermal Protection Systems (TPS)
Advanced or new TPS materials and concepts are solicited for many likely robotic, cargo, and human exploration missions to the Moon and Mars, for human missions to low-Earth orbit (LEO), and to address the current shortfalls for other Solar System Exploration missions. Interest is limited to reasonably mature materials concepts. Man-rated, multi-use ablative thermal materials manifesting significantly enhanced performance and reduced weights are solicited for safe round-trip human missions to Mars. Multiple-use, significantly advanced (in terms of enhanced durability, performance, and reduced weights), non-ablative thermal materials and advanced single use ablative materials are also required for safe manned and unmanned missions to the Moon and to LEO. Along with advanced or new materials, material property data for probabilistic design, spallation characteristics, end of life property

prediction tools, and usage and compatibility tests are required. Advanced multilayer TPS concepts and advanced adhesives exceeding the current state-of-the-art 523 K temperature limitation are sought. Innovative TPS concepts are solicited to reduce current TPS mass fractions by 25–50% and to reduce TPS costs.

Existing arc-jet facilities are inadequate for developing and certifying thermal materials for future exploration needs. New conceptual designs for arc-jet test facilities or conceptual design for extending the capabilities of existing arc-jet facilities are solicited to simultaneously simulate convective and radiative heating and to extend peak enthaply from about 30 MJ/kg to 90 MJ/kg. Instrumentation that can be integrated with TPS is sought to define freestream flow conditions, including the chemical and thermodynamic state of gases, and to assist in the interpretation of ground test data. This includes microsensors for measuring heat flux, pressure, and surface recession which can be integrated into a broad range of TPS materials. Testing techniques are solicited to develop human-rated materials and to significantly reduce TPS development cost and time. A combination of integrated health monitoring (IHM) and innovative nondestructive evaluation techniques are solicited to reduce maintenance time for reusable TPS.

Guidance, Navigation, and Control (GN&C)
Innovative concepts are solicited to improve navigation and low speed (below Mach 4) aerodynamic maneuver capability to achieve Mars landing accuracy of tens of meters relative to landmarks or predeployed assets as opposed to about 10 km for upcoming Mars Landers. Present Mars Landers are constrained in landed mass by the atmospheric density profile, the entry vehicle ballistic coefficient, and low speed (below Mach 4) deceleration capability. Innovative concepts are sought to improve the efficiency of low speed deceleration and to expand the operating envelope beyond the present limits that are based on Viking technology. The Apollo Lunar Excursion module relied on humans to detect and avoid landing hazards. Human intervention cannot be used for robotic missions and long duration Mars missions will have an automated landing capability. Innovative concepts are, therefore, sought for sensors to detect landing surface hazards, and for improving the vehicle's planet-relative navigation at Earth, the Moon, and Mars. Innovative, efficient concepts are sought to incorporate direct drag control into the control system. Improved steady-state wind, wind gust, and wind turbulence models are sought for Mars that include time of day, season, position, and local terrain effects.

X6.04 Vehicle Subsystems
Lead Center: GRC
Participating Center(s): ARC

NASA seeks highly innovative concepts for operable (high reliability, low maintenance) subsystems and components for vehicles to support exploration missions. Exploration vehicle elements may include ETO launch vehicles, crew and service stages, upper/transfer stages, landers, and ascent stages. Specific technical areas include the following.

Electrical Power Devices/Components Capable of Operating During Ascent, In-Space, and Descent Environments

- Power Generation: Advanced non-toxic power generation devices such as non-toxic turbine generators (120 V and higher, 100 kW and higher) and advanced fuel cells (28 V and higher, 10 kW and higher) and components. Key components for fuel cells include gravity-independent water separators and separation techniques, high-efficiency long-life membrane-electrode assemblies, and passive gas circulation and re-circulation devices/methods.
- Energy Storage: High energy density storage and peak load leveling devices such as advanced batteries (30 A/hr and greater, 10°C and greater) and supercapacitors (greater than 400 A rate 100 ms)
- Power Management and Distribution: Development of high voltage, 5000–6000 VDC and VAC, switch gear for fault protection and normal switching of current. Switch gear up to 6000 V adjustable trips current for fault protection. Application of fuses for instantaneous fault current protection.
- Innovative ideas in the area of cabling and connectors for high power reusable modular systems (120–270 V systems).

Vehicle Health Management

- Subsystem health management technologies including self-diagnostics, prognostics and remediation, built-in testing technology, advanced sensor and smart component technologies, and subsystem smart interfaces;
- Pre-and post-flight ground and space processing including automated post-flight planners, schedulers, and work-order generators, automated pre-flight readiness process, advanced built-in tests, and troubleshooting; and
- Advanced information technologies including automated data mining, management and trending tools, diagnostic reasoners and prognostics, real-time fault detection and isolation, ultra-high-speed networks, and human machine interactions (interfaces).

Actuators and Mechanisms

- Advanced high horsepower (50 hp and greater) electric actuators (e.g., electromechanical and electrohydrostatic) for launch thrust vector control applications;
- High reliability, low mass and volume, and fault tolerant electric actuators;
- Advanced motors and motor and drive electronics; and
- Liquid lubricants and additives to provide long life and high reliability with minimal or no maintenance – characteristics include efficiency, wear, resistance to lubricant breakdown, nonreactivity with nascent aluminum and iron (as created by wear particles), corrosion protection, and resistance to outgassing (including breakdown products). Lubricants must perform under conditions of high speed or low speed (including zero speed), high contact loads, dither (back and forth) motion, vibration (such as launch), wide temperature range (-100 to +300°C), and vacuum. One specific need is for extreme pressure (antiwear) additives that are soluble in the perfluorinated polyether oils commonly used for space mechanisms. Another area of interest is a means to replenish a solid lubricant in space mechanisms.

X6.05 In-Space Propulsion (Chemical and Thermal)
Lead Center: MSFC
Participating Center(s): GRC, JSC

To meet the challenges of future spacecraft missions, NASA is seeking innovative concepts for chemical and thermal propulsion systems, subsystems, and components. These innovations are needed to improve the safety, operability, reliability, and performance of in-space propulsion systems and to extend the existing technology base to include capabilities required for human and robotic exploration missions.

These complex missions will involve a broad range of in-space propulsion applications including spacecraft attitude control, orbit insertion, translunar injection, lunar descent, lunar ascent, trans-Mars injection, Mars descent, and Mars ascent, as well as other spacecraft pointing and translation systems.

System masses will be critical in these far-reaching missions, dictating the use of lightweight components and the use of propellant(s) 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). These new systems are also expected to present new challenges, such as cryogenic propellant acquisition, thermal management of cryogenic propellants in small-diameter widely distributed feed lines, accurate determination of onboard cryogenic propellant inventories, and long duration onboard storage of cryogenic propellants.

If gaseous oxygen is used as a propellant, then flammability hazards may need to be mitigated with new or improved materials. The need for lightweight, highly reliable gas compressors is also strongly related to some system architectures that may require pumping gases into pressure vessels either in-flight or on a terrestrial surface.

The use of non-toxic propellants is another area with significant payoffs, because such propellants would enhance the safety and efficiency of prelaunch processing. Formulation of advanced non-toxic monopropellants and bipropellants could offer significant advantages for future missions, provided that specific impulse values are comparable to existing technologies such as monopropellant hydrazine (N_2H_4) or monomethylhydrazine (MMH) and nitrogen tetroxide (N_2O_4). Devices or concepts that enhance the usefulness of leading non-toxic propellant combinations (e.g., liquid oxygen (LO_2)-Hydrocarbon, LO_2-liquid hydrogen (LH_2), etc.) are also highly desirable. One specific area of interest is the development of injectors with low thermal mass that can withstand the thermal environment in a long-life (pulsing) attitude control thruster.

Advances in other key areas such as fast-acting valves, upper stage engines, and pulse detonation engines will also find application in the broad range of propulsion systems identified with exploration. Throttling engines with wide thrust ranges (perhaps varying from 1,000 lb_f to 10,000 lb_f) and pulsing capability will also be needed for descent spacecraft.

To address the technical challenges outlined above, NASA is seeking innovative solutions in the following areas:

LO_2-LH_2 In-Space Propulsion
- Improvements to the operability and reliability of current LO_2/LH_2 engine designs
- Innovative concepts for turbopump-fed or pressure-fed engines
- Pulse detonation engines using LO_2/LH_2

LO_2-Hydrocarbon In-Space Propulsion
- Improvements to the operability and reliability of current LO_2/hydrocarbon engine designs
- Innovative concepts for turbopump-fed or pressure-fed engines
- Pulse detonation engines using LO_2/hydrocarbon propellants

Advanced In-Space Propulsion Concepts
- Liquid acquisition devices for cryogenic propellants for use in zero-gravity and omni- gravity acceleration fields
- Innovative concepts for propellant quantity gauging for cryogens
- Novel concepts for flow measurement of cryogens for spacecraft propellant management
- Approaches for long-term on-orbit storage of cryogenic propellants (for periods ranging from several days to several months)
- Novel concepts and devices for use in transferring propellants from one spacecraft to another in space
- Novel pressurization approaches that minimize dissolution of pressurant gas in storable propellants (e.g., nitrogen tetroxide, hydrazine, and hydrazine derivatives)
- Gelled propellant formulations for in-space propulsion systems (including both attitude control and delta V propulsion) for long-duration missions involving low-power consumption (i.e., minimal use of heaters)
- Novel concepts that increase performance or decrease mass of pressurization systems
- Non-toxic monopropellants and bipropellants for in-space propulsion systems, including spacecraft "delta V" and attitude control propulsion systems
- Development of advanced materials that exhibit high compatibility with gaseous oxygen
- Propulsion systems based on microelectromechanical systems (MEMS) technology

- High-performance advanced propellants (as indicated by high specific impulse and high specific impulse density)
- Advanced nozzle concepts for in-space propulsion systems
- High-accuracy methods for gauging propellant quantities in tanks in space (for zero- gravity and omni-gravity environments)
- Long-life combustion chambers (e.g., based on use of advanced materials)

Solar Thermal Propulsion

- Novel concepts for direct-gain engines, storage engines, or bimodal engines for solar thermal propulsion

In-Space Reaction and Attitude Control Propulsion

- Concepts for thrusters that burn *in situ* and non-toxic propellants (e.g., methane, oxygen, ethanol, and hydrogen) at thrust levels useful for attitude control systems (2 lb_f to 1000 lb_f thrust level) and spacecraft delta V engines (1000 lb_f and higher)
- Innovative thruster designs that minimize or prevent high heat soak-back during pulse mode operation
- Innovative thruster valve designs that tolerate high thermal loading due to heat soak-back during pulse mode operation
- Innovative concepts for thermal management of distributed cryogenic feed systems for reaction control systems (including thermal loading from attitude control thrusters)
- Pulse-mode engine concepts offering two or more discrete thrust levels
- Pulse-mode engine concepts offering variable thrust levels (i.e., throttling capability)
- Highly reliable, lightweight compressors for use in gaseous propellant storage and distribution systems
- Advanced lightweight multi-use positive expulsion devices for cryogenic or storable propulsion systems
- Innovative concepts for fast acting valves to enable use of larger thrusters for small impulses (i.e. spacecraft fine pointing)
- Innovative concepts for long-life, high-reliability ignition systems for use in attitude control systems.
- Long-life, low-mass components for use in cryogenic propellant systems

X6.06 In-Space Propulsion (Electric and Magnetic)
Lead Center: GRC
Participating Center(s): JPL, JSC

High power electric propulsion (e.g., ion, Hall, magnetoplasmadynamic (MPD) thrusters, pulsed inductive thrusters (PIT), Variable Specific Impulse Magnetoplasma Rocket (VASIMR) and other plasma thrusters) is an essential technology for orbit insertion and planetary transfers of future nuclear and non-nuclear human exploration spacecraft. This subtopic solicits innovative component technologies related to high power electric propulsion systems for these applications. Innovations may 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. For this subtopic, high power electric propulsion is defined as systems with power levels of 100 kW to several megawatts and higher. 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% are desired. System lifetimes commensurate with mission requirements (typically 10,000+ hours of operation) are desired. Component technologies for high power applications of particular interest are those that can be commercially spun-off or can also be applied to lower power electric propulsion devices and applications. Proposed high power electric thruster component technologies must have near-term applications that can be pursued in a Phase-II effort. Examples of component technologies of interest include but are not limited to:

- High voltage propellant isolators (10 kV);
- Long-life, high current cathodes (100,000 hours);
- Innovative plasma neutralization concepts;
- Metal propellant management systems and components;

- Cathodes for metal propellants;
- Low mass, high efficiency power electronics for RF discharges;
- 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;
- High fidelity methods of determining the thrust of ion, Hall, MPD, VASIMR engines without using conventional thrust-stands; and
- Heat transfer and rejection components for high temperature and cryogenic regimes (applications of advanced materials, heat pipes, etc.).

X6.07 In-Space Propulsion (Nuclear)
Lead Center: GRC
Participating Center(s): MSFC

NASA is interested in the development of nuclear thermal rocket (NTR) propulsion systems, subsystems, and components for use in future robotic science missions, as well as for human exploration missions to the Moon, Mars, and near-Earth asteroids. Besides providing high thrust and high specific impulse (Isp) primary propulsion, the basic NTR can also be configured for electrical power generation, bipropellant operation, ascent /descent and hybrid propulsion system applications.

In-Space Primary Propulsion
The high thrust and high Isp (~875–1000 s) NTR uses a fission reactor with U-235 fuel as its source of thermal energy production. During the various short primary propulsion maneuvers, large quantities of thermal power (100s of MW) are produced within the NTR and removed using LH2 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.

Electrical Power Generation
The "Bimodal" NTR (BNTR) option produces both high thrust propulsion and electrical power for spacecraft operations (e.g., active refrigeration of cryogenic propellants, crew life support and high data rate Earth communications). During the "power generation phase," the BNTR operates in an "idle mode" at greatly reduced power (~150 kW). Energy generated within the reactor is removed using a "closed" gas loop (He-Xe) and then routed to an efficient (~20%) dynamic power conversion system (e.g., Brayton turbine-alternator-compressor unit) to generate low-to-moderate levels (~10s to 100s of kW) of electricity.

Bipropellant Operation
In the "LOX-augmented" NTR (LANTR) option, gaseous oxygen is injected into the hot hydrogen exhaust downstream of the nozzle's sonic throat. Here it undergoes "supersonic combustion" providing LANTR with an "afterburner" nozzle feature allowing a variable thrust and Isp capability that depends on the operating oxygen-to-hydrogen mixture ratio. Transition to LANTR operation provides a number of engine, vehicle and mission benefits that include thrust augmentation for small engines, reduced gravity losses, shortened burns, and increased bulk propellant density leading to smaller tanks and reduced stage sizes.

Ascent and Descent Propulsion
With its high thrust, power generation, and bipropellant (LH2 and LOX) operational capability, bimodal LANTR propulsion could allow interesting sample return missions from the frozen "water-ice" worlds of the outer Solar

System. Samples can be collected and returned using LH2 and LOX propellants produced from *in situ* ice for ascent and return propulsion maneuvers.

Hybrid Propulsion Operation
In the "hybrid" BNTEP system, the electrical power output of the BNTR is increased to support the addition of electrical propulsion (EP) thrusters. The benefits of the BNTEP concept includes high thrust for quick departure and capture maneuvers, as well as sustained operations at higher Isp values (1000s of seconds) resulting in reduced propellant consumption and potential spacecraft mass reductions on both nearer term robotic and future human exploration missions.

Key technologies and concepts being investigated include:

- High temperature (~2500 – 3000 K), low-to-moderate burn-up carbon- and ceramic-metallic (cermet)-based nuclear fuels for NTR / BNTR propulsion
- Improved chemical vapor deposition (CVD) and coating techniques for carbon-based fuels that prevent cracking, fuel erosion via H_2 attack and fission product release
- Innovative concepts for non-nuclear, hot H_2 and He-Xe, simulation tests of BNTR fuel element designs
- Concepts for LANTR propulsion that differ from the "afterburner" nozzle concept discussed above
- Noninvasive, radiation hardened instruments for measuring temperature, pressure, propellant flow rate at H_2 temperatures in the ~2500–3000 K temperature range
- Concepts for autonomous connection and leak monitoring of "tank-to-tank" propellant lines

Supporting technologies and concepts include:

- Lightweight, high pressure turbopumps providing ~2.5–7 kg/s of LH2 propellant for 5–15 klbf NTR / BNTR engines
- Lightweight, high heat flux regeneratively-cooled nozzles
- Lightweight, high heat flux LOX "afterburner" nozzles and supersonic injectors for LANTR operation
- High temperature (~1300 K), long life, high reliability Brayton rotating units
- Lightweight, high temperature radiators for BNTR operation
- Lightweight, low power LH2 refrigeration system to eliminate propellant boiloff
- High strength metal alloys and/or composites for structures and LH2 and LOX tanks
- Radiation tolerant systems and materials

For long duration robotic science and future human exploration missions, increased safety and reliability are of extreme importance. It is also highly desirable that key technologies have applicability to a wide range of missions. For example, high temperature, high burn-up UO2 in tungsten metal "cermet" fuel can potentially be used for both NTR, BNTR, nuclear electric propulsion (NEP) and planetary surface power system applications. Lastly, technologies that can easily and efficiently be scaled in size (e.g., thrust level and electrical power output) and can be used in a host of applications (high degree of commonality) are highly desirable.

X6.08 Launch Infrastructure and Operations
Lead Center: KSC
Participating Center(s): GRC, GSFC

The purpose and scope of the subtopic is to develop technologies and concepts for safe and efficient prelaunch preparation, checkout, launch, landing, and launch countdown recycle support of the launch vehicle, spacecraft and payload elements in addition to range and rescue support systems. Included in this area are ground-based facility systems and equipment, instrumentation and control systems, safety systems to protect both the human elements and hardware, work control, planning and scheduling, receiving, shipping and handling, maintaining large fluid and high power infrastructure hardware and protecting and mitigating the hardware from the effects of natural and man-made elements.

Safety Management and Control Systems
Safe and efficient operations, which are improved by orders of magnitude, is the goal of this solicitation. Development of innovative capabilities for metric tracking, area surveillance, navigation aids, communications, and atmospheric sensing are required. Technology development in the following areas will be needed: integrated multi-, hyper-, and ultra-spectral instrumentation and sensors; multi-channel, low power, spectrum efficient transceivers high gain antennas that can integrate with the National Airspace System for vehicle ascent and decent. Cost effective and innovative implementations of communication technologies for the Distress Alerting Satellite System (DASS) to support Search And Rescue (SAR). Improving survivability of Emergency Locator Transmitter (ELT) beacons, developing beacon compatibility with the planned Automatic Dependent Surveillance Broadcast (ADS-B) System, and improving Personal Locator Beacon (PLB) antenna patterns are sought.

Technologies that improve the basic 406 MHz beacon protocols, while remaining compatible with the existing Cospas-SarSat satellite system and the DASS system. Development of technologies for improved link margins and techniques capable of supporting interactive analysis and target recognition in airborne polarimetric SAR at foliage penetrating wavelengths. Techniques to support interactive analysis of spectral and polarization signatures of targets using hyperspectral instruments. Develop ground-based and airborne time-resolved, real-time instruments to measure atmospheric chemical species associated with spaceport propellants and combustion products. Expected products include concept papers and subsystem or component level prototype demonstrations.

Payload Packaging and Vehicle Integration
Development of innovative packaging techniques and systems that offer efficiency and reliability improvements to payload components for test and replacement while assuring rugged mounting to withstand handling and launch. The design should promote the step-by-step buildup of payload systems to support unit testing and integrated payload, and eventually integrated vehicle test and verification. Development of technologies and concepts that support standardization of payload containers that are self-contained with built-in health monitoring which can support the payload from its birth at the factory to prelaunch processing, integration, and launch through deployment. Expected products include concept papers and subsystem or component level prototype demonstrations.

Large Scale Propellant, Fluid, Mechanical, and Power Systems
Advanced cryogenic technologies that support systems which range from the small (20 l for supercritical air, payload cooling) to very large (>3400 m^3 for LOX and LH2 ground propellant storage). Development of concepts and technologies that support thermal conductivity cryogenic tank penetrations, cryogenic insulation systems for application in ambient air environments, insulation concepts for reusable launch vehicles, high efficiency insulation for in-place replacement of perlite in large ground storage tanks, valves for cryogenic applications that minimize thermal losses, and pressure drops that are failure resilient, innovative LOX pumping systems, small and low power efficient circulation pumps, leak proof and easy-to-use cryogenic couplings using robust sealing technology, smart umbilical systems and components designed for high reliability and safety, as well as special control components for densified propellants with zero boiloff. Capabilities and technologies for separation and recovery of gaseous hydrogen and/or helium from waste gas streams, purification and re-use. Expected products include concept papers and subsystem or component level prototype demonstrations.

Launch Command and Control Systems and Information Networks
Traditional Command and Control Systems that support only a specific class of space vehicle must evolve to adaptable systems that can interact with different classes of spacecraft at spaceports located in diverse environments. Improved sensing capability for inline and other non-intrusive techniques including, but not limited to; gas composition determination, flow rate, pressure, temperature, valve position, voltage, current, strain, vibration, and liquid level. “Smart” sensors, i.e., sensors capable of performing qualification, integrity checking, and self-identification, and are aware of their performance history so that they know when they are operating in a degraded mode. Wireless or self-healing wired technology that supports health monitoring. Advanced data bus and data bus control hardware, e.g., IEEE 1394 b, for spaceport operations. Automated and autonomous control systems for automated inspection applications. Software concepts and architectures for integrated spacecraft checkout that can execute in either an Earth-based or non-terrestrial spaceport and that hide the differences between the two platforms. Architectures for

portable software that would support service discovery and remote execution in support of future spacecraft and spaceport interaction. Evaluate languages with software components that are portable at run-time to support spaceport processing. Real-time systems must be stable, responsive, and support remote operations. Evaluate abstraction techniques to provide the capability to develop a common set of software to support spaceport and spacecraft servicing operations. Evaluate techniques for the automated generation of end-item control software and software test and validation procedures from a common predefined set of end item specifications. Expected products include concept papers, simulation demonstrations, and subsystem or component level prototype demonstrations.

Launch Operations Systems Health Management
Development of capabilities and technologies that support detection, prediction, isolation, and mitigation of system faults, degradations and failures for the purpose of enhancing safety, availability, and maintainability. Health determination, current or future, may require access and collaboration with other spaceport computational systems for history data, component pedigree determination, problem reporting and corrective action (PRACA), work control, planning, and scheduling systems. Ground support health information will need to be integrated with launch vehicle and spacecraft health information and presented in a form to allow human operators maximum situational awareness of dynamic events. Development of standards for communication between the various health management components will have to be developed. Systems developed will have to support software updates and major upgrades over the life of the hardware. Health algorithm details may require frequent updates to refine failure characterizations and should not drive costly revalidation and certification efforts. Expected products include concept papers and subsystem or component level prototype demonstrations.

Work Control and Process Verification
Development of advanced and integrated work control systems that allow ease of user interaction for the generation, review, execution, verification, and audit review of process control procedures. Systems should support multimodal communication capabilities and user input and output functions specialized to the environment used. Technologies developed must be robust mission critical applications with audit recording and retrieval, backup and redundant capabilities. Development of metric collection, analysis, and reporting capabilities that allow local and remote entry and review. Development of simulation capabilities for the verification of process changes. Verification should be integrated and simulation compared with actual real-time or recorded data. Expected products include concept papers, simulation demonstrations, and subsystem or component level prototype demonstrations.

Integrated Infrastructure – Vehicle Launch Architectures
Development of process, architecture, and cost models in support of vehicle launch architectures and required integrated spaceport infrastructure. Develop and mature the capabilities to effectively trade launch vehicle architectures and integrated spaceport infrastructure to support the reduction of life cycle costs and improved safety. Development of concepts and technology for integrated transportation and handling of large and small elements and equipment, together with precision alignment and placement of hardware elements within the infrastructure. Develop architecture concepts and technology that would support the reduction and elimination of unique spaceport infrastructure and support common infrastructure that would support multiple types of vehicles and spacecraft. Expected products include concept papers, simulation demonstrations, and system or subsystem level prototype demonstrations.

X6.09 Space Transportation Test Requirements and Instrumentation
Lead Center: SSC
Participating Center(s): MSFC

The goal of this subtopic is to identify and develop new technologies that can significantly increase the capabilities for improved rocket engine ground testing and safety assurance while reducing costs. Specific areas of interest include the following:

- Improved cryogenic high-pressure and high-flow rate instrumentation. Temperature sensors that are exposed to the high pressure (up to 15,000 psi) and high flow rates (up to 2000 lb/sec, 300 ft/sec) required in cryogenic (down to 34R) rocket engine testing must be built with significant mass to survive the testing environment. Such robust sensors tend to have slower response rates. There is a need for temperature sensors with millisecond response times that can withstand the aforementioned rocket engine testing environment. 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. Improved cryogenic propellant conditioning methods. New propulsion systems using cryogenic fueled rocket engines are tested using low and high pressure propellant feed systems.

- Non-proprietary wireless technologies for real-time data acquisition, verification, distribution, analysis, control, and storage from field instrumentation and control systems associated with ground testing and ground test facilities. In addition, real-time safety and condition monitoring of facility and test article investments. This includes data management and intelligent sensor fusion across local and mobile computational platforms, real-time graphical representation, methods for collaborative distribution, efficient storage and archival. Wireless instrumentation areas of interest include modular plug-and-play electronics, structurally embedded intelligent sensor networks, and self- and environmentally-aware, localizing and adjusting instrumentation. These capabilities address instrumentation robustness and aging through system redundancy, self-quantizing degradation and autonomous diagnostics, reference and timing calibration using nonintrusive, self-powered, multisensing instrumentation, designed to function within a distributed wireless intelligent networking environment. This system will enable paperless testing configuration, checkout, and verification. Also of interest is robotic manipulation and positioning for audio and visual capture, and real-time multimedia representation distributed across local and remote computational platforms. The system is capable of supporting and integrating model-based control and decision modeling. Where wireless solutions are not feasible, automated inspection and self-healing of wired technologies are required. These technologies should be portable from ground-testing to flight systems.
- Model development and validation of flare stacks, flare stack flame geometry, and flare stack atmospheric effects. When using hydrogen as a rocket engine propellant, hydrogen from boil-off, or hydrogen exhaust from testing components cannot be vented to the atmosphere. Flare stacks are used to burn off this excess hydrogen during both standby and testing operations. New techniques for modeling and designing flare stacks are needed to develop flare systems having improved operational ranges, reduced cost for supplemental purge gas usage, and low environmental impact. These flare systems must operate over a wide range of hydrogen flow rates, which span the range of a few cubic feet per minute to hundreds of pounds per second.
- Economical techniques to maintain the lowest possible liquid propellant feed temperatures (LN, LOX, LH) are sought, including techniques to subcool the propellant.
- New, innovative nonintrusive sensors for measuring flow rate, temperature, pressure, rocket plume constituents, and detection of effluent gas. Sensors must not physically intrude at all into the measurement space. Submillisecond response time is required. Temperature sensors must be able to measure cryogenic temperatures of fluids (as low as 160R for LOX and 34R for LH2) under high pressure (up to 15,000 psi) and high flow rate conditions (2000 lb/sec, 300 ft/sec) for LH2. Pressure sensors must have a range of 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.
- Modeling of the high temperature rocket engine plume radiance and transmittance. Modification of MODTRAN code to include HITEMP database and to include radiance emanating from the engine and the test stand structural materials at high temperatures. Modeling of the engine plume water vapor condensation clouds hovering over and near the test stands. All these effects are required in order to predict radiance effects of the rocket engine testing accurately.
- Methods and instrumentation for rocket plume spectral signature measurements. There are requirements to develop enhanced capabilities in the area of rocket exhaust plume spectral signature measurements. Emphasis is on developing data acquisition, analysis, display software, and systems to support infrared spectrometers, imaging systems, and filter radiometer systems. Overall system concepts should include instrument system calibration methodologies and data uncertainty analysis.

- Development of a methodology to produce design tools with simple interfaces (such as graphical user interfaces [GUIs]) that encapsulate results from high-fidelity analyses and measurements in such a way to allow these results to be manipulated and used to provide optimized and highly-accurate flow performance estimates within a defined design space in a simple, intuitive, and time-efficient manner in the design or modification of flow system components, such as control valves, check valves, pressure regulators, flow meters, cavitating venturis, and/or propellant run tanks.

TOPIC X7 Information and Communication

This topic covers information and communications technologies essential to the manned and unmanned exploration of Cis-Lunar, Lunar, Cis-Martian space and beyond. Exploration to Mars and the outer planets will be conducted in a "staged" approach in which unmanned and manned missions to the Moon, and Mars will be used as proving grounds, as well as destinations on the path to the next objective. To accomplish this effort, advanced systems including manned and unmanned spacecraft, space stations, lunar and Martian surface facilities, as well as a combination of robotic explorers and human exploration crews will be employed. It is essential that interoperable communication and knowledge transfer exist between each class of system. Specific areas of interest include RF and laser-based telecommunication systems, intelligent onboard systems, and mission training systems. Technologies are being sought to provide communication hardware, data links, high data rate, teleoperation, knowledge transfer, data fusion, simulation modeling, sensory immersion, and human and machine interfaces to allow sustained human presence beyond low-Earth orbit. Innovations are sought at the component and subsystem level and include software, electronics, materials, and manufacturing processes.

X7.01 Radio Frequency (RF) Telecommunications Systems
Lead Center: GSFC
Participating Center(s): GRC

The intent of this subtopic is to seek innovations in RF telecommunications systems in support of the Exploration Systems Enterprise plan for manned and unmanned exploration beyond Earth orbit, resulting in a permanent human presence throughout the Solar System. NASA envisions a future including manned and robotic missions to the Moon, Mars, the asteroid belt, and beyond.

These missions require both long-range data links of hundreds of megabits per second, as well as short range (surface-to-surface and surface-to-orbit) data links between power-limited systems including rovers and personal radios. Current systems do not support the high data rates, low power, and low mass required by large numbers of robotic and manned explorers. Near term efforts should focus on the needs of robotic and Cis-Lunar operations. Specific areas of interest include wireless communication crosslinks between robotic rovers, teleoperation of robotic explorers on the lunar surface, communication links between the lunar surface and lunar orbit, and high bandwidth, direct surface-to-Earth links.

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

Fault Tolerant Digital Signal Processing (DSP)
DSP and software defined radio techniques provide tremendous flexibility and power to a communication system. To fully realize the benefits of SDR and DSP, powerful, reconfigurable systems are required using a combination of FPGA and general purpose processors. Current space-qualified DSP elements do not support high bandwidths because of power consumption associated with radiation hardened manufacturing processes, while high bandwidth commercial components cannot survive the space environment.

NASA is interested in the development of a component technology based on commercial DSP and FPGA architectures that provides autonomous fault detection and correction with a graceful degradation in performance over the service life. Single event upsets (SEUs) would be detected and corrected without requiring redundant logic design. Physical "hard" damage due to heavy ionizing radiation would be detected, and affected logic would be re-routed to avoid damaged areas.

Phase I deliverables would include a demonstration to NASA of the technology implemented in commercial components with the prototype delivered to NASA for testing and evaluation. Phase II deliverables would include delivery to NASA of small volume production runs of flight capable components suitable for evaluation, test, and integration into technology demonstration flights.

High Efficiency Power Amplifiers
Data links are envisioned from the Moon and Mars in the hundreds of megabits, requiring powerful RF transmitters. With large amounts of power being used for data return, it is essential to provide an efficient conversion to RF. Higher amplifier efficiency translates directly into lower power consumption for a given bandwidth, immediately extending the science-return of a mission.

Amplifiers are needed in the S and Ku bands. Low power amplifiers should be on the order of a few hundred grams, with power levels between 5–10 W, and efficiencies greater than 60%. High power amplifiers should exceed 100 W for SSPA with greater than 60% efficiencies.

Phase I would include the delivery of a prototype system to NASA for evaluation and test. Phase II would include the delivery of a limited production run to NASA for use in laboratory testing and flight demonstrations.

X7.02 Intelligent Onboard Systems
Lead Center: ARC
Participating Center(s): GSFC, JSC

The intent of this subtopic is to seek innovative technologies that enable intelligent onboard systems to dramatically increase onboard autonomy. As NASA prepares for future exploration missions, system status and performance capability is required to ensure crew safety and mission. Traditional means of providing this information, such as inspections and preventive maintenance, are an extremely 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 intelligence of the onboard systems provides the best means of managing onboard system operations. Intelligent onboard system technologies generally involve the use of goal-oriented autonomous operations, requiring means for sensing the environment and making intelligent choices with regard to resources, operations, health and safety, logistics, and configuration. Specific areas of research include the following:

Intelligent Onboard System Architecture
Proposals addressing this area may focus on developing innovative methods that integrate the core set of intelligent system elements including system reconfiguration, integrated vehicle health management, planning and execution, and human machine interactions, to ensure the right information is delivered at the right place and time to execute the onboard vehicle system functions throughout all mission phases.

Reconfigurable Systems
Proposals addressing this area may focus on developing innovative techniques and strategies for performing system reconfigurations based on Integrated Vehicle Health Management (IVHM) information. System reconfiguration is an important element of system and vehicle management functions. One of the main characteristics of this element is that an intelligent agent will sense and react to the environment by reconfiguring the vehicle systems based on the current situation and resource requirements to maximize operational margins. In addition, the reconfiguration function must take into account the avionics architecture which includes hardware and software cross strapping of systems and data, and redundancy management of the vehicle.

Integrated Vehicle Health Management (IVHM)
Proposals addressing this area may focus on developing innovative techniques for performing system health management functions. IVHM holds many promises for future flight improvements. The function is designed to decrease the anomaly response time. Different inference mechanisms may be explored to focus on detecting failures, determining the root cause, and reporting the severity of the failures based on the operating context and priority. Prognostic techniques might also be used to anticipate system degradation, which enables further improvement in mission success probability, operational effectiveness, human-machine teaming, and automated functional restoration.

Planning and Execution (P&E)
Proposals addressing this area may focus on developing innovative techniques for performing the P&E functions. The planning function is designed to facilitate the coordination of plans and to resolve conflicts across multiple systems and operational constraints, such as coordinating multiple procedures, flight rules, and malfunctions, to achieve the mission objectives. The execution function is to perform the planned procedures. In order to improve the robustness of the execution function, however, alternatives paths should also be modeled to accommodate the changing environment. For this area of research, the performance and the scope of the P&E function must be evaluated in the context of the future space vehicle operation concepts. The issue related to how much the long-term planning function needs to be modeled onboard should be assessed and traded for the complexity of knowledge capture, verification, and validation costs.

Human/Machine Interface
Proposals addressing this area may focus on developing innovative techniques for performing the human/machine interface functions. The goal of the human/machine interface element is to integrate the human crewmembers into a highly automated onboard system. While most vehicle functions will occur under the control of the automation, the human crew must be able to take control of some or all of the vehicle functions in certain mission phases. Because the vehicle is highly automated, it is anticipated that the crewmembers will allow the onboard vehicle automation to handle most, if not all, of the routine operations. Another important goal of the human/machine interface element is to explore the various techniques for providing situational awareness of the current vehicle state. Using this awareness, the crew must have the ability to safely transition from automated control to manual control during all mission phases. Subsequent manual control must be safe, effective, and efficient.

Operations Knowledge Management
Proposals addressing this area may focus on developing innovative tools, techniques, and representations to capture the corporate knowledge about manned spacecraft operations and to quickly and effectively update, test, and certify the operational knowledge and rule bases. Currently, the space flight operations knowledge is being documented in a variety of different sources. For example, flight rules are used in manned space operations to document policies affecting crew safety, vehicle integrity, and critical capabilities and mission success. These policies describe permitted, prohibited and required actions, mission priorities, and program standards. In order to effectively use this set of information for developing the intelligent onboard system, a knowledge capture system must be developed to assist the capturing of the operational knowledge for both human and automated reasoning systems.

Verification and Validation of the Intelligent Onboard Systems
Proposals addressing this area may focus on developing innovative techniques and tools for verifying and validating the intelligent onboard systems. The verification and validation objective is to allow the engineers who are responsible for developing the onboard system to use the tools routinely during design and development, and also during maintenance operations to check for critical system errors. As the onboard software becomes more complex and increasingly more autonomous, a guarantee of intelligent software and knowledgebase correctness becomes even more important and challenging. Example technologies that might be used for intelligent onboard systems are model-based reasoning, rule based systems, and adaptive learning systems.

Life Support System Intelligence
Proposals addressing this area may focus on developing innovative techniques and approaches for providing life support system intelligence for maintaining biological samples. This also involves continuous monitoring of environmental conditions and life support equipment, reprocessing and filtering of consumables, and autonomous management of the supply, control, and distribution of energy.

X7.03 Mission Training Systems
Lead Center: JSC

The technologies required for this subtopic focus on getting away from large training facilities and to provide the same fidelity of training in virtual environments or small training systems. We are looking for training technologies that will facilitate distributed training across an international community and even to a lunar base. Finally, we are looking for innovations that will enable integrated robotic and human operations training in a virtual environment.

Distributed Training
We are looking for innovations that use, build upon, and innovate on the distributed training technologies of the military High Level Architecture (HLA) and the distributed Web training technologies. These innovations should enable simulation and model interaction across an international community. It should ensure secure model interaction over public networks to facilitate low cost connectivity between the international training facilities. The innovation should ensure low bandwidth “real-time” simulation interaction across an international community. Finally, we are looking for innovations that will stretch the distance of the simulation/model interaction across a lunar distance.

Integrated Human/Robotic Training Systems
Innovations and technologies that will enable integrated training environments for autonomous or semi-autonomous robotic systems with human activities are required. These integrated environments should enable the robotic training systems to be located at one location (e.g., Jet Propulsion Laboratory) and the human training systems to be located at a different location (e.g., Johnson Space Center). The training simulation would be controlled at both locations but the participants and robots in the training session would interact as if they were collocated in the same facility.

Training Systems on the Operational Platform
Weight and space considerations will require us to have the training systems collocated with the operational capabilities of the transportation vehicle or on the lunar base. We are looking for innovations that will provide for isolated simulation systems that are embedded and accessible on the operational platform. These systems must enable the individual to train for a task on the operational system without affecting the performance of the vehicle or facility. These innovations should also enable the ability to use the simulation models as part of the analysis tools that are used to monitor the systems. The models used for the training would provide the predicted behavior of the vehicle and could be tied into an Integrated Vehicle Health Monitoring system that would compare the predicted models with the actual system performance and inform the user of any deviations.

Distributed Virtual Environments
Along with technologies that enable distributed model interaction, we are seeking technologies that will facilitate interactive virtual environments across an international community. These systems should provide realistic sensory feedback including tactical, audible and visual in order to provide the distributed team with the appropriate perception required to complete the task. The feedback should also reflect the realistic sensory feedback in a micro-gravity, 1/6 g or 1 g environment. The virtual environments should provide realistic models of the lunar environment and the objects rendered should be realistic representations of the systems on the space vehicle tied to the distributed models mentioned above. The virtual environments should enable easy reconfiguration of the environment (including the gravity aspects mentioned previously) and should enable the connection with other models including a virtual human for realistic human performance. The training environments should also provide the operations community to interact with the participants in the training. We are looking for environments that not only train the individuals

performing a task, but the team that is tasked with monitoring their operations and the systems being used to enable the task to be performed. At NASA, this team is known as the Control Center Operations team.

Modular Training Systems
We are looking for innovations that will enable various models and simulations to be easily plugged into a training environment. Currently, the training systems are so integrated with the simulations that it takes extensive effort to reconfigure the training environment from models from different companies or countries. We are looking for new standard simulation interfaces that will enable this plug-and-play capability. This would also extend to the interface side where it would be easily integrated with a virtual environment, a desktop environment, or an autostereoscopic display.

Adaptive Training Environments
We are looking for innovations that will use and build upon the gaming industries ability to automatically reconfigure the simulation based on a student's demonstrated expertise in the simulation. We are looking for this capability applied to operations and tasks associated with a translunar or lunar environment. Also in the joint robotic/human operations, we are looking for systems that will enable the robotic autonomy to be tunable to train varying degrees of human interaction with the robotic systems. Finally, the adaptive training environments should allow the student to determine the depth of training in the virtual environment.

X7.04 Human Surface Systems Electronics and Communications
Lead Center: JSC

This subtopic focuses on the electronics and communications technologies needed for deploying human expeditions in deep space and on planetary surfaces. The target environment is beyond the protection of the Earth's magnetic field, exposing devices to a high rate of cosmic radiation that induces latch up and single event upset (SEU), but low total dose because excess crew exposure will be avoided. On planetary surfaces, equipment outside habitable areas also sees temperature extremes and physical contaminants. The system architecture will require a larger number of diverse and complex devices, closer in function to commercial devices than is the case with unmanned missions. Minimizing weight and volume are critical requirements for missions into deep space and planetary gravitational wells. This introduction spells out common objectives, while each area description provides a technical objective and specifies the relative emphasis the environment should be given at this time.

The function and use of these systems should be similar to the function and use of automated, semi-automated, and information technology systems otherwise in use near the time in which the exploration mission occurs, but with additional self-monitoring for fault detection and management. Where a system's function is critical it requires fault tolerance and rapid reconfiguration. Unlike the low-Earth orbit environment, commercial components will rarely be usable, and unlike smaller unmanned projects, custom development of a significant percentage of the components will not be feasible.

Specific areas of interest relating to human surface systems for human exploration include the following:

Integrated Multi-Channel Control Devices
Human mission support systems tend to require actuators and motor controllers for micro-flyers and teleoperated robots (hand with fingers) that demand high reliability. Temperature range and more particularly, radiation tolerance requirements, must be met. Radiation induced latch-up failure of power devices must be strictly avoided as it creates a high-energy failure that can cascade into other nearby systems.

For actuators, 4–12 channels of 1–4 amperes high side switching of 28 V with back electromotive force (EMF) clamping are desirable. Use of complementary metal oxide semiconductor (CMOS) technology would ease on-chip integration with other functions. Fabrication processes chosen should be affordable for prototyping, as well as modest production runs. Channel fault monitoring should be integrated, along with latch-up prevention, for use in the target environment.

For multi-channel motor controllers, actuator devices should be integrated with radiation tolerant control circuitry, and they should be able to generate optimum sine wave control signals in power circuits using pulse width modulation.

We are primarily interested in components or systems which function in the target environment. Phase I proposals should include prototype hardware demonstrations delivered to NASA for test and evaluation. Phase II proposals should include sample quantities of production quality hardware for evaluation, test and use in-flight experiments.

Integrated Multi-Channel Data Acquisition Components
These are devices that provide filtering, amplification, and multiplexing to support the acquisition of low-level signals in a noisy environment with a minimization of wiring and power. Unlike commercial devices, which usually do not provide per-channel filtering for large channel counts, and frequently are implemented with very radiation-susceptible mixed-signal process technologies, the components required for surface exploration systems must be very robust both with respect to noise and radiation.

The purpose is to avoid limiting the number of channels monitored and to always provide sufficient data to determine the health and status of systems and equipment deployed to the surfaces of other planets. Requirements include acquiring data from sensors with low level output, such as strain gauges and thermocouples, easily swamped by noise and filtering.

The desired architecture would allow configurability of gain up to several hundred and filtering down to a few tens of Hertz, with control and output data multiplexed onto a small number of wires or communication channels. Both wired and wireless systems are of interest. Ability to integrate with other functions, such as control and communications, is preferred. Devices should contain calibration and self-test functions.

Phase I proposals should include prototype hardware demonstrations delivered to NASA for test and evaluation. Phase II proposals should include sample quantities of production quality hardware for evaluation, test and use in-flight experiments. Proposals may optionally use patented NASA radiation tolerant technology (US 6,3777,097 B1) and patent-pending instrumentation technology for on-chip filters and multi-channel architectures.

Environmentally Rugged and Reliable Versions of Commercial Computer and Communications Devices
This area addresses both complete devices such as laptops and communication handsets, and components such as processors and field programmable gate array's (FPGA's). NASA relies increasingly on complex FPGA devices, which may contain memory, bus interfaces, processors or other complex intellectual property. The environment of deep space and planetary surfaces is more severe; however, it is estimated that the qualification testing approach will not be sufficient.

The diversity of devices needed to support human exploration and the closeness to commercial state-of-the-art which is expected, are not typically addressed when deploying robotic-only missions. The continuously growing complexity and proprietary intellectual property content make it undesirable to completely re-engineer such devices as flat panel displays and their controllers, multigigahertz central processors, and the communication protocols. Cost-effective processes implementing environmentally suitable versions of common commercial computer and communications devices are highly desired.

Methods for cost-effectively producing radiation tolerant and thermally enhanced versions of near state-of-the art digital, radio frequency (RF), FPGA, display, and user interface components are desired. Issues of design tool affordability, design flow completeness, and viability for low or moderate volume applications should be considered. Note that shielding is generally not adequate mitigation for cosmic radiation.

Phase I should include demonstrations of tool flow and process flow as applicable and an actual demonstration of some aspect of the ruggedization, which can be evaluated and tested by NASA. Phase II should include sample quantities of complete systems or process flows delivered to NASA for use in prototype flight projects. Proposals may optionally use patented NASA radiation tolerant technology (US 6,377,097 B1).

Reconfigurable Software Defined Radio (SDR)
Human planetary surface exploration and deep space missions will deploy a wide variety of vehicles, tools, and experiments that have unique requirements for modulation, data rate, etc. Reconfigurable SDR techniques are desired to minimize the development time and cost for diverse communication systems, as well as the number of separate radios necessary on various spacecraft.

SDR components must be small and low power to broaden their application range. Target applications include such functions as integrating communications functions with remote battery or solar powered single-chip data acquisition functions. An ultrasimplified and efficient form of SDR is also desirable, for implementation in smaller FPGA's or Application-Specific Integrated Circuits (ASICs).

The SDR should consist of a limited RF front end, followed by a high bandwidth analog/digital (A/D) (receive side) and digital/analog (D/A) (transmit side), and a final reprogrammable processing stage. Prototype hardware should be accompanied with a development system using commercially available and/or custom software with models of various components that can be used to simulate a communication system. The development system should be able to convert the computer-aided design/electronic design automation (CAD/EDA) model to firmware, and should include the hardware and software necessary to program the SDR. The SDR should be able to accommodate various NASA- and contractor-developed communication systems, which support surface-to-surface, space-to-space, and space-to-surface links, by reprogramming the SDR and with minimum RF front-end hardware changes.

Emphasis should be on reusable environmentally qualified components and development processes, which NASA can employ in integrated embedded systems, with the delivery of a complete SDR system serving primarily to validate the bidder's proposed approach. Consideration should be given for any CAD/EDA or other commercial tools or components used as to suitability, configuration control, and maintainability for use in a long-duration mission-critical environment. Phase I proposals should demonstrate interoperability with at least one NASA communications system (such as, but not limited to, Space to Space Communications, Wireless Video System, Tracking and Delay Relay Satellite System Spaceflight Tracking and Data Network (TDRSS STDN), TDRSS Ku Band, etc.). Phase II should develop hardware and software that can be used in some on-going NASA project and provide interoperability with at least two communication systems.

TOPIC X8 Systems Integration, Analysis, Concepts and Modeling

This topic addresses the development, deployment, and operation of methods, tools, and infrastructure providing new capabilities in NASA systems analysis, model-based design and acquisition, and decision support. This will include capabilities enabling the modeling of key system and infrastructure elements in support of analyses, concept and mission studies to inform future decisions on supporting technology research, enabling technology developments, and demonstrations and validations for emerging products.

X8.01 Technology-Systems Analysis and Infrastructure Modeling
Lead Center: JPL
Participating Center(s): ARC

The purpose of this subtopic is to advance capability in technology analysis and systems analysis. This includes the process, methods, and tools to characterize and model technology in terms of performance, risk and cost, and the means to exercise that knowledge in the context of system-wide trades and design. It also includes the quantification of suitable metrics and processes that optimize the overall development and integration of technology into flight units. This year’s solicitation will give priority to advancing this capability in the following areas:

- Methods for the conduct of impact studies against Design Reference Missions and/or other future system representations;
- Development of Trade Structures and methods for determining relative benefit, risk, and cost of the utilization of various technologies;
- Methods for assigning quantitative value to missions and/or sets of missions;
- Methods for modeling and quantifying technological capability and risk, and projections to the future including uncertainties;
- Means for overall prioritization and/or optimization of technological approaches for different resource allocations or other constraints; and
- Development of decision-based structures representing system and mission designs.

This subtopic will also focus on developing Model-Based Design/Model-Based Engineering (MBD/MBE) capabilities in order to provide effective full-phase, full-breadth mission and system models that could be exercised in a variety of design environments, trade studies, system and investment analysis efforts, and program and technology planning activities. It will address both the model development itself and the development of methods and structures necessary to exercise them effectively in system and mission design and operations environments. This will provide not only the basis to extend available commercial-off-the-shelf (COTS) MBD/MBE capabilities, but also provide the means to evaluate infusion benefits and effects and relative costs for existing or future technologies.

Technical areas to address include:

- Model integration efforts, focused on methods for subsystem integration of disparate models, particularly non-physics-based models;
- Development and integration of risk models including uncertainty methods and propagation at the subsystem and system levels;
- Methods to evaluate model performance and validation to ensure agile evolution of the models, particularly as it affects or is affected by phase transition;
- Development and usage of MBD/MBE constructs in reviews;
- Construct development of technology models;
- Integration and validation of cost models, particularly addressing technology elements; and
- Integration of MBD/MBE constructs with mission design.

X8.02 Design Technologies for Entry Vehicles
Lead Center: ARC
Participating Center(s): MSFC

Highly reliable, highly credible, highly efficient, and increasingly affordable design technologies are enabling and enhancing technologies for future human or robotic exploration missions. Innovative design technologies, knowledge, and infrastructures are solicited both to explore and support decisions about vehicles and missions. This subtopic solicits systems-level innovations and high-leverage technologies, derived from clear concepts of design operations to conduct conceptual design, preliminary designs and final design. Design tools need to be demonstrated with realistic entry vehicles.

The current entry vehicle design approach is time consuming, loosely coupled across disciplines, and of varying fidelity across various disciplines. The general approach that has been employed for the current generation robotic exploration entry vehicles starts with the selection of a simple forebody shape. Trajectory optimization and guidance, navigation, and control (GN&C) are then used to establish the best robust trajectory, either based on heat flux and heat load or determined through Monte Carlo techniques, for the particular entry mission of interest. Finally, the thermal protection system (TPS) material selection and thicknesses are designed such that the given vehicle shape can withstand (with margins) the robust entry trajectory. While this design approach has been successful for current low mass robotic missions its usefulness for future missions is dependent on future mission requirements. In some cases, the approach may result in excessive margins in TPS weight or entry vehicle mass margin to yield a mission success.

Innovative, integrated, credible, rapid, efficient, and robust design technologies, which include simulation tools and processes, are solicited. The tools and processes with the appropriate modeling fidelity should be able to treat coupled multi-objective and multi-disciplinary design optimization incorporating uncertainty. Integrated design tools and processes are sought for entry systems that combine vehicle shape optimization, vehicle control design, trajectory optimization, thermal-structural responses, and thermal protection system material selection and thickness design. The disciplines that must be accounted for and integrated in these future entry vehicle design tools and processes are: aerodynamics, aerothermodynamics, TPS thermal stress analysis, thermal-structural analysis, GN&C, and trajectory. Technologies are sought for credibly predicting performance parameters and relevant physical quantities in relevant flight environments, after establishing the acceptable level of credibility of these parameters and quantities in test conditions. Design Technologies must be able to accommodate uncertainties and dispersions in atmospheric uncertainty, entry angle uncertainty, entry velocity uncertainty, aerodynamic uncertainty, vehicle mass uncertainty, aerothermal environments uncertainty, GN&C uncertainty, and material response uncertainty. Advanced risk assessment technologies are also solicited to determine mission risks and probability of Loss of Crew (LOC) and of Loss of Vehicle (LOV).

At the completion of the Phase I effort for this subtopic, the work performed will be evaluated (1) to validate the relevancy of the proposed effort (considering available, relevant Level 1 mission requirements); (2) to establish the technical merit and feasibility of the proposed innovation; and (3) to provide a basis for continued development in Phase II. The desired, innovative Phase I product is principally one or more of the following items: computational methods, processes, tools, analyses, conceptual designs, computer simulations, and trade studies. All computer simulations need to be presented with uncertainties to establish their credibility.

This page has intentionally been left blank.

9.1.5 SPACE SCIENCE

The Space Science Technology Development Program develops and makes available new space technologies needed to enable and enhance exploration, expand our knowledge of the universe, and ensure continued national scientific, technical, and economic leadership. It strives to improve reliability and mission safety, and to accelerate mission development. Since the early 1990s, the average space science mission development time has been reduced from over 9 years, to 5 years or less, partly by integration and early infusion of advanced technologies into missions. For missions planned through 2004, we hope to further reduce development time to less than 4 years. Our technology program encompasses three primary capabilities, in space where necessary, so that they can be confidently applied to space science flight projects. Finally, we apply these improved and demonstrated capabilities in the space science programs and transfer them to U.S. industry for public use through programs such as the Small Business Innovation Research Program. For more information on space science at NASA, see:

http://spacescience.nasa.gov/

TOPIC S1 Sun Earth Connection....... 168

S1.01 Technologies for Particles and Fields Measurements....... 168
S1.02 Deep Space Propulsion....... 169
S1.03 Multifunctional Autonomous Robust Sensor Systems....... 171
S1.04 Spacecraft Technology for Micro- and Nanosats....... 171
S1.05 Information Technology for Sun-Earth Connection Missions....... 172
S1.06 UV and EUV Optics....... 173

TOPIC S2 Structure and Evolution of the Universe....... 174

S2.01 Sensors and Detectors for Astrophysics....... 174
S2.02 Terrestrial and Extraterrestrial Balloons and Aerobots....... 175
S2.03 Cryogenic Systems....... 176
S2.04 Optical Technologies....... 177
S2.05 Advanced Photon Detectors....... 178
S2.06 Technologies for Gravity Wave Detection....... 179

TOPIC S3 Astronomical Search for Origins....... 181

S3.01 Precision Constellations for Interferometry....... 181
S3.02 High Contrast Astrophysical Imaging....... 182
S3.03 Precision Deployable Lightweight Cryogenic Structures for Large Space Telescopes....... 183
S3.04 Large-Aperture Lightweight Cryogenic Telescope Components and Systems....... 183

TOPIC S4 Exploration of the Solar System....... 184

S4.01 Science Instruments for Conducting Solar System Exploration....... 184
S4.02 Extreme Environment and Aerial Mobility....... 185
S4.03 Advanced Flexible Electronics and Nanosensors....... 186
S4.04 Deep Space Power Systems....... 187
S4.05 Astrobiology....... 188

TOPIC S5 Mars Exploration....... 189

S5.01 Detection and Reduction of Biological Contamination on Flight Hardware and in Return Sample Handling....... 189
S5.02 Mars *In Situ* Robotics Technology....... 190
S5.03 Mars and Deep-Space Telecommunications....... 191

TOPIC S1 Sun Earth Connection

The overarching goal of the Sun–Earth Connection (SEC) theme in Space Science is an understanding of how the Sun, heliosphere, and planetary environments are connected in a single system. The three principal science objectives spring from this goal:

1. Understanding the changing flow of energy and matter throughout the Sun, heliosphere, and planetary environments;
2. Exploring the fundamental physical processes of plasma systems in the solar system; and
3. Defining the origins and societal impacts of variability in the Sun–Earth Connection.

SEC missions investigate the physics of the Sun, the heliosphere, the local interstellar medium, and all planetary environments within the heliosphere. They address problems such as solar variability, the responses of the planets to such variability, and the interaction of the heliosphere with the galaxy. Increasingly, SEC investigations have focused upon space weather, the diverse array of dynamic and interconnected space phenomena that affects life, society, and exploration systems. Technology plays an important role in maximizing the science return from all SEC missions.

S1.01 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.
- 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.
- 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.
- Miniaturized, radiation-tolerant and autonomous electronic systems for the above, within resource envelopes of 1–2 kg and 1–2 W.

S1.02 Deep Space Propulsion
Lead Center: MSFC
Participating Center(s): GRC, GSFC, JSC

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 solar electric, chemical and thermal, solar sails, aeroassist and aerocapture and emerging technologies.

Solar Electric Propulsion
Innovations in electric propulsion system technologies are being sought for space science applications. One area of emphasis pertains to high-performance propulsion systems capable of delivering specific impulse (Isp) greater than 2000 s, using electrical power from radioisotope or solar energy sources. Thruster technologies include, but are not limited to, ion engines, Hall thrusters, and pulsed electromagnetic devices. Other areas of interest include propellant storage, direct drive and other innovative power processing, power management and distribution, heat-to-electrical power conversion, and waste heat disposal. Innovations considered here may focus on the component, subsystem or system level, and must ultimately result in significant improvements in spacecraft capability, longevity, mass, volume, and/or cost.

Solar Sails
Solar sails are envisioned as a low-cost, efficient transport system for future near-Earth and deep space missions. NASA mission's enabled and enhanced by solar sail propulsion include Tech Pull Missions such as Geotail, Comet Sample and Titan Flyby all to be launched between 2009 and 2012. Another category of NASA missions is the Particle Acceleration Solar Orbiter, including the L1-Diamond and the Solar Polar Imager, both to be launched between 2015 and 2028. Solar Sails are enabling for several strategic missions in the Sun-Earth Connection Space Science theme, including Solar Polar Imager and Interstellar Probe, the latter being a sail mission to explore interstellar space. Missions in the Exploration of the Solar System theme would be broadly enhanced by the availability of proven sail technology. Innovations are sought that will lower the cost and risk associated with sail development and application, and enhance sail delivery performance. Innovations are sought in the following areas: systems engineering, materials, structures, mechanical systems, fabrication, packaging and deployment, system control (attitude, etc.), maneuvering and navigation, operations, durability and survivability, and sail impact on science. Development of ultra-lightweight inflatable and deployable support structures is of significant interest, including rigidization approaches. Innovations in ultra-light reflective thin films are also sought. Three parameters have been used as sail performance metrics in mission applications: sail size, sail survivability for close solar approaches, and areal density (ratio of mass of the sail to area of the sail). In addition, important programmatic metrics are cost, benefit, and risk. Technologies of interest should be geared toward a wide range of sail sizes, solar closest approach distances, and aerial densities, and may be optimized for one portion of the range rather than trying to cover the whole range. Sail sizes may range from very small (meter-sized for use with very tiny picosat payloads

or for use as auxiliary propulsion), to medium (50–100 m size for achieving high-inclination solar orbits or non-Keplerian near-Earth orbits) and ultimately to the very large (hundreds of meters for levitated orbits, high delta V, and for use in leaving the Solar System at high speed). Sail weight should include, but not be limited to, ultra-lightweight sail materials (<1 gram/m^2). Closest solar approaches may range from 1 AU down to 0.1 AU. Aerial densities for a solar sail subsystem (excluding payload) may range from 1–15 g/m^2. Unconventional sail architectures are also sought (e.g., heliogyros, spinners, rigid sails, tensegrity structures, solar photon thruster, dual mode with aerobraking, solar thermal, microwave beam, etc.).

Chemical and Thermal Propulsion
Innovations in low-thrust chemical propulsion system technologies are being sought for Space Science missions applications. One area of interest is a bipropellant engine with Isp greater than 360 s. Component, subsystem, or system level technology development will be considered but work must ultimately result in significant reductions in spacecraft system mass, volume, and/or cost. Other areas to be considered include lightweight, compact and low-power propellant management components, such as valves, flow control/regulation, fluid isolation, dependable ignition systems, and lightweight tankage.

Aeroassist
Aeroassist is a general term given to various techniques to maneuver a space vehicle within an atmosphere, using aerodynamic forces in lieu of propulsion 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:

<u>Aerocapture</u>
Thermal Protection Systems: Development of advanced thermal protection systems and insulators. Materials need high strength (modulus in the tens of GPa) and very low density (tens of kg/m^3). Improvements needed in materials include having highly anisotropic thermal properties, i.e., high thermal diffusivity tangential to the spacecraft shape and low thermal diffusivity normal to the spacecraft shape.
Sensors for Inflatable Decelerators: Health monitoring method for inflatable thin film systems.
Analytical Tools: Development of advanced tools to perform coupled aeroelastic and aerothermal analysis of inflatable decelerator systems.

<u>Aerogravity Assist</u>
Aerogravity Assist Technology Analysis: Research advancements in leading edge materials and provide CFD analysis of heating environment for aerogravity assist maneuvers at a small planet (e.g., Venus).

Emerging Propulsion Technologies
This effort will focus on technologies supporting innovative and advanced concepts for propellantless propulsion and other revolutionary transportation technologies. The categories under Emerging Propulsion Technologies include, but are not limited to: electrodynamic and momentum-exchange tether propulsion, beamed energy, ultra-light solar sails, bimodal sails, and low to medium power electric propulsion (including pulse inductive devices). The electrodynamic tether propulsion uses electromagnetic interaction with a planetary magnetic field to exchange angular momentum . Momentum exchange tethers (such as the MXER tether concept use a strong tether to transfer angular momentum and orbital energy to a payload. Beamed energy propulsion concepts include lasers or microwave energy to directly propel a spacecraft or to supply power that is utilized for propulsion onboard the spacecraft. Ultra-light or bimodal sail propulsion developing conventional solar sails into extremely high-performing systems. The low to medium electric propulsion is a general category for fresh variations of electric thrusters (Hall, MHD,

PIT, etc.) that support near or mid-term solar powered spacecraft (e.g., below ~50 kW). Unique, innovative and novel propulsion ideas are sought but with reasonable expectations to progress to hardware prototypes. The concept must be above TRL 2 with rapid demonstration to TRL 4 expected. Distinctive variations of existing propulsion methods or chief subsystem component improvements are also suitable for submission. Proposals should provide development of specific innovative technologies or techniques supporting any of the above approaches. A clear plan for demonstrating feasibility, noting any test and experiment requirements, is also recommended. Key to each idea is an unambiguous knowledge of past research and concepts conducted on related work, and specifically, how this new proposal differs to the extent that it appears to offer a significant benefit. Identification of the fundamental technology to be developed is also crucial.

S1.03 Multifunctional Autonomous Robust Sensor Systems
Lead Center: LaRC
Participating Center(s): GSFC, JPL

NASA seeks innovative concepts for Multifunctional Autonomous Robust Sensor Systems (MARSS) to increase spacecraft autonomy and robustness. These concepts are intended to lower overall mission costs, reduce reliance on human control and monitoring, and allow for systems that are inherently robust and provide maximum flexibility of the space vehicles throughout mission lifecycle and for various space/planetary exploration missions. The systems should include the ability to couple the data from a variety of distributed sensor technologies to relevant response actuation systems of the vehicle. As we move from 10s of sensors to 1000s of sensors and beyond, new approaches must be investigated that will allow the vehicle to efficiently obtain “knowledge” about the health and optimization of its systems, and the ever changing environment it is in.

Robustness and autonomy in space vehicles are two of the keys to achieving maximum efficiency of missions and increasing the probability of success. Distributed, self-sufficient, reconfigurable sensors are at the heart of this capability. Technologies such as, but not limited to, MEMS, nanotechnology, integrated /distributed processors and fuzzy logic are potential elements of MARSS. These systems should be able to provide their own power by scavenging it from the environment and provide real-time knowledge from large numbers of sensors to various response systems to comprise “sense and respond” systems. In addition, methods are sought to improve radiation shielding of systems components. This includes, but are not limited to, metal and metal matrix materials that may offer better radiation protection properties than the current state-of-the-art aluminum alloys, and high atomic number intercalated graphite composites for light weight strong radiation shielding of electronics to improve their robustness.

Emphasis should be placed on technologies that provide a sense-and-respond capability using technologies that are small, reliable, low-cost, lightweight, and would allow space probes to adapt to a wide range of space missions. Sensing requirements include both intrinsic (relating to the performance and health of the vehicle itself) and extrinsic (relating to the performance of the mission and adapting to the operating environment).

Evaluators will be looking for system concepts and not just individual pieces that could be used for a system. This requires multidiscipline collaboration on various proposals and clear explanations of system functionality, benefit, and improvement over existing technology. In addition, details of how systems will function in relevant space environments should be provided. The Technology Readiness Level(TRL) for submissions should be in the TRL 4-6 range. Please see the SBIR Web site for more details.

S1.04 Spacecraft Technology for Micro- and Nanosats
Lead Center: GSFC

NASA seeks research and development of components, subsystems and systems that enable inexpensive, highly capable small spacecraft for future SEC missions. The proposed technology must be compatible with spacecraft somewhere within the micro-to-nano range of 100 kg down to 1 kg. All proposed technology must have a potential for providing a function at current performance levels with significantly reduced mass, power, and cost, or have a potential for significant increase in performance without additional mass, power, and cost. These reduction and/or improvement factors should be significant and show a minimum factor of 2 with a goal of 10 or higher.

A proposed technology must state the type or types of expected improvements, (performance, mass, power, and cost), list the assumptions for the current state-of-the-art, and indicate the spacecraft range of sizes for which the technology is applicable.

The integration of multiple components into functional units and subsystems is desirable but not a requirement for consideration.

- Avionics and architectures that support command and data handling functions, including input and output, formatting, encoding, processing, storage, and analog-to-digital conversion. System level architecture, software operating systems, low voltage logic switching, radiation-tolerant design, and packaging techniques are also appropriate technologies for consideration.
- Sensors and actuators that support guidance, navigation, and control functions such as Sun–Earth sensors, star trackers, inertial reference units, navigation receivers, magnetometers, reaction wheels, magnetic torquers, and attitude thrusters. Technologies with applications to either spinning or three-axis stable spacecraft are sought.
- Power system elements including those that support the generation, storage, conversion, distribution regulation isolation, and switching functions for spacecraft power. System level architecture, low voltage buss design, radiation tolerant design, and novel packaging techniques are appropriate technologies for consideration.
- New and novel application of technologies for manufacturing, integration and test of micro and nano size spacecraft are sought. Limited production runs of up to several hundred spacecraft can be considered. Efficiencies can derive from increased reliability, flexibility in the end-to-end production process, as well as cost, labor, and schedule.
- Technologies that support passive and active thermal control suitable for micro and nano size spacecraft are sought. These functions include heat generation, storage, rejection, transport, and the control of these functions. Efficient system level approaches for integrated small spacecraft that may see a wide range of thermal environments are desirable. These environments may range from low heliocentric orbits to 2 hr shadows.
- Elements that support Earth-to-space or space-to-space communications functions are sought. This includes receivers, transmitters, transceivers, transponders, antennas, RF amplifiers, and switches. S and X are the target communications bands.
- System architectures and hardware that lead to greater spacecraft and constellation autonomy and, therefore, reduce operational expenses are desired. Technologies that derive added capability for a fixed bandwidth, efficient utilization of ground systems, status analysis, and situation control or other enhancing performance for operations are sought.
- Structure and mechanism technologies and material applications that support the micro and nano class of spacecraft are desired. Exoskeleton structures, spin release mechanisms, and bi-stable deployment mechanisms are typical of the desired technology.
- Propulsion system elements that provide delta-V capability for spinning and/or three-axis stable spacecraft are sought. This includes solid, cold-gas, and liquid systems, and their components such as igniters, thrust vector control mechanisms, tanks, valves, nozzles, and system control functions.

S1.05 Information Technology for Sun-Earth Connection Missions
Lead Center: GSFC

A large number of multiple-spacecraft missions are planned for the future of SEC science. Cost-effective implementation of these missions will require new information technology: tools, systems and architectures for mission planning, implementation, and operations; and science data processing and analysis that facilitate scientific understanding. Specific research areas of interest for these SEC multi-spacecraft missions include the following items below.

Information Technology for Cost-Effective Mission Planning and Implementation
Tools or systems are needed that improve the system engineering, integration, test, and synchronous operations of semiautonomous multispacecraft missions with intermittent contact and large communication latencies; automated approaches to onboard science data processing and reactive onboard instrument management and control; and tools that capture and represent scientific objectives as preplanned and reactive onboard autonomous drivers.

Data Analysis
Items of interest in this area focus on innovative approaches and the tools necessary to support space and solar physics virtual observatories (physically distributed heterogeneous science data sources considered as a logical entity).

Tools are needed for enabling automated systematic identification, access, ad hoc science analysis, and distribution of large distributed heterogeneous data sets from space and solar physics data centers; and technologies and tools supporting inclusion of individual researcher provided, ad hoc, science analysis modules as a component of search criteria for remote data mining at space and solar physics data centers.

S1.06 UV and EUV Optics
Lead Center: GSFC
Participating Center(s): MSFC

From the Sun's atmosphere to the Earth's aurora, remote imaging, spectroscopy, and polarimetry at ultraviolet (UV) and extreme ultraviolet (EUV) wavelengths are important tools for studying the Sun-Earth connection. A far ultraviolet (FUV) range is sometimes interposed between UV and EUV, but the terminology is arbitrary: the pertinent full range of wavelength is approximately 20–300 nm.

Proposals should explain specifically how they intend to advance the state-of-the-art in one or more of the following areas.

Imaging Mirrors
- Large aperture: 1–4 m
- Low mass: 5–20 kg m^{-2}
- Accurate figure: ~0.01 wave rms or better at 632 nm. 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)
- Low microroughness: ~1 nm rms or better on scales below 1 mm.

Optical Coatings and Transmission Filters
- Coatings (filters) with improved reflectivity (transmission) and selectivity (narrow bands, broad bands, or edges). Technologies include (but are not limited to) multilayer coatings, transmission gratings, and Fabry-Pérot étalons.

Diffraction Gratings
- High groove density (> 4000 mm^{-1}) for high spectral resolving power in conjunction with achievable focal lengths and pixel sizes
- High efficiency and low scattter (microroughness)
- Variable line spacing
- Echelle gratings
- Active gratings (replicated onto deformable surfaces)
- Aspherical concave substrates, such as toroids and ellipsoids

Proposals that address detector requirements of Sun-viewing instruments, such as large format, deep wells, fast readout, or "3-D" (spatial-spatial-energy) resolution, should be submitted to Topic S2.05.

TOPIC S2 Structure and Evolution of the Universe

The goal of the Space Science Enterprise's Structure and Evolution of the Universe (SEU) Theme is to seek the answer to three fundamental questions:

1. What is the structure of the universe and what is our cosmic destiny?
2. What are the cycles of matter and energy in the evolving universe?
3. What are the ultimate limits of gravity and energy in the universe?

SEU's strategy for understanding this interactive system is organized around four fundamental Quests, designed to answer the following questions:

1. Identify dark matter and learn how it shapes galaxies and systems of galaxies,
2. Explore where and when chemical elements were made,
3. Understand the cycles in which matter, energy, and magnetic fields are exchanged between stars and the gas between stars,
4. Discover how gas flows in disks and how cosmic jets formed,
5. Identify the sources of gamma-ray bursts and high energy cosmic rays, and
6. Measure how strong gravity operates near black holes and how it affects the early universe.

S2.01 Sensors and Detectors for Astrophysics
Lead Center: JPL

Future NASA astrophysics missions like Sofia, Herschel, Planck, FAIR, MAXIM, EXIST, and ARISE (http://spacescience.nasa.gov/missions/index.htm) need improvements in sensors and detectors. Beyond 2007, expected advances in detectors and other technologies may allow the Filled Aperture Infrared instrument (FAIR) to extend HST observations into the mid- and far-infrared (40–500 micron) region; the Micro-Arcsecond X-ray Imaging Mission Pathfinder (MAXIM) will demonstrate the feasibility of x-ray interferometry with a resolution of 100 micro-arc seconds, which is 5000 times better than the Chandra observatory; the Energetic X-ray Imaging Survey Telescope (EXIST) will conduct the first high sensitivity, all-sky imaging survey at the predominantly thermal (x-ray) and non-thermal (gamma-ray) universe requiring a wide-field coded aperture telescope array; and the Advanced Radio Interferometry between Space and Earth (ARISE) mission will create an interferometer including radio telescopes in space and on Earth.

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 Very Long Baseline Interferometry (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.

S2.02 Terrestrial and Extraterrestrial 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 Space and Earth Science Enterprises. 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. 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. Robotic balloons, known as aerobots, have a wide range of potential applications both on Earth and on other solar system bodies. NASA is seeking innovative and cost-effective solutions in support of terrestrial and extraterrestrial balloons and aerobots in the following areas.

Stratospheric Long Duration Balloon (LDB) Support

Materials
- Innovative membranes for terrestrial applications to support the Long Duration Balloon (LDB) and Ultra-Long Duration Balloon (ULDB) development efforts. The material of interest shall meet all environmental, design, fabrication, and operational requirements and must be producible in large quantities in a lay-flat width of at least 1.6 m.
- Innovative concepts for reducing the UV degradation of flight components including balloon membranes, load carrying members, and parachute components.

Support Systems
- Innovative concepts for trajectory control and/or station-keeping for effectively maneuvering large terrestrial and small extraterrestrial aerobots 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 a duration of 30 days or more.
- Innovative, low cost, low power, low mass, precision instrument pointing systems that permit arcsecond or better accuracy.
- Innovative sensor concepts for balloon gas or skin temperature measurements.
- Innovative floatation systems for water recovery of payloads.

Design and Fabrication
- Innovative, efficient, reliable and cost-effective balloon fabrication and inspection techniques to support the current ULDB development efforts.
- Innovative balloon design concepts for long duration missions which can provide any or all of the following:
    - Reduced material strength requirements;

- Increased reliability;
- Enhanced performance;
- Reduced manufacturing time;
- Reduced manufacturing cost; and
- Improved mission flexibility.

Titan Missions Support
Titan is the second largest moon in the solar system and the only one that features a sufficiently dense atmosphere for buoyant vehicle flight. Targeted for exploration by Cassini-Huygens in 2004 and beyond, Titan is expected to be a geologically and chemically diverse world containing important clues on the nature of prebiotic chemistry. NASA is starting to lay the ground work for post-Cassini-Huygens exploration of Titan using highly autonomous, self-propelled aerobots capable of surveying many widely separated locations on the world and potentially including surface sampling and composition analysis. Innovative technologies are sought in the following areas:

- Concepts, devices and materials for sealing (repairing) of small holes in the balloon envelope material during flight at Titan. Repair of these holes may be required to enable the long mission lifetimes (6–12 months) desired at Titan. Although the balloon envelope material for Titan has not yet been specified, repair strategies should be generally compatible with polymer materials and the 90 K environment. It is imperative that proposed solutions be low mass (on the order of a few kilograms) and low power (a few Watts).
- Concepts and devices for the processing of atmospheric methane into hydrogen gas and its use as a makeup gas to compensate for leakage during operational flight at Titan. It is imperative that proposed solutions be low mass (on the order of a few kilograms) and low power (a few Watts).

Venus Missions Support
Venus is the second planet from the Sun and features a dense, CO_2 atmosphere completely covered by clouds. Although already explored by various orbiters and short-lived atmospheric probes and landers, Venus retains many secrets pertaining to its formation and evolution. One of NASA's long-term objectives is to develop the technologies required for a surface sample return mission. A high temperature balloon is one key element that will be needed to loft the sample from the surface to a high altitude for launching a return rocket back to Earth. Innovative technologies are, therefore, sought in the following area:

- Designs, materials, and prototypes for surface-launched Venus balloons. Balloon volumes in the range of 0.5–5 m^3 are required when fully inflated. The balloon must be storable in a packaged condition for up to 1 year and have an areal density of less than 1000 g/m^2. Proposed concepts must include an automatic surface launch that will work in the Venus environment consisting of 460°C temperature, 90 atmosphere pressure, and surface winds of up to 1 m/s.

S2.03 Cryogenic Systems
Lead Center: GSFC
Participating Center(s): ARC, JPL, MSFC

Cryogenic systems have long been used to perform cutting edge space science, but at high cost and with limited lifetime. Improvements in cryogenic system technology enable further scientific advancement at lower cost and/or lower risk. Lifetime, reliability, mass, and power requirements of the cryogenic systems are critical performance concerns. Of interest are cryogenic coolers for cooling detectors, telescopes, and instruments. In addition, cryogenic coolers for lunar and interplanetary exploration are of interest. The coolers should have long life, low vibration, low mass, low cost, and high efficiency. Specific areas of interest include the following:

- Highly efficient coolers in the range of 4–10 K as well as 50 mK and below, and cryogen-free systems that integrate these coolers together;

- Low-mass, highly efficient coolers for gas sample collection and liquefaction of gases for use in propulsion systems;
- Essentially vibration-free cooling systems, such as reverse Brayton cycle cooler technologies;
- Highly reliable, efficient, low-cost Stirling and pulse tube cooler technologies in the 10 K, 15 K, and 35 K regions;
- 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.

S2.04 Optical Technologies
Lead Center: GSFC
Participating Center(s): JPL

The NASA Space Science Enterprise is studying future missions to explore the Structure and Evolution of the Universe (SEU). To understand the structure and evolution of the universe, a variety of large space-based observatories are necessary to observe cosmic phenomena from radio waves to the highest energy cosmic rays. It will be necessary to operate some of these observatories at cryogenic temperatures (to 4 K) beyond geosynchronous orbits. Apertures for normal incidence telescope optics are required up to 40 m in diameter, while grazing incidence optics are required to support apertures up to 10 m in diameter. For some missions, these apertures will form a constellation of telescopes operating as interferometers. These interferometric observatories may have effective apertures up to 1000 m diameter. Low mass of critical components such as the primary mirror, its support and/or deployment structure, is extremely important. In order to meet the stringent optical alignment and tolerances necessary for a high quality telescope and to provide a robust design, there are significant benefits possible from employing systems that can adaptively correct for image degrading sources from inside and outside the spacecraft. This includes correction systems for large aperture space telescopes that require control across the entire wavefront, typically at low temporal bandwidth. The following technologies are sought:

- Grazing incidence focusing mirrors with response up to 150 keV.
- Large, ultra-lightweight grazing incidence optics for x-ray mirrors with angular resolutions less than 5 arcsec.
- Wide field-of-view optics using square pore slumped microchannel plates or equivalent.
- Develop fabrication techniques for ultra-thin-flat silicon (or like material) for grating substrates for x-ray energies < 0.5 keV.
- Large area thin blocking filters with high efficiency at low energy x-ray energies (< 600 eV).
- Ultraviolet filters with deep blocking (<1 part in 105) 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.
- Develop novel materials and fabrication techniques for producing ultra-lightweight mirrors, high-performance diamond turned optics (including freeform optical surfaces), and ultra-smooth (2–3 angstroms rms) replicated optics that are both rigid and lightweight. Lightweight high modulus (e.g., silicon carbide) optics and structures are also desired.
- High-performance (e.g., high modulus, low density, high thermal conductivity) materials and fabrication processes for ultra-lightweight, high precision (e.g., subarcsecond resolution or <=1 nm figure quality) optics.
- Advanced, low-cost, high quality large optics fabrication processes and test methods including active metrology feedback systems during fabrication, and artificial intelligence controlled systems.
- Large, ultra-lightweight optical mirrors including membrane optics for very large aperture space telescopes and interferometers.
- Cryogenic optics, structures, and mechanisms for space telescopes and interferometers.
- Ultra-precise, low mass deployable structures to reduce launch volume for large-aperture space telescopes and interferometers.

- Segmented optical systems with high-precision controls; active and/or adaptive mirrors; shape control of deformable telescope mirrors; and image stabilization systems.
- Advanced, wavefront sensing and control systems including image based wavefront sensors.
- Wavefront correction techniques and optics for large aperture membrane mirrors and refractors (curved lenses, Fresnel lenses, diffractive lenses).
- Nanometer to sub-picometer metrology for space telescopes and interferometers.
- Develop ultra-stable optics over time periods from minutes to hours.
- 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.
- Develop portable and miniaturized state-of-the-art optical characterization instrumentation and rapid, large-area surface-roughness characterization techniques are needed. In addition, develop 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.
- Develop 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 are needed for testing the figure of large, convex aspheric surfaces to fractional wave tolerances in the visible.

S2.05 Advanced Photon Detectors
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, 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 observations 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.
- 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.

S2.06 Technologies for Gravity Wave Detection
Lead Center: JPL
Participating Center(s): GSFC

Instruments that detect low frequency gravity waves offer a new window on the universe, its origin, evolution and structure. Complementing ground-based experiments such as the Laser Interferometer Gravitational Wave Observatory (LIGO), the Laser Interferometer Space Antenna (LISA), and the follow on vision mission, Big Bang Observer, will implement ambitious systems to detect and characterize gravity waves associated with the Big Bang, mergers of black holes, and other significant astrophysical phenomena. The success of such investigations will largely depend on the technology building blocks that are needed to implement multiple spacecraft constellations with extremely precise laser interferometers and test masses which are actively decoupled from systematic and random disturbances.

The technology areas are organized into two subsystems, one dealing with the disturbance rejection subsystem, which houses the proof mass with active sensors and thrusters to cancel non-gravity wave disturbances, and the other implementing the network of laser interferometers with nanometer-level resolution of relative range between the test masses. Because the systems will be deployed in space, the technologies to be considered must be, or have, credible paths toward full space flight qualification, including thermal and radiation considerations. Background information on LISA, along with preliminary technology discussions, can be found in the proceedings of the 4th International LISA Symposium, Penn State University, 19–24 July 2002, published in the Classical and Quantum Gravity Journal, Volume 20, Number 10, 21 May 2003.

Disturbance Reduction System (DRS)

- Vacuum system – non-magnetic vacuum pump for reaching pressures of $<10^{-6}$ Pa with a pumping volume of 1 liter; with associated valves and electronics
- Vacuum gauge – read pressure down to 10^{-6} Pa on orbit, must be non-magnetic
- Caging actuator – hold 2 kg mass ~4 cm^3 against launch loads of ~25 g rms, with the capability for moving caged test mass over ~10 micron range with ~1 nm precision during ground testing
- Test mass, ~4 cm^3, mass ~1–2 kg, magnetic susceptibility $< 10^{-6}$ (e.g., 73% gold/27% platinum)

Laser Interferometer

- Laser with exceptional power, frequency noise, amplitude noise, lifetime characteristics.
    - Fiber coupled output power (1 W) CW
    - A combination of a lower power master oscillator with suitable amplifier to yield 1 W of total fiber coupled output power may be acceptable
    - Frequency and amplitude noise characteristics: Frequency stability to (30 Hz/√Hz at 1mHz), and power stability to ($2x10^{-4}$ /√Hz at 1 mHz)
    - Lifetime of 10 years or more.
    - Wavelength is nominally 1.064 micron, but +/- 20% of that value is acceptable.
    - Semiconductor diode pump laser with outstanding reliability to operate with a suitable solid-state laser (e.g., non-planar ring oscillator [NPRO] laser) is required.
- Electro-optical modulator – produce phase modulation of continuous laser beam with 10% (power) modulation depth at frequencies from 1.9–2.1 GHz with fiber coupled input and output. Baseline operation will be at 1.064 microns. In addition to the space qualification requirements, the modulator must be able to handle optical power levels at ~ 1 W.

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

TOPIC S3 Astronomical Search for Origins

The questions “How did we get here?” and “Are we alone?” have driven mankind to explore and expand our understanding of the universe and our role in it since before recorded history. Today, we move our attention to the cosmos. Understanding of how galaxies, stars, and planetary systems formed in the early universe will provide a basis for future exploration. Are planetary systems and Earth-like planets typical? Is life beyond the Earth rare or non-existent? If life in the universe is robust, has it spread throughout the galaxy? Current missions using innovative technology research are Space Interferometer Mission (SIM) and Terrestrial Planet Finder (TPF). New missions in the planning phase, which requires innovative technology, are Space Astronomy Far Infrared Telescope (SAFIR), Life Finder and Planet Imager. The Origins technology program develops the means to achieve the most ambitious and technically challenging measurements ever made. New large space telescopes and instruments are required to detect the extremely faint signatures from the deep universe. Innovations are needed in these areas: Precision constellations for interferometry, advanced astronomical instrumentation, deployable precision structures, high-contrast astrophysical imaging, large aperture lightweight telescope mirrors, and wavefront sensing and control. These technologies will enable NASA to explore the early universe, find planets around other stars, and search for life beyond Earth.

S3.01 Precision Constellations 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, multitiming, 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 testbeds.

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 inhomogeneity, scattering, spectral dispersion, thermal variations, and to otherwise estimate the accuracy of masks and stops is needed.
- Interferometric starlight cancellation instruments and techniques to include aperture synthesis and single input beam combination strategies.
- 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.
- 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 104 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.

- 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

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 II 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): GSFC, JPL

Planned future NASA infrared, far infrared and submillimeter missions such as the Single Aperture Far-IR (SAFIR) telescope, 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. Potential architecture implementations include 2 m class segments, 4 m class mirrors, or membrane systems. 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, 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 Solar System

NASA's program for Exploration of the Solar System 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. Numerous new technologies will be required to enable such ambitious missions.

S4.01 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.

- 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 I and show a path toward a Phase II hardware and software demonstration, and when possible, deliver a demonstration unit or software package for JPL testing at the completion of the Phase II contract.

S4.02 Extreme Environment and Aerial Mobility
Lead Center: JPL

This subtopic is composed of two elements: (1) Technologies for High Temperature/High Pressure Environments and (2) Technologies for Aerial Mobility. Both areas are focused on the future *in situ* exploration needs for Titan and Venus, worlds featuring dense atmospheres with low and high temperature extremes, respectively. Note that some technologies developed for the cryogenic environment of Titan will also be applicable to other severe low temperature destinations such as asteroids, comets, and Europa.

Titan is the second largest moon in the solar system and the only one that features a sufficiently dense atmosphere for buoyant vehicle flight. The atmosphere is predominantly nitrogen with a surface temperature of approximately 90 K. Targeted for exploration by Cassini-Huygens in 2004 and beyond, Titan is expected to be a geologically and chemically diverse world containing important clues on the nature of prebiotic chemistry. NASA is starting to lay the ground work for post-Cassini-Huygens exploration of Titan using autonomous, self-propelled aerobots capable of surveying many widely separated locations and potentially including surface sampling and composition analysis. Venus is the second planet from the Sun and features a dense, CO_2 atmosphere completely covered by clouds with sulfuric acid aerosols, a surface temperature of 460ºC 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 use of long lived (days or weeks) balloons and landers.

Technologies for High Temperature and High Pressure Environments

- Advanced thermal control for Venus, including lightweight (50 kg/m^3), insulated pressure vessels able to protect the electronics and instruments enclosed inside for a few hours at 460ºC and 100 bar; new lightweight thermal insulation materials (0.1 W/mK at 460ºC), thermal storage (with 300–1000 kJ/kg energy density), thermal switches (over 1 W/K for “on” and 0.01 W/K for “off” mode), and high performance heat pipes (0.05 W/mK at 460 ºC and 100 bar).
- Science and engineering sensors able to operate at 460ºC and 100 bar, including seismometers.
- High temperature electronics and electronic packaging for sensor and actuator interfaces at 460 ºC, including low noise (10 nV/sqHz) preamplifiers, transmitters (S-band), 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.
- High temperature primary batteries (200 Whr/kg, 100 cycles) for operation at 460ºC.
- Sample handling and acquisition systems including high temperature drills, motors, and actuators able to operate in the 460ºC, 90 atmosphere surface environment of Venus.

Technologies for Aerial Mobility

In addition to the severe environment technologies above, innovative technologies are also sought in the following areas of robotic technologies for aerial mobility:

- Concepts and devices for a low mass (~1–2 kg), high efficiency electric drive motor for the 90 K Titan environment. This motor needs to operate continuously for up to 12 months on Titan and drive the main propulsion propeller at up to 5 revolutions per second with a controllable power input across the range of 0–50 W.

- Concepts and devices for a low mass (<5 kg), low power (<10 W), steerable high-gain antenna that can operate in the 90 K Titan environment and provide direct-to-Earth aerobot telecommunications at S or X-band wavelengths. The required antenna size is approximately 0.8 m in diameter with an operational lifetime of 12 months. This antenna is required to track the Earth during normal aerobot flight at Titan which corresponds to a tracking requirement of <0.5° with vehicle angular disturbances of up to 50 deg/s. Small packaging and operating volumes are also important because the antenna must be delivered with the aerobot inside of a volume-constrainted aeroshell vehicle.
- Concepts and devices for surface sample acquisition from an aerobot in the 90 K surface environment of Titan. These can include, but are not limited to, station keeping, landed or anchored (tethered) aerobots. Both liquid and solid (ice or rock; loose particle or drilled core) samples are of interest.

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

S4.03 Advanced Flexible Electronics and Nanosensors
Lead Center: JPL
Participating Center(s): ARC, GRC

The strategic plan within the Office of Space Science at NASA calls for intense exploration of a wide variety of bodies in the solar system within a modest budget. To achieve this will require revolutionary advances over the capabilities of traditional spacecraft systems and a broadening of the tool set through the introduction of new kinds of space exploration systems. These systems will include, but are not limited to, orbiters, landers, atmospheric probes, rovers, penetrators, aerobots (balloons), planetary aircraft, subsurface vehicles (ice and soil), and submarines. Also of interest are delivery of distributed sensor systems consisting of networks of tiny (<<1 kg) individual elements that combine sensors, control, and communications in highly integrated packages, and which are scattered over planetary surfaces, atmospheres, oceans, or subsurfaces. New technology is needed in all spacecraft areas for mass, power, and volume reductions, and for application to harsh environments such as extreme temperature, radiation, and mechanical shock.

Nanosensors
The nanosensing and bio-nanotechnology for the sensing aspect of this 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 environments. This harsh environment includes steady operation and cycling in the temperature range of -180°C to 100°C, 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 µm and detectors in the greater than 15 µm wavelength range.

Flexible Electronics
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 I and show a path toward a Phase II hardware and software demonstration, and when possible, deliver a demonstration unit or software package for JPL testing at the completion of the Phase II contract.

S4.04 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, storage, power electronics, and power system materials. Power levels of interest range from tens of milliwatts, to hundreds of watts. NASA Space Science missions in deep space environments require energy systems with long life capability, high energy density, 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
Advances in photovoltaic technology are sought, including high power solar arrays and ultra lightweight thin and concentrator arrays with substantial increases in specific power watts per kilogram. Advances in radioisotope power conversion to electricity (tens of milliwatts to hundreds of watts with efficiencies >20 %) are sought. This includes advances in thermophotovoltaics, thermoelectrics, and Stirling. All proposed energy conversion technologies must be able to operate in deep-space environments with high radiation and wide-temperature operations.

Energy Storage
Includes advances in primary and secondary (rechargeable) battery technologies. Rechargable technologies include lithium ion batteries, lithium polymer batteries, and other advanced concepts providing long life capability, and dramatic increases in mass and volume energy density watt hours per kilogram and watt hours per liter. Primary battery technologies include Li-CFx and other high specific energy electrochemical systems. Must be able to operate in deep-space environments, including high radiation and low (-100°C) to high (400°C) temperature regimes.

For operation on planetary surfaces, the use of regenerative fuel cells, both conventional and unitized - passive designs, with substantial increases in mass and volume-specific energy for those situations where there are substantial time periods of charging and recharging (anywhere from hours to days).

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 (25–200°C), and/or high levels of space radiation (>150 krad) resistance.

Electronics Packaging
Advanced electronics packaging technologies that reduce volume and mass capable of either high temperature or wide temperature operation and space radiation resistance for use in space power systems are of interest. Also of interest are thermal control technologies of high heat flux capability which are integral to the electronic package.

Power System Materials
Advances are sought in materials, surfaces, and components that are durable for soft x-ray, electron, proton, and ultraviolet radiation and thermal cycling environments, lightweight electromagnetic interference shielding, and high-performance, environmentally-durable thermal control surfaces.

S4.05 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 down 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 micron. 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, 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.
- Robotic systems designed to provide access to environments such as deep-ocean hydrothermal vents.

TOPIC S5 Mars Exploration

Technology enables us to answer our scientific questions. Without the continual development of new technologies, our thirst for knowledge will go unfulfilled. Our goal is to invent new technologies, rigorously test them here on Earth or in space and apply them to Mars Exploration. 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.

S5.01 Detection and Reduction of Biological Contamination on Flight Hardware and in Return Sample Handling
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. Missions designed to return the first extraterrestrial samples since the Apollo moon landings are currently in space–the Stardust and Genesis spacecraft will return cometary and solar wind particles to Earth within this decade. A mission to return samples from Mars 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. To fulfill its commitment, NASA seeks technologies and system approaches that will support compliance with planetary protection requirements.

Examples of such technologies include:

- Techniques for cleaning of organics to the nanogram per square centimeter level on complex surfaces (nondestructively and without residues) and 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
- A device or methodology for controlled measurement of microbial reduction at temperatures from 200–300°C to enable generation of microbial lethality curves.

Examples of systems approaches include:

- Containerization and encapsulation of samples to be returned to Earth, including innovative mechanisms for isolation, sealing, and leak detection
- 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
- 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 I and show a path toward a Phase II hardware and software demonstration, and that will, when possible, deliver a demonstration unit or software package for JPL testing before the completion of the Phase II contract.

S5.02 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. Systems enabling navigation in very rough terrain with explicit consideration of limited sensing, computation, and power. Development of new sensor prototypes, with a clear path to flight-ready status within a short time span and at minimum cost. 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. Infrastructure for research, including low-cost, mass producible, research-quality rovers and supporting elements.

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

S5.03 Mars and Deep-Space Telecommunications
Lead Center: JPL

This subtopic seeks innovative technologies for both RF and Free-Space Optical Communications supporting missions to Mars, including both planetary and proximity ranges, and for other planetary missions and local planetary networks.

RF Communications

- Ultra-small, low-cost, low-power, innovative deep-space 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 BPSK/QPSK modulation at X-band (8.4 GHz) and Ka-band.
- Sub-microradian antenna pointing techniques for Ka-band spacecraft antennas.
- High rate (10–200 Mbps) turbo-encoder and decoder and wavelet compression chips.
- Technologies for surface-to-surface communications in planetary environments.
- Fault-tolerant digital signal processing: Current space qualified DSP elements do not support high bandwidths because of the power consumption associated with radiation hardened manufacturing processes. Reconfigurable signal processing elements are sought that provide autonomous fault detection and correction with a graceful degradation in performance over the service life.
- Antenna systems: Novel materials and approaches are sought to construct large, inflatable reflective and RF focusing surfaces for use as large aperture antennas. Need to provide highly directional surface to orbit antenna patterns to maintain high rate data links.

Optical Communications

- Efficient (greater than 20% wall plug), lightweight, flight-qualifiable, variable repetition-rate (1–60 MHz), pulsed lasers with greater than 1 kW of peak power per pulse (over the entire pulse-repetition rate), and potential for up to 10 W of average power.
- Photon counting 1064 nm and 1550 nm detectors with the gain greater than 1000, detection efficiency greater than 50%, very low additive noise, about 0.5 mm in diameter, bandwidth greater than 500 MHz, saturation levels > 50Mcounts/s.
- 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 antennae that must operate when pointed to within a few (about 3) degrees of the Sun.
- Low-cost, lightweight, efficient, compact, high precision (one micro-radian accuracy) star-trackers for spaceflight application.

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

9.2 STTR Research Topics

Each STTR Program Solicitation Topic corresponds to a specific NASA Center. One or two subtopics per Topic (rotating from year to year) reflect the current highest priority technology thrusts of that Center.

TOPIC T1 Ames Research Center 194

T1.01 Information Technologies for System Health Management, Autonomy, and Scientific Exploration 194
T1.02 Space Radiation Dosimetry and Countermeasures 194

TOPIC T2 Dryden Flight Research Center 195

T2.01 Flight Dynamic Systems Characterization 195
T2.02 Advanced Concepts for Flight Research 195

TOPIC T3 Glenn Research Center 197

T3.01 Aeropropulsion and Power 197

TOPIC T4 Goddard Space Flight Center 198

T4.01 Earth Science Sensors and Instruments 198
T4.02 Space Science Sensors and Instruments 199

TOPIC T5 Johnson Space Center 201

T5.01 Understanding and Utilizing Gravitational Effects on Molecular Biology and for Medical Applications. 201

TOPIC T6 Kennedy Space Center 202

T6.01 Self-Healing Repair technologies 202

TOPIC T7 Langley Research Center 203

T7.01 Personal Air Vehicle (PAV) Research for Rural, Regional, and Intra-Urban On-Demand Transportation 203

TOPIC T8 Marshall Space Flight Center 204

T8.01 Aerospace Manufacturing Technology 204
T8.02 Advanced High Fidelity Design and Analysis Tools For Space Propulsion 204

TOPIC T9 Stennis Space Center 205

T9.01 Rocket Propulsion Testing Systems 206
T9.02 Integrated Life-cycle Asset Mapping, Management, and Tracking 207

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) and in 1958 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 interests.

T1.01 Information Technologies for System Health Management, Autonomy, and Scientific Exploration

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.
- 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

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
- Microdosimetry for research applications including implantable dosimeters for biological studies

Radiation Hardened Electronic Systems
- Methods for hardening pre-existing technologies
- 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
- 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
- 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
- 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
- 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, in space technology. The newest, the fastest, the highest – all have made their debut in the vast, clear desert skies over Dryden.

T2.01 Flight Dynamic Systems Characterization

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 in 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 regular daily basis. Furthermore, the effective use of high-performance computing equipment and computer graphics development is also considered as 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

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,
- Modeling, identification, simulation, and control of aerospace vehicles in-flight test, 4/ flight sensors, sensor arrays and airborne instruments for flight research, and 5/ 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 system and to develop the optimal plan for transitioning to the future system. 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 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, 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 require a demonstration in an actual flight environment to fully characterize or validate.

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. Our 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 our 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 hand has four large, 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 PhD degrees.

T3.01 Aeropropulsion and Power

The research sponsored by the Propulsion and Power Project focuses on ensuring the long-term environmental compatibility and efficiency of aircraft propulsion and power systems. The project addresses critical propulsion and power technology needs across a broad range of investment areas including revolutionary advances in combustion-based aeropropulsion systems and technologies and unconventional propulsion and power systems and technologies. High-risk, high-potential research investments include fuel-cell based propulsion systems, high-temperature nanotechnology, and pulse detonation engine components and subsystems. Ultimately, the Propulsion and Power Project seeks to demonstrate (in a laboratory environment) key component technologies to enable nonconventional combustion-based propulsion systems and electric and hybrid propulsion and power systems. The Propulsion and Power Project directly supports the NASA objectives of: "Protect the Environment–Protect local environmental quality and the global climate by reducing aircraft noise and emissions" and "Explore New Aerospace Missions–Pioneer novel aerospace concepts to support Earth and space science missions."

Innovations sought include:

- Alternative fuels and/or alternative propulsion systems, i.e., aeronautical propulsion technology concepts with horizons of 20–40 years from today with potential for two times the payload-range performance. Such high-payoff propulsion systems would set new, revolutionary directions well beyond the evolutionary approaches. These alternative fuel and/or alternative propulsion systems may include, but are not limited to the following areas.
  - Revolutionary engine design (technologies beyond the conventional Brayton cycle gas turbine engine). For example, micromachined SiC microengines which may have potential for use in a distributed propulsion architecture.
  - Nano- and autonomous systems. For example: nanotechnology fibers, tubes, spheres, and high temperature shape memory alloys and piezoelectric materials for their unique role in tribology, structures and composite reinforcements, and control systems for autonomous, adaptive engine control and sealing.
- Non-combustion (electric) propulsion and power systems, e.g., hydrogen-based and electric aeropropulsion (propulsion systems capable of flight while producing zero CO_2 emissions), and new missions enabled by quiet, clean, electric propulsion. Key technologies to enable design of an alternatively fueled, fuel cell or hybrid propulsion system. These technologies may include, but are not limited to:
  - Hydrogen tankage;
  - Fuel cell systems, components, and subcomponents; and
  - Power management and distribution materials, components, and configurations.

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

The mission of the Earth Science Enterprise is 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 from terrestrial applications, as well as the vantage point of space, we seek to observe, analyze, and model the Earth system to discover how it is changing and the consequences for life on Earth.

This STTR solicitation is to help provide advanced remote sensing technologies to enable future Earth and Lunar Science measurements.

Analytical Instrumentation for Planetary Atmospheres Research
Innovations and the application of new technologies are sought for improving the operating characteristics of gas chromatograph-mass spectrometer systems in harsh environments. Reductions in volume, weight, power, and cost while increases in performance, serviceability, and functionality of system components is highly desirable. The overall goal is to develop an instrument with increased performance in the areas of improved collection, detection, and measurement. Specific areas of interest include:

- Miniaturized and ruggedized gas chromatograph columns
- Microvalves
- Improved stability and performance of secondary electron multipliers
- Performance increases in the areas of size and conversion efficiency of high voltage DC/DC converters
- Rigid miniature vacuum pumps

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 systems must be compact upon launch, they must achieve high precision surface form factors, and they must include beam-scanning capabilities. The antenna compactness on launch can be achieved either through folding technologies or from some assemblage of small components into the larger final system in space. The microwave antenna surface characteristics must be accurate enough to produce microwave beam patterns with adequately small side lobes. 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. The beam widths must be small enough to resolve the few kilometer scales needed for many geophysical observations. The microwave wavelengths will be determined according to the geophysical measurement of interest. The antenna concepts may include large single apertures or apertures composed of multiple elements that are operated synergistically to produce the desired performance.

Active Optical Systems and Technology for UAVs and Ballooncraft
Lidar remote sensing systems are required to meet the demanding requirements for future Earth Science missions. It is envisioned that lidar systems will be used in the following application areas: high spatial and temporal resolution observations of the land surface and vegetation cover (biomass); profiling of clouds, aerosols, and atmospheric state variables including temperature, humidity, winds, and trace constituents including tropospheric and stratospheric ozone and CO_2 (profiling and total column); measurement of the air/sea interface and mixed layer. New systems and approaches are sought in these areas, which will:

- Enable a new measurement capability;
- Enhance an existing measurement capability by significantly improving the performance (spatial/temporal resolution, accuracy, range of regard); and
- Substantially reduce the resources (cost, mass, volume, or power) required to attain the same measurement capability.

Systems and approaches will be considered that demonstrate a capability which is scalable to space or can be mounted on a relevant platform (UAV, long duration balloon, or aircraft) for calibration and validation of a space-borne system.

Unmanned Aerial Vehicle (UAV) Technologies for Remote Sensing
Avionics, real-time telemetry acquisition and remote sensing spectral imaging devices to support Unmanned Aerial Vehicles' (UAV) basic and applied science and application demonstrations (proposers need only to respond to a minimum of one of the below):

- Low cost avionics instrumentation for precise navigation and aircraft control, must have an attitude sampling rate greater than 25 Hz and an accuracy greater than 0.2° in roll and pitch.
- Real-time sensor fusion algorithms that combine low-cost inertial, GPS, magnetometer, and other sensor input to deliver aircraft state vectors at a rate greater than 50 Hz.
- Uncooled infrared and thermal spectral imager instrument to 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. It must have a built-in data acquisition system. The 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 11microns as well as a band in the visible at 0.6 microns. Quantization bit resolution should be 10-bit minimum.

Ballooncraft Trajectory Control and Station-Keeping
Trajectory Control and Station-Keeping are critical items for future Ultra-Long Duration Balloon remote sensing concepts.

- Trajectory control would allow for some authority of the path of the system that may be required or desired for several reasons such as science mission, geopolitical, or improved recovery options. Activities include concept studies for alternative systems, propeller design and fabrication, functional flight testing, airship design and analysis, material development, and performance modeling.

T4.02 Space Science Sensors and Instruments

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)
- 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/m^2) 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.
- 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
- High spatial resolution x-ray detectors, for producing ~50 meter 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)
- 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
- Trajectory simulation tools and software

TOPIC T5 Johnson Space Center

The Johnson Space Center's chief mission is the expansion of a human presence in space through exploration and the utilization of space for the benefit of mankind. The Center is also the lead center for curation and research of astromaterials (including Lunar rocks and other specimens), the International Space Station, the Space Shuttle, home to the Mission Control Center and to the NASA astronaut corps, and leads the development, testing, production and delivery of U.S. human spacecraft.

T5.01 Understanding and Utilizing Gravitational Effects on Molecular Biology and for Medical Applications

The microgravity environment enables scientists to perform unique studies on metabolic and functional changes in cells, and modified growth of multiple cells for artificial tissue development and behavior. NASA has developed novel rotating bioreactor technologies to model microgravity effects on cultures of suspended and anchorage-dependent cells and tissues. The spin-off from the NASA research has been the use of these novel culture methods for Earth-based research into mechanisms of enhancing cytokine and hormone secretions, production of 3-D tissue spheroids, interactions of cancer cells and normal cells in co-culture, and molecular mechanisms of altered immune cell functions, bone formation, and special uses of stem cells. The current focus is on development of new methods for enhancing production of commercial products from cultured cells for medicine and biotechnology applications. NASA cell science research includes development of space bioreactors for culture of fragile human cells; mechanisms for enhancing production of IFNs and cytokines from human white blood cells, near-infrared light mechanisms that stimulate wound healing and bone formation, and also for photodynamic therapy for local treatment of solid tumors; and tissue engineering systems which grow 3-D tissue constructs. New systems have been developed for microencapsulation of drugs and cells for transplantation in concert with the new culture systems for *in vitro* testing of the effectiveness of new drug combinations and biomodulators, and methods for measuring metastatic potential of tumor biopsies, and new tests for changes in specific cellular immune functions of persons under physiological stress. New fluorescent and bioluminescence imaging technologies are being developed to aid in the real-time assessment of these various effects on cultured cells in bioreactors and then applied to clinical tests especially for monitoring treatments for cancer.

Specific areas of interest are:

- New methods for culturing mammalian cells in bioreactors, including advanced bioreactor design and support systems; miniature sensors for measurement of pH, oxygen, carbon dioxide, glucose, glutamine, and metabolites; and microprocessor controllers. Neural fuzzy logic network systems for the control of mammalian cell culture systems. Methods to minimize biofilm formation on fluid-handling components, sensors, and bioreactors. Spectroscopic and biochemical analysis of biofilm formed in bioreactors. Micro-scale bioreactors for biomonitoring of radiation and other external stressors.
- Technologies that allow automated biosampling and biospecimen collection, handling, preservation and fixation, and processing in cellular systems. Methods for separation and purification of living cells, proteins, and biomaterials, especially those using electrokinetic or magnetic fields that obviate thermal convection and sedimentation, enhance phase partitioning, or use laser light and other force fields to manipulate target cells or biomaterials.
- Techniques or apparatus for macro-molecular assembly of biological membranes, biopolymers, and molecular bioprocessing systems; biocompatible materials, devices, and sensors for implantable medical applications including molecular diagnostics, *in vivo* physiological monitoring and microprocessor control of prosthetic devices.
- Methods and apparatus that allow microscopic imaging including hyperspectral fluorescent, scattering and absorption imaging and biophysical measurements of cell functions, effects of electric or magnetic fields, photoactivation, and testing of drugs or biocompatible polymers on live tissues. Integrated instrumentation for separation and purification of RNA, DNA, and proteins from cells and tissues.
- Quantitative applications of molecular biology, fluorescence imaging and flow cytometry, and new methods for measurement of cell metabolism, cytogenetics, immune cell functions, DNA, RNA, oligonucleotides, intracellular proteins, secretory products, and cytokine or other cell surface receptors. Means to enhance and augment genomics and proteomics techniques, including molecular and nanoscale tools. Small-scale mass spectrometers. Development of novel fluorophores that tag proteins mediating cellular function, particularly those that can be excited using solid-state lasers.
- Micro-encapsulation of drugs, radiocontrast agents, crystals, and the 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 to better understand and improve manufacturing processes on Earth.
- Miniature bioprocessing systems, which allow for precise control of multiple environmental parameters such as low-level fluid shear, thermal, pH, conductivity, external electromagnetic fields, and narrow-band light for fluorescence or photoactivation of biological systems.
- Novel low temperature sample storage methods (-80°C and -180°C) and biological sample preservation methods. Methods to reduce launch/return mass of biological samples and support reagents.
- DNA template for molecular wiring that permits macro- to nanoscale connectivity. Nanoscale electronics based on self-assembling protein-based molecular structures.
- Computer models and software that better handle large numbers of coupled reactions in cell science systems.
- Tools and techniques to study mechanical properties of the cell: subcellular rheology, cell adhesion, affect of shear flow, affects of direct mechanical perturbation. Tools and techniques to facilitate multiple simultaneous probing and analyzing of a cell or subcellular region (examples include atomic force microscope coupled with microelectrode or micro-Raman, Optical trap).
- Nanosensors for subcellular measurements: ultra-microelectrodes with less than 1micron diameter including cladding, nanoparticle reporters that provide spectroscopic information, and other novel intracellular sensor devices to provide spectroscopic data on intracellular processes.

TOPIC T6 Kennedy Space Center

An entire chapter of U.S. history has been written at the John F. Kennedy Space Center (KSC). As the departure site for our first journey to the Moon, and hundreds of scientific, commercial, and applications spacecraft, and now as the base for Space Shuttle launch and landing operations, KSC plays a pivotal role in the nation's space program.

T6.01 Self-Healing Repair technologies

It is highly desirable to develop technologies for polymeric and composite materials that mimic the repair processes of biological systems. Much can be learned by relating the repair processes of biological systems to these inanimate materials, in particular, learning methods to initiate the self-healing processes. One example of inanimate 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. Another approach might be to combine animate and inanimate systems in such a way that the repair of the inanimate material is done by the animate system. Applications for self-healing processes of inanimate materials can be found in areas were failures could result in catastrophic consequences. Examples of these are failure of structural members in spacecraft or aircraft; failure of electrical wire insulation materials used in spacecraft, aircraft, or buildings; or failure of polymers membranes used in critical separations in the space exploration or medical devices.

Proposals are sought for innovative technologies and technology concepts in the areas of self-healing and repairing of electrical wiring insulation, which is an area under ASTRA’s Advanced Technology Development (2.4.6). 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, Teflon, or vinyl-type 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 effect of the manufacturing process used to produce the insulated wire on the final product. These methods must produce a flexible water-tight seal over the damaged area. The physical and chemical properties of the final repair material should be similar to the initial insulating materials.

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 Vehicle (PAV) Research for Rural, Regional, and Intra-Urban On-Demand Transportation

NASA is performing preliminary design studies of Personal Air Vehicle missions, concepts, and technologies for the purpose of augmenting on-demand personal transportation mobility and capacity. The intent of this research is to perform the analysis and demonstration 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.

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, providing improved comfort levels for passengers.

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.

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.

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.

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.

TOPIC T8 Marshall Space Flight Center

High power levels needed for space exploration missions (including reactor powered electric propulsion, reactor powered surface systems, etc.) result in the need to reject large amounts of waste heat. Conventional radiator technologies, i.e., finned tube, heat pipe fed radiators, etc., are heavy, hard to package and deploy, and must be made quite redundant to assure long life operation. This solicitation seeks proposals for advanced heat rejection concepts that include belt and/or liquid droplet radiators, and other advanced radiator concepts that promise to lower mass by a factor of 3 to 10.

T8.01 Aerospace Manufacturing Technology

NASA is interested in encouraging innovation in manufacturing through the Small Business Innovation Research (SBIR) and the Small Business Technology Transfer (STTR) programs. 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. 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 in 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; 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

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 development of the experimental approaches and data required to validate these tools. Transition of that technology, however, from the 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 the NASA's investments at the Nation's colleges and universities.

This subtopic solicits partnerships between academic institutions and small business 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 (3-D), time accurate analysis tools for modern rocket engine combustion chamber and turbomachinery environments and performance;
- Efficient, three-dimensional (3-D), time accurate analysis tools for predicting the environment and loads internal to valves, lines, and ducts in modern rocket engines;
- Practical 3-D 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 3-D flow simulations;
- Automated approaches for validating and assuring quality of application software;
- Practical unsteady 3-D 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 institutions 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 4,500 employees, about l,600 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, thus making it cheaper for each to accomplish its independent mission at SSC.

T9.01 Rocket Propulsion Testing Systems

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 LH2) under high pressure (up to 15,000 psi), high flow rate conditions (2000 lb/s - 82 ft/s for LOX, 500 lb/s - 300 ft/s for LH2). Flow rate sensors must have a range of up to 2000 lb/s (82 ft/sec) for LOX and 500 lb/sec (300 ft/s) for LH2. Pressure sensors must have a range up to 15,000 psi. Rocket plume sensors must determine gas species, temperature, and velocity for H2, O2, 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 LH2) under high pressure (up to 15,000 psi), high flow rate conditions (2000 lb/s - 82 ft/s for LOX, 500 lb/s - 300 ft/s for LH2). Response time must be on the order of a few milliseconds to the 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 LH2) 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 LH2). 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 the 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 predicts 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, and 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

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
- A comprehensive portal for Earth and lunar mapping data, both image- and vector-based.