SBIR/STTR 2002-1

National Aeronautics and Space Administration

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

Program Solicitations

Opening Date: June 6, 2002
Closing Date: August 21, 2002

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

Cover: Comet Hale-Bopp (photo by Fred Espenak) provides the backdrop for NASA's latest cometary exploration spacecraft (From top, Deep Space 1, Stardust, and Contour) and the Stonehenge astronomical observatory.
Cover layout: *Dr. James Kalshoven and Jay Friedlander of NASA Goddard Space Flight Center.*

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1. Program Description

1.1 Introduction

This document includes two NASA program solicitations with separate research areas under which small business concerns (SBCs) are invited to submit proposals: the Small Business Innovation Research (SBIR) program and the Small Business Technology Transfer (STTR) program. Program background information, eligibility requirements for participants, the three program phases, and information for submitting responsive proposals is contained herein. The 2002 Solicitation period for Phase I proposals begins June 6, 2002 and ends August 21, 2002.

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.

A proposal directed towards system studies, market research, routine engineering development of existing products or proven concepts and modifications of existing products without innovative changes is considered non-responsive. 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 20 STTR Phase I proposals will be selected for negotiation of fixed-price contracts in November 2002. Historically, the ratio of Phase I proposals to awards is approximately 7:1 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

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.

1.3 Program Management

The Office of Aerospace Technology 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 five 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 is aligned with the NASA Centers of Excellence. Each Center of Excellence participates every other year. 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 websites:

NASA Strategic Enterprises	
Aerospace Technology	http://www.hq.nasa.gov/office/aero
Biological and Physical Research	http://SpaceResearch.nasa.gov
Earth Science	http://earth.nasa.gov
Human Exploration and Development of Space	http://www.hq.nasa.gov/osf/heds/
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:

	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.

Maximum value and period of performance for Phase II contracts:

	SBIR	STTR
Maximum Contract Value	$ 600,000	$ 500,000
Maximum Period of Performance	24 months	24 months

1.4.3 Phase III. NASA may award Phase III contracts for products or services with non-SBIR/STTR funds. Phase I and Phase II awards satisfy the requirements of the Competition in Contracting Act for subsequent NASA Phase III contracting. The small business is also expected to use non-Federal capital to pursue private sector applications of the R/R&D effort.

1.5 Eligibility Requirements

1.5.1 Small Business Concern. Only firms qualifying as SBCs, as defined in Section 2.12, 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 2.16). However, based on a rare and unique circumstance, for example, a supply or material or other item or project requirement that 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 may 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 2002 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 712
Goddard Space Flight Center
Greenbelt, MD 20771-0001
paul.mexcur@gsfc.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 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.

2.7 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.

2.8 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 non-profit research institution as defined in section 4(5) of the Stevenson-Wydler Technology Innovation Act of 1980, or (3) a non-profit college or university.

2.9 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.

2.10 SBIR/STTR Technical Data

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

2.11 SBIR/STTR Technical Data Rights

The rights a 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.

2.12 Small Business Concern

A SBC is one that, at the time of award of Phase I and Phase II funding agreements, meets the following criteria:

(1) Is independently owned and operated, is not dominant in the field of operation in which it is proposing, has its principal place of business located in the United States, and is organized for profit;

(2) Is at least 51 percent owned, or in the case of a publicly-owned business, at least 51 percent of its voting stock is owned, by United States citizens or lawfully admitted permanent resident aliens; and

(3) Has, including its affiliates, a number of employees not exceeding 500 and meets the other regulatory requirements found in 13 CFR Part 121. Business concerns, other than investment companies licensed, or state development companies qualifying under the Small Business Investment Act of 1958, 15 U.S.C. 661, et seq., are affiliates of one another when, either directly or indirectly, (1) one concern controls or has the power to control the other or (2) a third party controls or has the power to control both. Control can be exercised through common ownership, common management, and contractual relationships. The terms "affiliates" and "number of employees" are defined in greater detail in 13 CFR 121.

Small business concerns include sole proprietorships, partnerships, corporations, joint ventures, associations, or cooperatives. Eligible joint ventures are limited to no more than 49 percent participation by foreign business entities.

2.13 Socially and Economically Disadvantaged Individual

A member of any of the following groups: Black 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).

2.14 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.

2.15 Subcontract

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

2.16 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.

2.17 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. An offeror may submit **different** proposals in response to any number of subtopics, but every proposal must be based on an unique innovation, must be limited in scope to just one subtopic, and may be submitted only under that subtopic. *Submitting substantially equivalent proposals to several subtopics is not permitted and 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. It must also identify the eventual commercial application potential of the product or service and discuss how the SBC would bring it to market.

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. Proposal items required in Section 3.2.2 will be included within this total. 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.

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 proposal will depend on the project chosen and the offeror's approach.

Each proposal submitted must contain the following items in the order presented:

(1) Proposal Cover (Form A), electronically endorsed, as page 1
(2) Proposal Summary (Form B), as page 2
(3) Technical Proposal (11 Parts in order as specified in Section 3.2.4), including all graphics, and starting at page 3 with a table of contents
(4) Summary Budget (Form C)
(5) Briefing Chart (Optional – not included in the 25-page limit)

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 Proposal Cover and Proposal Summary

Page 1: Proposal Cover (Form A). The Proposal Cover 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.

Page 2: Proposal Summary (Form B). The 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 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.

3.2.4 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. Page 3 of the proposal 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. Phase I R/R&D should address the objectives and questions cited in Part 3. The work plan should indicate how, what and where it will be done (Section 1.5.2). The methods planned to achieve each objective or task should be discussed in detail. Schedules, task descriptions and assignments, 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. Not less than 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 not less than 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 on 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 2002 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 non-profit 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 5.17)

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 policy prohibits the use of any SBIR award funds for the use of government equipment and facilities. This does not preclude a SBC from utilizing a government facility, but such use cannot be paid for with SBIR funds.

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 should also include relevant information on the funding source(s) (private, other government, internal) for the effort.

Part 9: Subcontracts and Consultants. 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. 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).

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 proposer, in the Phase II proposal, will be required to provide more detailed information regarding product development and potential markets (Sections 3.3 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:

(1) The name and address of the agencies to which proposals have been or will be submitted, or from which awards have been received (including proposals which have been submitted to previous NASA SBIR Solicitations);
(2) Dates of such proposal submissions or awards;
(3) Title, number, and date of solicitations under which proposals have been or will be submitted or awards received;

(4) The specific applicable research topic for each such proposal submitted or award received;
(5) Titles of research projects;
(6) Name and title of the PI/project manager for each proposal that has been or will be submitted, or from which awards have been received;
(7) If resubmitting to NASA, please briefly describe how the proposal has been changed and/or updated since it was last submitted.

Note: All eleven (11) parts 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 Proposed Budget

Summary Budget (Form C). The offeror shall complete the Summary Budget, following the instructions provided with the form (Section 8) and include it and any explanation sheets, if needed, as the last page(s) of the proposal. 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 a SBIR/STTR contract using NASA funds should be American-made to the extent possible. NASA will not fund facility acquisition under Phase I as a direct cost (Section 5.17).

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 5.12.

Cost Sharing. See Section 5.11.

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 advocating your proposal, a single-page briefing chart, as described in the on-line electronic handbook, is encouraged. Submission of the briefing chart is optional and is not counted against the 25-page limit. An example chart has been provided in Appendix B.

3.2.8 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.

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. 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.

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 proposal will depend on the project and the offeror's approach.

Each proposal submitted must contain the following items in the order presented:

(1) Proposal Cover (Form A), electronically endorsed, as page 1
(2) Proposal Summary (Form B), as page 2
(3) Technical Proposal (11 Parts in order as specified in Section 3.3.4), including all graphics, and starting at page 3 with a table of contents
(4) Summary Budget (Form C)
(5) Briefing Chart (Optional – not included in the 50-page limit)

3.3.3 Proposal Cover and Proposal Summary

Page 1: Proposal Cover (Form A). A sample copy of the Proposal Cover 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.

Page 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.

3.3.4 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 need. 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 and Work Plan. Define the specific objectives of the Phase II research and technical approach; and provide a work plan defining specific tasks, performance schedules, milestones, and deliverables.

Part 4: Company Information. 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.

Part 5: Facilities and Equipment. This section shall 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 5.17)

Government-wide SBIR policy prohibits the use of any SBIR award funds for the use of government equipment and facilities. This does not preclude a SBC from utilizing a government facility, but such use cannot be paid for with SBIR funds.

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 should also include relevant information on the funding sources(s) (private, other government, internal) for the effort.

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: Subcontracts and Consultants. 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 commitment 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. Subcontractors’ and consultants’ work must be performed in the United States. Failure to provide subcontractor/consultant commitments may result in rejection of proposal. Note the following restrictions on subtonctracts/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 8: Potential Applications: Describe both the potential NASA and non-NASA commercial applications of the project assuming successful development of the proposed objectives.

Part 9: 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 10: Capital Commitments 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.

Part 11: 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.

3.3.5 Proposed Budget

Summary Budget (Form C). The offeror shall complete the Summary Budget, following the instructions provided with the form (Section 8) and include it and any explanation sheets, if needed, as the last page(s) of the proposal. 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 a SBIR/STTR contract using NASA funds should be American-made to the extent possible. NASA will not fund facility acquisition under Phase I as a direct cost (Section 5.17).

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 5.12.

Cost Sharing. See Section 5.11.

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 recommending your proposal, a single page briefing chart, as described in the on-line electronic handbook is encouraged. Submission of the briefing chart is optional and is not counted against the 50-page limitation. An example chart has been provided in Appendix B.

4. Method of Selection and Evaluation Criteria

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 on a competitive basis.

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 and by qualified experts outside of NASA (including industry, academia, and other Government agencies) 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. Non-cost factors are substantially more important than cost factors for Phase I proposals. Each proposal will be judged and scored on its own merits using the factors described below:

Factor 1. Scientific/Technical Merit and Feasibility
The proposed R/R&D effort will be evaluated on whether it offers a clearly innovative and feasible technical approach to the NASA problem area described in 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 5.17).

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.

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. After a proposal is reviewed based on the stated evaluation criteria, it will be ranked relative to all other proposals. Selection decisions will consider the recommendations from all Centers, Strategic Enterprises, overall NASA priorities, and program balance. 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 web site **(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 (Applicable for 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.

As in Phase I, non-cost factors are significantly more important than cost factors. However, the reasonableness of the proposed costs of the effort to be performed will be examined to determine those proposals that offer the best value to the Government. Where technical evaluations are essentially equal in merit, cost to the government will be considered in determining successful offerors.

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 technical payoff potential if successful, 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. Future Importance and Value to NASA
The eventual value of the product, process, or technology results to the NASA mission will be assessed.

Factor 3. Capability of the Small Business Concern
NASA will assess the capability of the SBC to conduct Phase II based on (a) the validity of the project plans for achieving the stated goals; (b) the qualifications and ability of the project team (Principal Investigator/ Project Manager, company staff, consultants and subcontractors) relative to the proposed research; and (c) the availability of any required equipment and facilities.

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 high numerical scores 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.

Each NASA Installation managing Phase I projects will use these factors to evaluate the Phase II proposals. Final selections will be based on recommendations from all Installations and Strategic Enterprises; assessments of project value to NASA's overall programs and plans; and any other evaluations or assessments (particularly of commercial potential) that may become available to the Source Selection Official.

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, or 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 Contracting Officer at the appropriate NASA Center (not the SBIR/STTR Program Manager) within 60 days after selection announcement. Late requests will not be honored.

5. Considerations

5.1 Awards

5.1.1 Availability of Funds. Both Phase 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

- 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 2002 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.

STTR

- NASA plans to announce the selection of approximately 20 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 2002 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 $500,000.

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: NASA is not responsible for any monies expended by the offeror before award of any contract resulting from this Solicitation.

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 proposal 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 Proprietary Information

It is NASA's policy to use information (data) included in proposals for evaluation purposes only. Public release of information in any proposal submitted will be subject to existing statutory and regulatory requirements. If information consisting of a trade secret, proprietary commercial or financial information, or private personal information is provided in a proposal, NASA will treat in confidence the proprietary information provided the following legend appears on the title page of the proposal:

> "For any purpose other than to evaluate the proposal, this data shall not be disclosed outside the Government and shall not be duplicated, used, or disclosed in whole or in part, provided that 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. This restriction does not limit the Government's right to use information contained in the data if it is obtained from another source without restriction. The data subject to this restriction are contained in pages _____ of this proposal."

Note: Do not label the entire proposal proprietary. The Proposal Summary (Form B) should not contain proprietary information**.**

5.5 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.

5.6 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.

5.7 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.

5.8 Rights in Data Developed Under SBIR/STTR Contracts

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 a 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 a 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.

5.9 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 a SBIR/STTR contract.

5.10 Patents

The contractor may normally elect title to any inventions made in the performance of a 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.

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.

5.11 Cost Sharing

Cost sharing is permitted, but not required for proposals under this Solicitation. Cost sharing, if included, should be shown in the summary budget but not in items labeled "AMOUNT REQUESTED." 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).

5.12 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.

5.13 Joint Ventures and Limited Partnerships

Both joint ventures and limited partnerships are permitted, provided the entity created qualifies as a SBC in accordance with the definition in Section 2.12. A statement of how the workload will be distributed, managed, and charged should be included in the proposal. A copy or comprehensive summary of the joint venture agreement or partnership agreement should be appended to the proposal. This will not count as part of the 25-page limit for the Phase I proposal.

5.14 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.

5.15 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.

5.15.1 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.

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

5.15.3 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.

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

5.15.5 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.

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

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

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

5.15.9 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.

5.15.10 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.

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

5.15.12 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.

5.15.13 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.

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

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

5.16 Additional Information

5.16.1 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.

5.16.2 Evidence of Contractor Responsibility. Before award of a 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.

5.16.3 Central Contractor Registration: Offerors should be aware of the requirement to register in the Central Contractor Registration 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 Central Contractor Registration (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 a 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.ccr2000.com or by calling 888-CCR-2423 (888-227-2423).

5.17 Property

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 contract. A 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 a SBC cannot furnish its own facilities to perform required tasks, a 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. Government-wide SBIR policy prohibits the use of any SBIR award funds for the use of government equipment and facilities. This does not preclude a SBC from utilizing a government facility, but such use cannot be paid for with SBIR funds.

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 should also include relevant information on the funding sources(s) (private, other government, internal) for the effort.

5.18 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 a 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. 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.

6.2.1 What Needs to Be Submitted

The entire proposal including Forms A, B and C must be submitted via the NASA SBIR/STTR home page located at (http://sbir.nasa.gov).

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. An example chart has been provided in Appendix B.

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.**

6.3 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 email 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.

6.4 Deadline for Phase I Proposal Receipt

All Phase I proposal submissions must be received no later than 5:00 p.m. EDT on Wednesday, August 21, 2002 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 accordingly.**

6.5 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 2002 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, 2002 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

6.6 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.

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.battelle.org/glitec

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, D.C. 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: 800-553-6847
URL: http://www.ntis.gov

8. Submission Forms and Certifications

FORM A – SBIR PROPOSAL COVER

Subtopic Number

1. PROPOSAL NUMBER: **02-** __ __ . __ __ __ __ __ __
2. SUBTOPIC TITLE:
3. PROPOSAL TITLE:
4. SMALL BUSINESS CONCERN (SBC):
   NAME:
   MAILING ADDRESS:
   CITY/STATE/ZIP:
   PHONE:
   FAX:
   EIN/TAX ID: DUNS + 4: CAGE CODE:
   NUMBER OF EMPLOYEES:
5. AMOUNT REQUESTED $ ________________ DURATION: __________ MONTHS
6. CERTIFICATIONS: OFFEROR CERTIFIES THAT:

As defined in Section 1 of the Solicitation, the offeror certifies:		
a. The Principal Investigator is "primarily employed" by the organization as defined in the SBIR Solicitation	Yes	No
As defined in Section 2 of the Solicitation, the offeror qualifies as a:		
b. SBC Number of employees: _____	Yes	No
c. Socially and economically disadvantaged SBC	Yes	No
d. Woman-owned SBC	Yes	No
As defined in Section 3.2.4 Part 11 of the Solicitation, the offeror certifies:		
e. Work under this project has been submitted for federal funding only to the NASA SBIR Program	Yes	No
f. Work under this project has not been funded under any other Federal grant, contract or subcontract	Yes	No
As described in Section 3 of this solicitation, the offeror meets the following requirements completely:		
g. All 11 parts of the technical proposal are included in part order	Yes	No
h. Subcontracts/consultants proposed?	Yes	No
i) If yes, limits on subcontracts/consultants met	Yes	No
ii) If yes, copy of agreement enclosed	Yes	No
i. 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. ENDORSEMENT BY SBC OFFICIAL:

   NAME:
   TITLE:
   PHONE:
   E-MAIL:
   SIGNATURE:
   DATE:

NOTICE: For any purpose other than to evaluate the proposal, this data shall not be disclosed outside the Government and shall not be duplicated, used, or disclosed in whole or in part, provided that if a funding agreement is awarded to this proposer as a result of or in connection with the submission of these data, the Government shall have the right to duplicate, use, or disclose the data to the extent provided in the funding agreement. 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 Proposal Cover

1. Proposal Number: This number does not change even if the firm gets a new phone number. Complete the proposal number as follows:
   1. Enter the four-digit subtopic number.
   2. Enter the four digits system generated numbers

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:	City name
State:	2-letter State designation (example VA for Virginia)
Zip:	9-digit Zip code (example 20705-3106)
Phone:	Number including area code
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, and 6g (see the referenced sections for definitions)

   6h. 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.

   6i. 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: An official of the firm must electronically endorse the proposal cover

FORM B – SBIR PROPOSAL SUMMARY

Subtopic Number

1. Proposal Number **02-** __ __ . __ __
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 Form B electronically.

1. **Proposal Number:** Same as Proposal Cover.

2. **Subtopic Title:** Same as Proposal Cover.

3. **Proposal Title:** Same as Proposal Cover.

4. **Small Business Concern:** Same as Proposal Cover.

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 SUMMARY BUDGET

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)	$ ______
(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)	$ ______

Guidelines for Preparing SBIR Summary Budget

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, on a budget explanation page immediately following the summary budget in the proposal.

Firm: Same as Proposal Cover.

Proposal Number: Same as Proposal Cover.

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 that 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.

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.

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.

SBIR CHECK LIST

For assistance in completing your proposal, use the following checklist to ensure your submission is complete.

1. The entire proposal including any supplemental material shall not exceed a total of 25 8.5 x 11 inch pages (Section 3.2.1).
2. The proposal and innovation is submitted for one subtopic only. (Section 3.1).
3. The entire proposal is submitted consistent with the requirements and in the order outlined in Section 3.2
4. The technical proposal contains all eleven parts in order. (Section 3.2.4).
5. Certifications in Form A are completed.
6. Proposed funding does not exceed $70,000. (Sections 1.4.1, 5.1.1).
7. Proposed project duration should not exceed 6 months. (Sections 1.4.1, 5.1.1).
8. Entire proposal including Forms A, B and C submitted via the Internet.
9. Form A electronically endorsed by the SBC Official.
10. **Proposals must be received no later than 5:00 p.m. EDT on Wednesday, August 21 2002** (Section 6.4).

FORM A – STTR PROPOSAL COVER

Topic Number

1. PROPOSAL NUMBER: **02-** __ __
2. RESEARCH TOPIC:
3. PROPOSAL TITLE:
4. SMALL BUSINESS CONCERN (SBC)
   NAME:
   ADDRESS:
   CITY/STATE/ZIP:
   PHONE:
   FAX:
   EIN/TAX ID:
   DUNS + 4: CAGE CODE:

   RESEARCH INSTITUTION (RI)
   NAME:
   ADDRESS:
   CITY/STATE/ZIP :
   PHONE:
   FAX:
   EIN/TAX ID:
5. AMOUNT REQUESTED: $____________________ DURATION: _________ MONTHS
6. CERTIFICATIONS: THE ABOVE SBC CERTIFIES THAT:

As defined in Section 2 of the Solicitation, the offeror qualifies as a:		
a. SBC Number of employees: ____	Yes	No
b. Socially and economically disadvantaged SBC	Yes	No
c. Woman-owned SBC	Yes	No
As described in Section 2.8 of the Solicitation, the partnering institution qualifies as a:		
d. FFRDC	Yes	No
e. Non-profit research institute	Yes	No
f. Non-profit college or university	Yes	No
As described in Section 3 of the Solicitation, the offeror meets the following requirements completely:		
g. Cooperative Agreement signed by the SBC and RI enclosed	Yes	No
h. All eleven parts of the technical proposal included in part order	Yes	No
i. Subcontracts/consultants proposed?	Yes	No
i) If yes, limits on subcontracts/consultants met	Yes	No
ii) If yes, copy of agreement enclosed	Yes	No
j. 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-SBIR funding source identified in Part 8?	Yes	No
As described in Section 3.2.4 of the Solicitation, the offeror certifies:		
k. Work under this project has been submitted for funding only to the NASA STTR Program	Yes	No
l. Work under this project has not been funded under 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. ENDORSEMENT BY SBC OFFICIAL:
   NAME:
   TITLE:
   PHONE:
   E-MAIL:
   SIGNATURE:
   DATE:

NOTICE: For any purpose other than to evaluate the proposal, this data shall not be disclosed outside the government and shall not be duplicated, used, or disclosed in whole or in part, provided that, if a funding agreement is awarded to this proposer as a result of or in connection with the submission of these data, the Government shall have the right to duplicate, use, or disclose the data to the extent provided in the funding agreement. 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 Proposal Cover

1. Proposal Number: This number does not change even if the firm gets a new phone number. Complete the proposal number as follows:
   1. Enter the two-digit Topic number.
   2. The system will generate a unique four digit number

2. Research Topic: NASA research topic number and title (Section 8).

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:	City name
State:	2-letter State designation (example VA for Virginia)
Zip:	9-digit Zip code (example 20705-3106)
Phone:	Number including area code
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, and 6f (see Section 2 for definitions)

   6g. 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).

   6h. 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).

   6i. 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.

   6j. 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 5, 5.17). 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.

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 1.1).

9. Endorsements: An official of the firm must electronically endorse the proposal cover.

FORM B – STTR PROPOSAL SUMMARY

Topic Number

1. Proposal Number **02 - __ __**
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 Proposal Cover

2. **Research Topic:** Same as Proposal Cover.

3. **Proposal Title:** Same as Proposal Cover.

4. **Small Business Concern:** Same as Proposal Cover.

5. **Research Institution:** Same as Proposal Cover.

6. **Principal Investigator/Project Manager:** Enter the full name of the PI/MS 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 SUMMARY BUDGET

PROPOSAL NUMBER:

SMALL BUSINESS CONCERN: PRINCIPAL INVESTIGATOR/PROJECT MANAGER:

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) $ ______________

(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) $ ______________

Guidelines for Preparing STTR Summary Budget

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, on a budget explanation page immediately following the summary budget in the proposal.

Small Business Concern - Same as Proposal Cover.

Principal Investigator/Project Manager - Same as Proposal Cover.

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 that 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.

Other Direct Costs (ODCs) - (Include budget for the Research Institution as a Other Direct Cost.)

- 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.

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 5.11 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 $100,000.

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, sub- licenses 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 non-disclosure 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 3.2.2, 3.2.5).

2. The proposal and innovation is submitted for one topic only. (Sections 1.4.1, 5.1.1).

3. The entire proposal is submitted consistent with the requirements and in the order outlined in Section 3.2

4. The technical proposal contains all eleven parts in order. (Section 3.2.4).

5. Certifications in Form A are completed.

6. Proposed funding does not exceed $100,000. (Sections 1.4.1, 5.1.1).

7. Proposed project duration should not exceed 12 months. (Sections 1.4.1, 5.1.1).

8. Cooperative Agreement has been electronically endorsed by both the SBC Official and RI (Sections 3.2.2, 3.2.5).

9. Entire proposal including Forms A, B and C submitted via the Internet.

10. Form A electronically endorsed by the SBC Official.

11. **Proposals must be received by the NASA SBIR/STTR Program Support Office no later than by 5:00 p.m. EDT on Wednesday, August 21, 2002.** (Section 6.4).

9. Research Topics for SBIR and STTR

9.1 SBIR Research Topics

Introduction

The SBIR Program Solicitation is aligned with the established NASA management structure of the Strategic Enterprises (http://www.nasa.gov).

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. Research topics and subtopics in this Solicitation are organized by the five NASA Strategic Enterprises:

Aerospace Technology
Biological and Physical Research
Earth Science
Human Exploration and Development of Space
Space Science

9.1.1 AEROSPACE TECHNOLOGY

NASA's Aerospace Technology 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 reducing 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.hq.nasa.gov/office/aero

TOPIC A1 Aviation Safety

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 has resulted in the absolute number of accidents also increasing. Despite the events of September 2001, the worldwide demand for air travel is expected to increase even further over the coming two decades—doubling or tripling by 2017. Without improvements, this could lead to 50 or more major accidents a year. This number of accidents would have an unacceptable impact on the aviation system, impeding anticipated growth. General Aviation (GA) system safety is also critically important as its accident rate is many times greater than that of commercial transport operations. Growth of the GA market is highly dependent upon safety and security considerations. Objectives of NASA's Aviation Safety Program (AvSP) include: (1) Eliminating targeted accident categories through delivery of precision approach and landing technologies and displays that provide intuitive guidance and piloting decision support, at any runway, at any airport, for both general and commercial aviation; affordable data-linked communication and on-board graphical display of worldwide aviation weather information; turbulence modeling and detection; icing prediction, detection, avoidance, and mitigation; and synthetic vision technologies that provide immediate, clear-day equivalent visual awareness in any weather or light condition. (2) Increasing accident survivability in those cases where accidents do occur through advanced structural and material designs that demonstrate greatly improved crash survivability and fire hazard mitigation. (3) Strengthening the overall safety of the aviation system by developments in aviation system modeling, human-error assessment methodologies, and integrated aviation system monitoring tools.

A1.01 Flight Deck Situation Awareness and Crew Systems Technologies
Lead Center: LaRC

Information technology has and will continue to provide operational opportunities to increase the safe and efficient use of the National Airspace System (NAS). Significant challenges for applications of this evolving technology include maintaining or enhancing NAS operators' situation awareness, facilitating and extending human perception and interpretation, counteracting human information processing limitations and biases, supporting collaborative work among geographically and temporally distributed operators, and sensitively evaluating the effectiveness of crew/system interfaces and procedures.

NASA seeks highly innovative crew systems technologies that will support appropriate situation awareness, decisions, and workload modulation for improved airspace safety and efficiency. These technologies may take the form of tools, models, techniques, procedures, substantiated guidelines, prototypes, and devices. In addition, NASA seeks tools and methods for measuring and analyzing human and group performance in complex, dynamic systems. Innovative and economically attractive approaches are sought to advance the current state of the art in the following areas:

- Systems monitoring with sensitive and informative advisements, alerts, and aids for NAS operators that enhance situation awareness and improve aviation safety.
- Crew-centered systems design methods and technologies.
- Innovative crew/system interface technologies.
- Human-error reduction in aircraft operations and systems monitoring.
- Error-tolerant flight deck systems including advanced displays, crew-system interfaces, and monitoring technologies.
- Human-error reliability approaches to analyzing flight deck displays, decision-aids, and procedures.
- Individual and team performance metrics, analysis methods, and tools for use in evaluating performance in complex systems.
- Human performance measurement technologies for use in operational environments.
- Decision-support tools and methods to improve collaborative and distributive decision-making among NAS operators.
- Integrated flight deck information systems and procedures.

- Decision-support to assist NAS operators in information acquisition, information integration, and response selection.
- Artificial Intelligence technologies and concepts that monitor crew and aircraft performance to ensure appropriate levels of engagement, crew workload, and situation awareness.
- Human-centered information technologies that enhance situation awareness and performance of less experienced NAS operators, especially at critical times.
- Development of human-centered information technology for intuitive guidance cues in advanced display concepts.
- Guidelines, measurement, and system design techniques that allow for successful assessment of the application of human-centered design principles to flight deck display concepts.

A1.02 Propulsion and Airframe Failure Data and Accident Mitigation
Lead Center: GRC
Participating Center(s): LaRC

NASA is concerned with the prevention of hazardous and accident conditions and the mitigation of their effects when they do occur. One particular emphasis is on fire. The prevention, detection, and suppression of fires are critical goals of accident mitigation. 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 crashworthiness. For all transport aircraft accidents, 45% of those that involve serious injuries or fatalities are survivable. Besides impact alone, survivability is often a function of the combined effects of subsequent fire and smoke. Technology is needed to further protect passengers from the effects of the crash or mitigate the after effects to allow the escape of passengers.

A third 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 final emphasis for this subtopic is on propulsion system health management in order to prevent or accommodate safety-significant malfunctions. 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 instrumentation, health monitoring algorithms, and fault accommodating logic are sought which help to further reduce the occurrence of and/or mitigate the effects of safety-significant propulsion system malfunctions.

With these four emphases in mind, products and technologies are sought to mitigate or prevent relevant accidents, to enhance human survivability in the event of an accident, and to monitor system health. Considerations should be made for affordability and retrofitability to the commercial transport, general aviation, and rotorcraft fleets. These include the following areas:

- Technology for fire prevention, detection, and suppression of potential in-flight fires in fuel tanks, insulation, cargo compartments, and other inaccessible locations.
- Technology to provide fuel tank vapor flammability reduction and on-board oxygen generation.
- Technology to minimize fire hazards in crashes and to prevent or delay fires. For example: fuel-system modifications to eliminate spills, and on-demand suppression while not presenting a weight or performance penalty.
- Design and injury criteria and dynamic analyses to enhance crash safety.
- Systems approach to crashworthy designs, which may include validated occupant/seat/structural interaction analyses.
- Energy-absorbing seat and structural concepts and materials.

- Technology for occupant protection in a crash, including advanced restraints and supplemental restraints.
- Advanced material/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/systems accordingly.
- Health management technologies such as advanced instrumentation, health monitoring algorithms, and fault accommodating logic, to predict, diagnose, and prevent safety significant propulsion system malfunctions.
- Low cost methods for failure prediction and testing of any of the above aircraft failure-prevention and mitigation technologies.
- Methods for integration any of the above aircraft failure-prevention and mitigation technologies into existing or new aircraft.

A1.03 Automated On-Line Health Management and Data Analysis
Lead Center: DFRC
Participating Center(s): LaRC

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/wide area networks. On-line health monitoring is a general concept involving signal-processing algorithms designed to support decisions related to safety, maintenance, or operating procedures. The concept of on-line emphasizes algorithms that minimize the time between data acquisition and decision-making.

This subtopic seeks solutions for on-line 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 a virtual flight research center, a disciplinary-specific collaborative laboratory, an onboard diagnostics system, or a maintenance and inspection network 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; airports; flight operations or mission control; air traffic management; or airlines. Proposers are encouraged to discuss data acquisition, processing, and presentation components in their proposal. Examples of desired solutions targeted by this subtopic include:

- 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 that 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.
- Innovative solutions for harvesting, managing, archival, and retrieval of aerospace vehicle health data.

A1.04 Aircraft Icing Systems
Lead Center: GRC

A major goal of the NASA Aircraft Icing Program 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 condition avoidance (icing weather information systems) or tolerance (aircraft icing protection systems and design tools). Creative teaming arrangements are encouraged to help meet proposal objectives. Of particular interest are technologies that are compatible with emerging aircraft designs (e.g. sensitive electronic systems, digital flight decks, and advanced wing designs). Onboard systems must be aerodynamically non-intrusive, practical, and must consider weight, power, size, and cost for successful integration into aircraft. To receive consideration for funding, all proposals submitted under this subtopic must demonstrate significant advantages over existing technologies. The areas of greatest interest are:

- New practical, ground-based, real-time scanning remote sensing techniques for the measurement of the supercooled water droplet and temperature environment. NASA is currently funding the development of radar and radiometry technologies that can profile the conditions directly above the ground station. Proposed technology must be capable of scanning a large volume of the atmosphere and quantifying the environment to allow for the prediction of the severity of airframe icing, and to identify potential avoidance and escape routes, and must have practical range (at least 20 km) and cloud penetration capability. Scanning update cycle rate needs to be on the order of one minute to account for rapid changes in the icing environment. Remote measurement systems must be capable of quantifying liquid water in both pure liquid clouds and those with ice crystals.
- Radome technology for microwave wavelength radar and radiometers that remain clear of liquid water and ice in all weather situations.
- In situ icing environment measurement systems that can provide practical, very low cost validation data for emerging icing weather information systems and atmospheric modeling. Measured information must include location, altitude, cloud liquid water content, temperature, and ideally cloud particle sizing and phase information. Solutions envisioned would utilize radiosonde-based systems.
- Low-power and low-cost anti-icing systems, including technologies that protect composite structures. A system must be capable of operating under all potential environmental conditions and should be capable of operating automatically or with minimal cockpit crew interaction.

TOPIC A2 Vehicle Systems

The Vehicle Systems Program within the Aerospace Technology Enterprise is developing revolutionary technologies at the laboratory, component or subsystem level, relying on strategic partnerships and opportunities with the aerospace industry and other government agencies, for further technology maturation and application. To ensure the technologies developed in this program are at an appropriate readiness level and the objectives of the program are met, the program will provide investments for significant advancements in critical components and designs. The overall progress of Vehicle Systems will be determined based on analytical integration of the technologies into system level assessments against the Enterprise's Revolutionize Aviation Objectives – Enable the safe, environmentally friendly expansion of aviation. Three projects: Breakthrough Vehicle Technologies, Propulsion & Power, and Flight Research focus on development of the fundamental technologies needed to enable the change state in aeronautics. The three projects: Ultra-Efficient Engine Technology, Quiet Aircraft Technology and 21st Century Aircraft Technology focus on the integration of these technologies into subsystems and systems that can be developed with industry partners into high leverage products. The Advanced Vehicle Concepts project takes those vehicle and technology concepts which require flight testing through additional systems analysis, 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 (NOx) 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(NOx) limits. 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 NOx, 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. Areas of particular interest include

- New concepts for reducing CO_2, oxides of nitrogen (NO, NO_2, NOx), 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 which minimize CO_2 and NOx 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 NOx, SOx, HOx, 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 2D and 3D data; time history measurements; and thin film, fiber optic, and 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 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 NOx emissions standards relative to current ICAO regulations for commercial aircraft concepts. Enabling technologies shall be identified for future research.

Advanced Materials for Reduced Emissions: Proposals are also sought to address advanced materials, their development, and their application to primary propulsion systems such as aircraft gas turbines, rocket and turbine based combined cycle engines, as well as auxiliary power sources in aircraft and space vehicles. Materials of interest include any especially used in propulsion systems such as high temperature polymers, nickel base alloys, ceramic matrix composites, coatings for these, and processes for their economical and reliable preparation.

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

With the increased emphasis on safety, enhanced performance and affordability, and the need to reduce the environmental impact of aircraft, there are many new challenges being faced by the designers of aerospace propulsion systems.

Electric aircraft propulsion & power systems have the potential to completely eliminate harmful emissions from aircraft while at the same time doubling fuel efficiency. Major strides have been achieved in the development of electrical systems and components especially in the automotive field. We now appear to be on the threshold of viable electric flight. There are still major technical advances required to make commercially viable electric aircraft a reality, but the goal does now appear to be achievable, possibly even in the nearer term for smaller family sized air vehicles. To achieve the implementation of environmentally harmonious twenty-first century air vehicles, innovations are needed to enable highly efficient, low cost, power dense (weight and volume) electric aircraft propulsions & power systems.

Intelligent propulsion technologies have the potential to enable the design of extremely safe, high performance propulsion systems that will also meet the stringent affordability and environmental requirements of the future. For turbomachinery based propulsion systems, the approach has been to design engine components such as combustors, fans and compressors, inlets, nozzles, etc., for optimum component performance within some overall system constraints and the control problem was to transition the operating point of the engine from one set point to another in the most expedient manner without compromising safety. With the advancements in information technologies and various disciplines relevant to aeropropulsion, the component designers are beginning to realize the potential of "Intelligent Engines" in helping them meet more stringent design requirements.

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 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.

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, motor drive systems, fuel storage (especially hydrogen). Highly integrated dual function components and systems that have the potential to reduce overall weight are of special interest (e.g., power conductors that are integrated into the airframe structure, motors directly integrated into the fan/propeller structure, etc.) Both component and system level technologies are solicited.

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, and smart sensors, electronics and actuators for enabling self-diagnostic and prognostic, and self-reconfiguration capabilities being sought. Concepts integrating distributed sensing and, actuation and control logic for micro level control of parameters, such as propulsion system internal flows, that impact performance and environment are of special interest. 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 present-day gas turbine engines to operate over a flight spectrum of up to Mach 8. Specific technical areas include the following:

- Advanced cooling concepts that minimize coolant penalties. This can include innovative cooling systems, materials concepts, fuel cooling of combustor, and endothermic fuels and/or fuel additives to increase the heat-sink capacity or cooling capacity of fuels.
- Innovative concepts relating to 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 NOx 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 flowpath or dual flowpaths.
- 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 advanced ceramic/composite materials or micro-electrical-mechanical systems that demonstrate the potential to enhance the performance and reduce the cost and weight; and 3) innovative inlet flow conditioning.
- New concepts for combined/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.

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. Improvements in noise prediction and control are needed for jet, propeller, rotor, fan, turbomachinery, and airframe noise sources to reduce the impact on community residents, aircraft passengers and crew, and launch vehicle payloads. Innovations in the following specific areas are solicited:

- Fundamental and applied computational fluid-dynamics techniques for aeroacoustic analysis, particularly for use early in the design process.

- Simulation and prediction of aeroacoustic noise sources particularly for airframe noise sources and situations with significant interactions between airframe and propulsion systems
- Innovative active and passive acoustic treatment concepts for engine nacelle liners.
- Concepts for active and passive control of aeroacoustic noise sources for advanced aircraft configurations.
- Reduction technologies and prediction methods for rotorcraft and advanced propeller aerodynamic noise.
- 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.
- Development and application of flight procedures for reducing community noise impact of rotorcraft and future subsonic and supersonic commercial aircraft while maintaining safety, capacity and fuel efficiency.
- Development of synthesis and auditory display technologies for subjective assessments of interior and exterior aircraft noise.

TOPIC A3 Airspace Systems

NASA's Airspace Systems (AS) program is investing in development of revolutionary improvements and modernization for the air traffic management (ATM) system. The AS Program will enable new aircraft, new aircraft technologies and air traffic technology to safely maximize operational efficiency, flexibility, predictability and access into airspace systems. The major challenges are to accommodate projected growth in air traffic while preserving and enhancing safety; provide all airspace system users more flexibility and efficiency in the use of airports, airspace and aircraft; reduce system delays; enable new modes of operation that support the FAA commitment to "Free Flight" and maintain pace with a continually evolving technical environment and 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 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 Small Aircraft Transportation System Technologies
Lead Center: LaRC

NASA seeks innovative technologies to support advances for small aircraft transportation systems that substantially increase the demand for retrofit of existing aircraft, new aircraft and airport and airspace utilization. Of specific interest are advanced, affordable, certifiable technologies for human-factors engineered display of flight information for total situational awareness and simplified integration of flight controls with displays and propulsion systems. In addition, innovations are desired in cost-effective, user-friendly improvements in the graphical display of weather, traffic, and National Airspace System (NAS) facilities' information services in the cockpit. NASA also seeks innovations in manufacturing methods and materials that can radically reduce the unit cost of small aircraft. Specifically, proposals are sought for the following areas:

Aircraft Configuration
Advanced concepts that reduce the landing speed for FAR Part 23 aircraft under 6,000 pounds. Advanced concepts for roadable aircraft are also desired. This category must include a sound business plan outline for production, with a technical plan providing for compatibility with the emerging National Airspace System architecture and a certification plan to meet at least one of the following applicable FARs: Part 103 (Ultra-

lite vehicle), Part 21.24 (Primary Category Aircraft), Part 23 (Certified Aircraft) or Part 27 (Rotorcraft), or Part 21.191 Advisory Circular AC No: 20-27 series (Experimental Homebuilt Aircraft).

Flight System Technologies, Information Systems and Pilot Vehicle Interface
Cost-effective advances in emerging navigation and graphical weather displays, flightpath management and energy management guidance, graphical depiction methods, intuitive cockpit display systems with emphasis on pilot-display interface, flight controls, voice interface, portable and wearable display technologies, communications and human factors engineering technologies to aid pilot decision-making and to reduce cockpit workload.

Certifiable Off-the-Shelf System Hardware and Software
Affordable cockpit systems including sensors, attitude-heading reference systems, terrain, obstacle, and hazardous weather avoidance systems, and applications for standardized data bus system architectures such as firmware, software, design and maintenance tools, and flight information and management products for airplane systems status and flight planning.

Airspace Infrastructure
Algorithms and displays for traffic conflict detection, alerting, and resolution to support airborne self-separation concepts, advances and innovations in digital high-speed, high-bandwidth communications, and intelligent system design for automated, collaborative decision making, and systems for collision avoidance.

Integrated Design and Manufacturing
Innovative manufacturing methods and materials providing significant advances in the cost, safety, weight, and cabin comfort for general aviation aircraft through materials technology, structural designs and assembly, and crash-worthiness. All proposals should include supportability plans (support infrastructure, maintenance requirements, operations, and training), certification plans (cite specific FARs), compatibility with current and future airspace architecture, and a clear path to commercialization.

A3.02 21st Century Air-Traffic Management
Lead Center: ARC
Participating Center(s): DFRC, LaRC

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); (4) is environmentally compatible; (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, enroute, 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
- Environmentally friendly ATM and aircraft operations
- Automation concepts for advanced ATM systems
- Application of methodologies from other domains to address ATM research issues
- Intelligent software architecture
- Runway-independent (e.g., VTOL, STOL, and V/STOL) aircraft technologies required to meet national air transportation needs and to satisfy requirements for airline productivity, passenger acceptance, and community-friendliness
- Intermodal transportation technologies
- Technologies fostering the operation of unpiloted aircraft within NAS under control of the ATM system, including, but not limited to innovative control, navigation, & surveillance (CNS) concepts

TOPIC A4 Next Generation Access to Space

NASA formed the 2nd Generation RLV Program to coordinate the development of the 2nd Generation RLV architecture. The Program, frequently referred to as the Space Launch Initiative (SLI), is focused on reducing the technical and business risks associated with developing a 2nd Generation Reusable Launch Vehicle system. The Program is built on four principles: (1) Commercial convergence - NASA seeks to fly its unique missions on privately owned and operated launch systems within an integrated architecture; (2) Competition - SLI seeks to enable at least two viable commercial competitors in the 2006 timeframe; (3) Assured access - Demonstrate the capability to autonomously deliver cargo to the International Space Station (ISS) as a backup to the Space Shuttle for meeting the United States' critical resupply manifest to ISS; (4) Evolvability - Develop systems that can affordably evolve to meet future mission requirements.

The Program focuses on four primary activities: (1) Systems Analysis/Engineering and Requirements Definition is critical to establishing the Program direction and determining NASA recommendations for the appropriate plans and budgets for architectures and systems that meet NASA requirements; (2) RLV Competition and Risk Reduction allows the government and US industry to mature technology and pursue significant technical and economic improvements that reduce risk through design maturation and hardware demonstration. It is this risk reduction that will enable a competition of architectures by the end of FY2006; (3) NASA Unique Systems will concentrate on developing the systems necessary to meet unique NASA mission requirements such as crew transport, cargo carriers, and rendezvous and docking; (4) Alternative Access will demonstrate the capability of providing an alternative and autonomous means of accessing ISS in the near term utilizing existing or emerging commercial launch vehicles.

A4.01 Space Transportation Architecture Definition
Lead Center: MSFC

Next generation RLV architectures will require high overall vehicle payload mass to lift-off mass ratios, propulsion systems which deliver higher thrust to engine weight ratios, increased trajectory averaged specific impulse, reliable overall vehicle systems performance, and extended reusability in order to achieve cost and crew safety goals. This subtopic emphasizes innovative launch vehicle architecture definition technology for subsystems, and vehicle system level design and analysis tools to support assessment of the credible physics and technical viability of proposed next generation launch vehicle architectures. Design and analysis tools proposed under this subtopic should address technical issues related to propellant tanks, thermal control subsystems, thermal protection systems, structures, guidance, navigation, and control (GN&C), loads and dynamics, fluid dynamics, integrated vehicle health management, turbomachinery , combustion devices, propulsion subsystems integration, vehicle layout, and overall vehicle level systems integration. Specific areas of interest for technology advancement and innovations include the following:

- Innovative analysis tools, and testing techniques applicable to assessment of credible physics associated with reusable launch vehicle thermal protection system designs, compartment thermal control requirements, cryo-tank thermal characteristics, and vehicle base heat shield requirements.
- Control and health management of vehicle structural systems by using sensors that have little influence on the structural parameters with the exception of the structural damping parameters
- Innovative vehicle preliminary design tools that support the design, analysis, and integration of vehicle systems and propulsions subsystems (such as the ability to assess operability of the overall launch vehicle concept and to model the impacts of design changes on vehicle cost, operations, crew safety, vehicle aerodynamics, and controllability). These tools would significantly enhance the overall systems engineering evaluation of potential reusable launch vehicle architectures.
- Integrated CAD, solid-model, structural, dynamic, thermal, and fluid-flow analysis methods for multi-disciplinary analysis and optimization of subsystems, components, and overall launch vehicle systems; and improved vehicle analysis tools in the areas of stress, thermal, structures, fluid dynamics, and acoustics.
- Manufacturing and testing techniques that will allow for significant reduction in the cost and schedule required to perform wind tunnel aerodynamic testing of candidate RLV configurations.
- Innovative analysis techniques to assess propellant management systems, feed lines, tank pressurization, fill , drain, and vent requirements
- Methodologies and analysis tools for investigation and assessment of optimal fault detection and redundancy management strategies; execution software and advanced navigation hardware/software architectures; adaptive GN&C utilizing data from sensors such as GPS; guidance concepts that will reduce operational costs and increase reliability by autonomously reshaping trajectories and retargeting landing sites in the presence of abort/failure situations to satisfy vehicle and control constraints to achieve a safe abort.
- Methodologies and analysis tools for investigation and assessment of advanced control concepts that will reduce operational costs and increase reliability by adapting to changing missions/payloads/vehicle models/failures and abort scenarios without requiring ground effort to retune.
- Methodologies and analysis tools for investigation and assessment of automated mission planning techniques for planning flight operations of RLVs, including trajectory planning, launch window and timeline determination, generation of initialization loads, and verification that the GN&C will successfully fly the vehicle.
- Analysis and testing techniques for assessment of damage and stress including life cycle predictions, progressive internal damage and dynamic response in structures containing ceramic-matrix, metal-matrix composites, or other composite materials; and nondestructive evaluation of structural integrity of vehicle subsystem and component materials. Methods for efficient characterization of frequency response functions of large structures, and analysis and testing techniques for passive and active vibration isolation devices for launch vehicles and payloads.
- Advanced methods and tools for prediction and assessment of dynamic and unsteady environments applicable to reusable launch vehicle systems and components. Methods to predict and evaluate the internal fluctuating environments of propellant delivery systems, dynamic contribution of cavitating pumps, and vehicle/engine system dynamic stability. Methods to predict and evaluate steady and unsteady external environments of complex vehicle/engine combinations relating to geometrically complex external aerodynamics, engine start/launch overpressures, and noise related to flow dynamics.
- Advanced methodologies for thermal and structural assessment of large integrated composite cryogenic tanks, assessment of efficient and effective tank repair techniques, and technologies associated with modal, acoustic and static testing of large-scale aerospace structural systems. Innovative experimental-empirical methods for composite material thermal characterization and response prediction.

A4.02 Space Structures, Materials, and Manufacturing
Lead Center: MSFC

Innovative manufacturing technologies including materials, processes, and structures development are sought for increasing safety and reducing cost and weight of space transportation propulsion, launch vehicle, and spacecraft systems and components. Only processes which are environmentally friendly and worker health oriented will be considered. Areas of interest include, but are not limited to:

Polymer Matrix Composites (PMCs)
Large scale manufacturing; non-autoclave curing; damage tolerant and repairable structures; advanced thermal and fluid systems; advanced materials and manufacturing processes for both oxygen-rich and high-temperature applications; improved thermal protection systems (such as thermally integrated structures with integral cryogenic tanks); aerogel technologies; rapid, multidimensional preformed fabrication for continuous fiber-reinforced composites with simple or complex geometry and/or large dimensions; adhesive bonding materials with high-performance capabilities in extreme environments such as cryogenic temperatures and elevated temperatures above 520K; optical cements with a stable refractive index resistant to ionizing radiation and low outgasing; conformal cryogenic tanks; designs for cryogen leakage prevention; innovations in the manufacture of thin film structures.

Metals and Metal Matrix Composites (MMCs)
Advanced manufacturing processes such as pressure infiltration casting (for MMCs), laser engineered near net shaping (Metals and MMCs), electron beam physical vapor deposition (Metals and MMCs), and in situ MMC formation; processes and joining techniques such as friction stir and friction plug welding for manufacturing components which target increasing specific strength, reduced weight, specific stiffness, and high pressure gaseous or liquid oxygen or high pressure gaseous or liquid hydrogen environments; metallic matrix alloy compositions which optimize high ductility and good joinability (welding/brazing); improved bonding and joining technologies; fiber or hybrid composites, functionally graded materials, 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; and advanced low cost manufacturing processes for engine applications.

Spray and Coating Processes
Innovative thermal spray or cold spray coating processes, or novel uses of existing thermal spray process that substantially improve material properties, combine dissimilar materials in new and useful ways or drastically increase efficiency, equipment life, or allow new applications previously limited by the current state-of-the-art; innovative methods of coating protection which will reduce coating application time, increase coating life, eliminate steps in the coating application process and extend hardware life, reducing refurbishment costs. Applications of interest include: dense deposits of refractory metals and metal carbides, thicknesses greater than 0.125 inch; thermally sprayed coatings on non-metallic composite materials to enhance or extend utility or service limitations; coating or spraying processes that allow forming of dense, high quality structural parts of complex geometry; processes, hardware, or materials that allow application of high melting point materials to heat-sensitive substrate materials; use of thermal spray, wholly or in part, as a means of rapid prototyping in metallic materials.

Joining and Bonding
Innovative technologies for bonding and joining of materials to improve joint efficiency, allow joining of a wider range of materials, improve the quality and cost-effectiveness of the joint, and extend the understanding of factors influencing these characteristics; joining of aluminum alloys especially those applicable to high-performance aluminum-lithium alloys and aluminum metal-matrix composites; improvement in control of welding, brazing and other joining processes as they are applied to joints for aerospace vehicles (these technologies should be compatible with the quality requirements for aerospace vehicles and should include process control technologies as well as non-destructive examination methods); sealant materials that remain ductile in cryogenic environments; sealants that will not crack, craze or peel when subjected to a high strain environment.

Electronic Systems and Computational Simulation and Analysis
Integrated design and analysis; advanced analysis, testing methods and tools; virtual product development and manufacturing simulation; process control and instrumentation for characterization and verification of material properties (including thermal, optical, electrical, mechanical, and moisture absorption);intelligent synthesis environment and collaborative engineering tools for manufacturing; health monitoring and maintenance technologies.

Rapid-prototyping
Rapid-prototyping technologies leading to improved structural integrity materials for use in end-item component processing; computer aided design driven additive manufacturing technologies producing near net shape hardware from metal or ceramic matrix composites, as well as improved monolithic and alloyed properties for direct hardware fabrication and custom part manufacturing (low run production); scalability effects for large component fabrication must be addressed as well.

Nanotechnology
Innovations that use nanotechnology, biomimetic, and self-healing processes to achieve low cost manufacturing of high quality materials for engineered structures; materials that have significantly improved physical and chemical properties; nano-sensors; reduction in the weight and volume of spacecraft; production of materials from the molecule upwards; continuous fibers based on nanotubes of carbon and other promising materials.

TOPIC A5 Space Transfer and Launch Technologies

Technology development for future generations of space transportation vehicles is necessary for the United States of America to recapture the majority of the space launch business. Development focused on increasing safety and reliability while decreasing the costs of space transportation systems is key to achieving delivery of robust, functional vehicles in the future. Technology advancement for Launch and In-Space propulsion, Spacecraft Airframe, and Ground Testing is sought to the meet the goals for space transportation . This includes propulsion related technologies that may enable new missions or launch concepts, or may provide very large performance improvements.

A5.01 Lightweight Engine Components
Lead Center: MSFC

Ceramic matrix composite materials are projected to significantly increase safety and reduce costs simultaneously, while decreasing weight for space transportation propulsion. Innovative material and process technology advancements are required to enable long life, reliable, and environmentally durable materials. Specific areas of technology development that are of interest include, but are not limited to, the following:

- Actively cooled combustion devices and flow path CMC components, or components lined with CMCs which can contain pressure (e.g. turbopump housings, gas paths structures, integral injectors and chambers),
- Development of functionally formed components; CMCs with optimal and hybrid fiber tows and architectures, interface coating systems, inhibitors, matrices, and environmental barrier coatings which best suits function of the component for a specific portion of the component (e.g. CMC face sheet with PMC backing, high conductivity material transitioned to low conductivity material in the same component, etc),
- Sealing and/or joining of CMCs to metals and ceramics for cooled components, manifolding, blisks, and end user specified components accounting for fiber directions, surface conditions of the materials to be seal/joined, system loads and environments, and potential interactions between the materials to be sealed/joined (both during processing and subsequent use).
- Development of turbomachinery components such as inserted CMC blades and integrally bladed disks, and

- Low cost (with metrics), rapid, scalable, repeatable CMC fabrication process development for the preceding applications. Clearly state how the process quality will be measured and validated from batch to batch or with respect to time. Note any limitations.

Ideally, technology development will include design, analysis, fabrication and testing of components, subsystems, and engine systems to enable full assessment and accountability of the technology product and fundamental findings with respect to their value toward reaching NASA's goals. Composites are desired composed of fibers selected by end users such as high strength carbon fibers, SiC fibers, or hybrid tows or architectures. Environmentally durable fiber interface coating systems yielding optimal composite life and composite performance with respect to cost and time for fabrication are desired. Ceramic based matrices, containing silicon- and/or refractory-compounds are of interest. Where applicable, proposals should include the following:

- Explanation of how aspects of similar, previous efforts are leveraged,
- Identification and explanation of key issues and how they are mitigated within the technology developed,
- Explanation of how the technology developed will address key issues and mitigate risks for targeted/candidate propulsion systems with respect to NASA goals,
- Identification of path to prove assessment and accountability of the technology product with respect to their value toward reaching NASA's goals,
- Identification of potential end users that would integrate the technology product(s) into a propulsion system,
- Listing of all deliverables. When components or systems are delivered to NASA for potential testing and analyses, plans for manifolding (for cooling and gas ducting), attachment and hardware assembly, and technology integration are sought. Desired deliverables include: Components, test data, and material analyses as appropriate, hoop or flat tensile stress-strain curves, interlaminar shear, and other coupon test data, microscopic analysis images, edge loaded tensile specimens (maximum of nine),
- Justification for selection of matrix material constituents, fibers, interface coatings, fabric architecture, etc.,
- For process development, inclusion of a flexible, process development matrix (e.g. which variables changed and how many processing trials),
- Correlation of processing variables to flexible, detailed test matrices (include in reports also),
- Verification of processes with microscopic analysis (e.g., microprobe, SEM, XRD, TEM, etc.) and macroscopic analysis (e.g., tensile strength, stress-oxidation, thermal mechanical fatigue, interlaminar shear strength, thermal and physical properties, etc.),
- Verification of specific end-use application by testing for permeability, thermal shock, etc.,
- Evaluation of components and/or coupon material using nondestructive characterization techniques, and
- Explanation of manufacturing scale-up necessary for the ultimate full-size target components.

A5.02 Reusable Launch Vehicle Airframe Technologies
Lead Center: LaRC
Participating Center(s): MSFC

Next generation space transportation systems must address the significant challenge of significantly reducing the cost of space access while providing orders-of-magnitude improvements in safety. To accomplish these goals, the airframes/spaceframes for future launch vehicles and upper stages must be reusable and incorporate advanced technologies in materials and structural concepts, validated, safe structural analysis and design technologies, and improved manufacture of large-scale, advanced structures; and must utilize advanced control, health monitoring, and maintenance technologies to enable low cost and safe operations. To facilitate the improvement of safety, the uncertainties in airframe loads, responses and failure mechanisms must also be reduced so that design margins that contribute to safety can be quantified with an accuracy much greater than is today possible. The conflicting requirements of low cost and safety must also be balanced with the need for performance sufficient for space transportation vehicles.

Airframe systems of primary interest in this subtopic include innovative concepts in reusable cryogenic propellant tanks, and "integrated thermal-structures" (i.e., airframe structures, such as integral cryogenic tanks, intertanks, wings/fins, thrust structures, fairings, control surfaces and leading edges that are hot structures or have the reentry thermal protection system closely integrated with the structure). Proposals for innovative research in design and mechanics, and in materials technologies addressing these airframe systems are solicited. Proposals of specific interest in this subtopic include one or more of the following items:

Design and Mechanics

- Specialized modeling, analysis, and design tools for integrated structural, thermal, thermal-structural, or acoustic responses, and innovative measurement and test methods for design validation. Application of methodology to circular and multi-lobed, membrane cryogenic tanks, and for conformal, non-membrane tanks is of special interest.
- Novel methods for prediction and testing of material and structural durability and damage tolerance with emphasis on cryogen leakage, environmental degradation, combined thermal-mechanical loads, and operation beyond nominal design conditions; and related methods to repair damaged structures.

Materials Technologies

- Significant advances in critical properties for high-temperature nickel, iron, and titanium alloys, intermetallics, refractory metals, PMC's, MMC's, and CMC's along with their related processing into useful product forms for fabrication into the airframe systems of interest.
- Materials technologies focused on advanced, high temperature materials compatible with cryogenic and gaseous hydrogen and oxygen; and for composite tanks, focused on cryogen leakage prevention and/or detection and/or sealing.
- Practical processing methods for large-scale manufacture of cryogenic tanks with efficient and reliable joining, and process development for advanced forming such as out-of-autoclave manufacture for composites, and near-net-shape and free-form fabrication for metals.

A5.03 Nuclear and Exotic Propulsion
Lead Center: MSFC
Participating Center(s): GRC, JPL

This subtopic focuses on innovative, advanced propulsion technologies, devices and systems that could lead to rapid and affordable in-space transportation, and ambitious exploration of the solar system and beyond. Technologies that offer significant improvements in propulsion system power densities and/or specific impulse over current space propulsion systems are sought. Concepts that can be applied to high-payoff commercial spin-offs and applications are of particular interest. Proposals should include analyses addressing feasibility and mission suitability, and plans for demonstrating concept feasibility via test/experiment. Areas of interest include:

- High-power, multi-megawatt nuclear electric propulsion systems. Technologies include, but are not limited to high-power density nuclear energy sources; advanced energy conversion techniques; and high-performance electric and plasma thrusters (e.g., ion, Hall, MPD, pulsed inductive and other electromagnetic thrusters).
- Nuclear thermal propulsion. Technologies include, but are not limited to, solid-core nuclear thermal rocket fuels, components and systems; gas-core thermal rockets; external pulsed plasma propulsion; and nuclear-based MHD cycles for high-power density energy production.
- Fusion propulsion. Technologies may include pulsed and steady-state fusion propulsion concepts and systems; efficient, lightweight laser and particle-based drivers; lightweight thermal radiators; and hybrid fission/fusion concepts.
- Antimatter propulsion. Technologies may include: highly-efficient techniques for antimatter production; long-duration antimatter storage and transportation; and methods for utilizing antimatter as a propulsion energy source

- Advanced propellants and high-energy density materials. Technologies include, but are not limited to advanced high-energy-density propellants; propellant combinations recovered in situ from extraterrestrial resources; and advanced cryogenic propellant storage/transfer techniques.
- Beamed energy propulsion. Technologies may include laser propelled vehicle systems and components; microwave energy transmission and energy conversion; and application of magnetohydrodynamic (MHD) interactions for thrust generation, drag reduction and power generation.
- Sails. Technologies include, but are not limited to magnetic, laser, microwave and plasma sail systems; lightweight, high-strength, high-temperature materials; and high-power, space-based lasers.
- "Breakthrough" propulsion. Application of newly discovered scientific phenomena to propellantless space transportation; travel near theoretical velocity limits; and energy production far beyond the capabilities of known nuclear sources.

A5.04 Ground Testing of Rocket Engines
Lead Center: SSC

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:

- New, innovative non-intrusive 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. Sub-millisecond response time is required. Temperature sensors must be able to measure cryogenic temperatures of fluids (160R for LOX and 34R for LH_2) under high pressure (up to 12,000 psi) and high flow rate conditions (2000 lb/sec, 333 ft/sec) for LH_2. Pressure sensors must have a range of up to 12,000 psi. Rocket plume sensors must determine gas species, temperature, and velocity for H_2, O_2, RP1, and hybrid fuels.
- On-line (real time) sampling and analysis of high pressure, high flow rate liquid oxygen-nitrogen mixtures. There is a significant need for real time, totally non-intrusive instrumentation for high pressure, high flow rate liquid oxygen (LOX) systems, having the capability to detect the presence of other chemical species present in the LOX, which may have been introduced through the pressurization process. An example would be the detection of N_2 in a LOX flow, where N_2 is used to pressurize the LOX delivery system. The technology should be expandable to include other rocket engine propellants.
- On-line particulate contamination sampling for facility propellant (LOX and LH_2) and gas systems (He, H_2, O_2, and N_2). A requirement exists for instrumentation that can detect, in real time, the presence of contaminants in the 30 micron to 100 micron range as these propellants and gases flow through facility piping. Sub-millisecond response time and ability to withstand cryogenic temperatures (down to 34R) and high pressures (up to 12,000 psi) are required features.
- Miniature front-end electronics to support embedding of intelligent functions on sensors. Requirements include computational power comparable to a 200 MHz PC with 32 MB of RAM or similar non-volatile storage, analog I/O (at least two of each, with programmable amplification, anti-aliasing filters, and 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 development kit for PC. Physical size should not occupy a volume larger than 4"x 4"x 2".
- 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 methods are required that can accurately predict the acoustic levels using fewer measurements. New, innovative techniques based on energy density measurements rather than pressure measurements show promise as replacements for the older models.
- 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.

- 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.
- Materials and components for high-pressure (up to 6000 psi), high-purity (90%+) hydrogen peroxide service. Materials, including seals, valve materials, and coatings that can withstand long-term hydrogen peroxide contact are required. Components for hydrogen peroxide service, including isolation valves, ball valves, and relief valves, which are designed for minimum number of sumps and seals, and clean flush-through, are required.

TOPIC A6 Computing, Information and Communications Technology

NASA's Computing, Information and Communications Technology (CICT) Program will enable scientific research, space exploration, and aerospace technology research to be performed with greater success, at less cost, and with increased return through the development and use of advanced computing, information and communications technologies. Research areas include goal-directed systems, enabling of seamless access to NASA's information technology resources, high rate delivery, and overall strategic research to develop, and evaluate a broad portfolio of fundamental information and bio/nano technologies for infusion into future NASA missions.

The CICT program seeks to develop more intelligent and adaptive systems and tools that work collaboratively with humans to achieve NASA's mission/science goals. This includes robotic and human-robotic exploration; safe, cost-effective operation of all launch vehicles; Earth-orbiting satellites for monitoring relationships associated with planetary phenomena; and development of methodologies to enhance the capacity, safety and security of our National Airspace System (NAS). It also seeks to enhance access to ground, air, and space-based distributed hardware, software, and information resources. This will allow scientists and engineers to focus on making new discoveries in science, design next-generation space vehicles, control missions or develop new concepts for the NAS.

Another aspect of the CICT program is enhancement of high rate data delivery from ground, air, and space-based assets directly to the users enabling NASA's twenty-first century missions, including: distributed networks of observing spacecraft to provide real-time multi-sensor information directly to users; multi-gigabit Internet-based communications in near Earth orbit; high rate communications from spacecraft traveling to the outer planets including, intra-planetary networks for surface exploration; and development of the NAS Communication, Navigation and Surveillance Architecture to meet future air travel demands.

A6.01 Human-Automation Interaction in Aerospace Systems
Lead Center: ARC
Participating Center(s): GRC

Aerospace systems rely increasingly on supervisory monitoring and control of automated systems supporting individual and distributed decision-making. Innovative proposals that are relevant to NASA aviation and space missions are sought in the following areas:

- Formal methods of analyzing flight deck and ground control human-automation interaction design
- Large-scale simulation of human-in-the-loop decision-making in the National Airspace System
- Individual and team performance modeling, visualization and prediction for design and operations
- Model-based intelligent tutoring approaches to human-automation interaction

- Data mining and visualization tools that extract causal human factors underlying aerospace mishaps from large amounts of text or quantitative data
- Human-system interaction supporting collaboration among human and synthetic agents.

A6.02 Nanotechnology
Lead Center: ARC
Participating Center(s): GRC, JPL

Nanotechnology is the science of creating functional materials, devices and systems through control of matter on the nanometer (atomic) scale and the exploitation of novel phenomena and properties (physical, chemical and biological) at that length scale. Control of organization at the atomic level provides the opportunity to create function-specific materials at the micro and macro scales. Nanotechnology is not simply another step toward top-down, miniaturization; it represents a fundamental change in approach that exploits new behaviors dominated by quantum mechanics, material confinement, and large interfaces.

Nanotechnology is expected to have a profound impact on all of NASA Enterprises by enabling revolutionary, lighter smaller spacecraft; powerful, small, low power consuming computers; radiation-hardened electronics; nano-electronics; nano-sensors and instruments, high power density fuel cell, biosensors for astrobiology and astronaut health monitoring; biomedical sensors and in-vivo medical devices; novel nanoelectromechanical systems (NEMS); and advanced materials for aerospace vehicles and space launch vehicle structures.

NASA's missions for Space Science, Earth Science and Aerospace Technology development have pushed the state of the art for extraordinary computational speed and memory capacity for at least two decades. The Space Science mission has the added requirement for computing devices that must have low power consumption, unparalled reliability, and resistance to harsh radiation environments. In the past, the electronics revolution has been based upon transistor miniaturization; smaller transistors are faster, and denser circuitry has more functionality. However, this miniaturization of transistors faces limitations due to quantum effects, wavelengths involved in lithography and cost barriers that will make the past approach to advancements futile within a decade.

Nanotechnology provides radical new approaches to size reduction and speed improvements through materials manipulation at the atomic scale. Possible candidates arising from potential advances in nanoelectronics include molecular computing (e.g., carbon nanotube based electronics and DNA computing), quantum computing, and artificial quantum-structure systems. These concepts can be realized through the concurrent development and fabrication of the underlying nanoelectronic building blocks (e.g. gates, interconnects), new system architectures and associated algorithms.

Specific interests for the 2002 solicitation include technology developments directed toward the above applications, including:

- Exploiting the extraordinary mechanical, electrical, magnetic, optical, and chemical properties of nanostructures including nanotubes (eg, carbon, silicon carbide, boron nitride), and nanowires.
- Controlled growth, dispersion and functionalization of nanotubes.
- Aligned nanotube fibers
- Growth and characterization of nanotubes and bio-inspired nanostructures
- Molecular electronics based chemical, gas, mechanical, and bio-sensors.
- Molecular and quantum computing, detecting, and sensing devices.
- Atomic chain electronics and sensors.
- Nanowire based electronic and sensing devices.
- Nanophotonics, including nanowire lasers.
- Fuel cell, batteries, and thermoelectric converters
- Biomolecular process for depositing metals for electrical or other surface properties.
- Design, development, fabrication and low-cost manufacturing processes of nanoelectronic components, connectors, switches and wires.

- Development of fault-tolerant, radiation resistant computing.
- Integration of nanodevices including sensors, communications and processing systems.

TOPIC A7 Engineering for Complex Systems

The Engineering for Complex Systems program is part of the Engineering Innovation objective of NASA's Aerospace Enterprise Pioneer Revolutionary Technology goal: To demonstrate advanced, full-life-cycle design and simulation tools, processes, and virtual environments in critical NASA engineering applications. The ECS program in particular focuses on the representation, reasoning, and mitigation of risk. Achieving this vision will require infusing new risk mitigation technologies and processes into our standard engineering practices throughout the program lifecycle. The Engineering for Complex Systems program is designed specifically to achieve the following goals: 1) Significantly advance the scientific and engineering understanding of system complexities and failures, including human and organization risk characteristics; and 2) Develop processes, tools, and organizational methods to quantify, track, visualize, and trade-off system designs and/or mission options with an emphasis on risk management throughout the lifecycle of the programs.

A7.01 Modeling and Control of Complex Flows Over Aerospace Vehicles and Propulsion Systems
Lead Center: LaRC
Participating Center(s): ARC

This subtopic solicits innovative ideas, concepts, and methodologies for the measurement, prediction, modeling and control of unsteady aerodynamic and aerothermodynamic phenomena that may be encountered by aerospace vehicles. Biologically inspired approaches and/or ideas for flow control are also solicited in this subtopic. Also of interest are advanced measurement systems and ground testing techniques to provide dynamic and global measuring capabilities, higher bandwidth, and improved resolution. Additionally, the subtopic is interested in innovative computational and experimental techniques that account for the complex aerothermodynamic, mixing, and combustion phenomena impacting the design and development of future space transportation vehicles, aero-assist orbital transfer vehicles, planetary entry probes, and hypersonic airbreathing propulsion systems. Unsteady phenomena of interest include, but are not limited to, active and passive flow control mechanisms; vortical and separated flows; equilibrium and finite-rate chemistry; thermodynamic and transport properties of multicomponent mixtures, gaseous radiation, gas-surface interactions, mixing and combustion, shock-wave/boundary-layer interactions; and laminar, transitional, and turbulent reacting and nonreacting flows. Specific areas of interest include:

- Flow-physics modeling and control of transition and/or transitional flows, turbulence, and turbulence-related phenomena such as heat transfer, skin-friction, acoustics, mixing and combustion, with an emphasis on separated flow and the scaling of ground-based experiments to flight Reynolds numbers.
- Control and/or mitigation of separation, vortical flows, and shock wave phenomenon, including their impact on vehicle drag (tubulent skin friction drag, profile drag, drag-due-to-lift, and wave drag).
- Non-conventional numerical methods for solving fluid-flow equations that increase computational efficiency, accuracy, speed, and utility, including construction of new algorithms, improved computer languages, efficient and adaptive grid-algorithm interfacing, and applications of automation techniques with discretization error assessments.
- Innovative techniques for robust and reliable handling and sharing of large CFD and experimental data sets.
- Analytical and/or computational models/algorithms applicable to the optimization of integrated hypersonic propulsion/vehicle systems.
- Innovative mixing techniques applicable to hypersonic propulsion, with special consideration placed on the stoichiometric fuel regimes.

- Concepts for small-scale devices that initiate and sustain fuel (hydrogen and/or hydrocarbon) ignition and flame holding in supersonic combustor environments, at conditions relevant to hypersonic airbreathing propulsion flight trajectories.
- Advanced test techniques and flow diagnostics (including non-intrusive flow diagnostics and surface diagnostics) for developing definitive databases across speed range from subsonic to hypersonic facilities including shock-expansion pulse facilities.
- MEMS and nano technology sensors and interface electronics for flow measurements including flow velocity, pressure, temperature, shear stress, vibration, force, attitude, and/or acceleration.
- A small onboard multichannel intelligent data system and/or a high-speed wireless (optical or radio frequency) data transfer system with 50 mega-bits-per-second or higher data rate for wind tunnel model applications.
- Optical flow diagnostic technologies capable of resolving velocity, density, temperature, etc., in a global sense to provide planar or volumetric data, or at multiple points within the flow to provide temporally dependent cross correlations at sample rates on the order of 100 kHz.

A7.02 Modeling and Simulation of Aerospace Vehicles in a Flight Test Environment
Lead Center: DFRC

Safer and more efficient design of advanced aerospace vehicles requires advancement in current predictive design 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 aerodynamics and the control system, in addition to pilot commands. The benefit of this effort will ultimately be increased flight safety (particularly during flight tests), more efficient aerospace vehicles, and an increased understanding of the complex interactions between the vehicle subsystems. This subtopic solicits proposals for novel, multidisciplinary, linear or nonlinear, dynamic systems simulation techniques. Proposals should address one or more of the objectives listed below:

- Prediction of steady and unsteady pressure and thermal load distributions on the aerospace surfaces, or similar distributions due to propulsive forces, by employing accurate finite element CFD techniques.
- Effective finite element numerical algorithms for multidisciplinary systems response analysis with adaptive three-dimensional grid/mesh generation at selected time steps.
- Effective use of high-performance computing machines, including parallel processors, for integrated systems analysis or pilot-in-the-loop simulators.
- Innovative applications of high-performance computer graphics or virtual reality systems for visualizing the computer model or results.
- Correlation of predictive analyses with test data or model update schemes based on measured information.

A7.03 Flight Sensors, Sensor Arrays 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, 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 subtopic solicits proposals for improving airborne sensors and sensor-instrumentation systems in subsonic, supersonic and hypersonic flight regimes. These sensors and systems are required to have fast response, low volume, minimal intrusion and high accuracy and reliability, and include wireless technology. Innovative concepts are solicited in the following areas:

Vehicle Environmental Monitoring

- Nonintrusive air data parameters (airspeed, air temperature, ambient and stagnation pressures, Mach number, air density, flow angle, and humidity at air temperatures as low as -20 deg. F).
- 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.
- Any of the above measurements in hypersonic flow.

Vehicle Condition Monitoring

- Optical arrays for robust flight control surface position and velocity measurement.
- Sensor arrays for structural load monitoring.
- Robust arrays for engine monitoring and control applications.

Advanced Instrumentation for Aeropropulsion Flight Tests.

- Thin film and fiber optic sensors, especially those compatible with advanced propulsion system materials such as ceramics and composites, and capable of withstanding the high temperatures and pressures associated with turbomachinery.
- Onboard processing for data condensation, failed sensor identification or other valuable onboard processing capability.

Vehicle Far Field Environmental Monitoring

- Nonintrusive measurements at range of 2-5 kilometers of environmental data (natural and induced flowfields, turbulence, weather, traffic).
- Onboard processing of sensed and telemetered data for integrated storage and strategic presentation to the flight crew.

A7.04 Knowledge Engineering for Safe Systems in Lifecycle Engineering
Lead Center: ARC

The Knowledge Engineering for Safe Systems area represents a synergy of human organizational modeling and simulation capabilities with knowledge management approaches that address explicitly issues of mission risk and safety in lifecycle engineering. Innovative proposals that are relevant to NASA missions are sought in the following areas:

- Computational organization models of risk management throughout the lifecycle of design, manufacture, operations, and maintenance
- Model-based simulation of the interactions between organizational decision making and hardware and software systems design and engineering that predict issues related to risk and resiliency
- Computational models of human and team performance that include fatigue, stress, workload, and risk-based decision making in a dynamic environment
- Ontologies and architectures for advanced product data management systems that explicitly incorporate the notions of risk, resiliency, and decision-making rationale
- Integration and interoperability of knowledge management, knowledge capture, and design rationale management capabilities into a heterogeneous distributed computing environment
- Immersive virtual environments and geospatial navigation approaches for user exploration of engineering facility and vehicle data

TOPIC A8 Enabling Concepts and Technologies

The Enabling Concepts and Technology (ECT) Program will identify, develop, verify, transfer and apply those high-payoff aerospace technologies applicable across a broad spectrum of systems needed to accomplish NASA's missions. The ECT program will enable the technology pipeline feeding focused technology development programs of NASA's Enterprises. ECT will perform fundamental research and development of high-risk, high-payoff technologies that are unique to NASA needs. The ECT Program objectives: (1) Explore revolutionary aerospace system concepts to enable the grand challenges and strategic visions of the NASA Enterprises, and to expand the possibilities for future NASA missions; (2) Develop advanced technology for sensing and spacecraft systems to enable bold new missions of exploration, and to provide increased scientific return at lower cost; (3) Develop advanced energetics technology to provide low-cost power and propulsion for enhanced mission capabilities, and to enable missions beyond current horizons; and (4) Perform fundamental research in high-payoff emerging technologies such as advanced materials, microelectronics and mechanical systems, and nanotechnology to stimulate breakthroughs that could enable new system concepts.

A8.01 Revolutionary Aerospace Vehicle Systems Concepts
Lead Center: LaRC
Participating Center(s): ARC

The emphasis in this subtopic is on advanced aerospace vehicle concepts for both military and civil applications that accelerate the exploration of high risk, breakthrough configurations in order to enable revolutionary departures from traditional approaches to air vehicle design. Concepts must contribute to improving safety, performance, capacity, reduced emissions and/or noise, and development, production, or operations cost of future air vehicles. The scope includes advanced aerospace vehicle concepts and airframe systems such as wing, fuselage, propulsion/airframe integration, and design tools enabling the above. Specific technical areas of interest include the following:

- Advanced aerospace vehicle concepts and configurations of subsonic to supersonic air-breathing vehicles and unique propulsion/airframe integration concepts that offer revolutionary increases in performance over conventional designs.
- Innovative system-oriented research to support, develop, and/or enable advanced airframe concepts that could impact the design and optimization of any future class of aerospace vehicles, including computational tools assisting in the design of that class of vehicles.
- Adaptation of newly emerging technologies, such as biomimetics and carbon nanotubes to aerospace vehicle concepts.

A8.02 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 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 the actual flight environment to fully characterize or validate.

The scope of this sub-topic is broad and includes advanced flight experiments that accelerate the understanding 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 inflight inflation methods, 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, 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. The benefit of this effort will ultimately be more efficient aerospace vehicles, increased flight safety (particularly during flight tests), and an increased understanding of the complex interactions between the vehicle or technology concept and the flight environment.

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://www.hq.nasa.gov/office/olmsa/

TOPIC B1 Cross-Disciplinary Physical Sciences

The Biological and Physical Research (BPR) Enterprise is taking advantage of the space environment which offers a unique laboratory to study biological, chemical and physical processes. Researchers will take advantage of this environment to conduct experiments in the biological and physical sciences that are impossible on Earth. BPR also seeks to engage the commercial sector in exploiting the economic benefits of the cross- disciplinary physical sciences. In this topic, cross-disciplinary research and enabling technology is sought to understand the effects of gravity on the physical sciences as well as in the area of vibration isolation/measurement technology. This research and technology will provide the basic foundation to integrate our understanding of the role of gravity in the evolution, development and function of living organisms, and in biological and physical processes. BPR is also taking advantage of revolutionary advances in the biomolecular community by conducting basic research to develop breakthrough technologies which will result in prototype biomolecular micro- and nano- systems for the detection, imaging, recognition and monitoring of biological signatures and processes at the molecular level.

B1.01 Exploiting Gravitational Effects for Combustion, Fluids, Synthesis, and Vibration Technology
Lead Center: GRC

The objective of this subtopic is introduce new technology in the form of devices, models, and/or instruments of use in microgravity and/or for commercial applications on earth. (For Biofluids, please see subtopic B1.03 Bioscience and Engineering.) Innovations are sought in the following areas:

- Understanding the effects of microgravity on fluid behaviors.
- Utilizing 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 thermal control systems application in space.
- 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.
- Understanding the effects of microgravity on combustion behaviors.
- Measuring the residual accelerations on spacecraft or in ground-based low-gravity facilities. Emphasis is placed on MEMS or nano scale devices.
- Novel vibration isolation technology for use in ground-based, low-gravity facilities.
- Improving in-space system performance that rely on fluid or combustion phenomena, principally spacecraft fire safety, especially fire prevention, smoke, precursor, and fire detection, fire suppression.
- Pollution reduction and improvement of the efficiency of liquid-fueled combustors.
- Characterization of ignitability, flame spread and spacecraft material selection.
- Micro-pumps and micro-valves; 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 through microcombustion.
- Microfluidics for fuel cells and other power systems.

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

NASA has interest in experiments that utilize the influence of microgravity on biotechnology processes and materials science to understand physical, chemical, and biological processes. Areas of interest include protein crystal growth and structural analysis techniques, separation science and technology, biomaterials, polymeric materials, advanced electronic and photonic materials, as well as metals and alloys, glass and ceramic materials technology. Other areas of interest relate to microgravity processing approaches such as containerless processing and advanced thermal processing techniques. Methods for conducting science and technology research required to enable humans to safely and effectively live and work in space are needed. Innovative studies are sought in the following research areas and in their enabling technologies including commercial applications on earth:

Biotechnology

- Advancement of high-throughput, automated preparation and/or analysis of biological crystals. This may include crystallization robotics, diffraction data collection, and the study of crystalline defects.
- Technology designed to improve our understanding of the effect of gravity on crystallization of biological macromolecules and crystal quality.
- Research and development of techniques in the field of separations of biological material designed to improve our understanding of the effect of gravity on separation efficiency.
- Technologies to determine the relationships between material substrates, tissue cell culture conditions, and subsequent cell culture development and expression.
- High-throughput technologies for the determination of gene expression.
- Biotechnology and instrumentation to help enable safe human exploration beyond Earth orbit for extended periods.

Materials Science

- Novel concepts and materials for efficient radiation shielding during human exploration of space. The materials must be capable of attenuating galactic cosmic rays, solar particles, and secondary particles to acceptable limits.
- Technology and instrumentation leading to high-leverage (useful product to Earth bound weight) materials processes for the utilization in situ of space resources, both materials and energy for application to the establishment of safe self sustaining self sufficient systems to enable science and a permanent human presence in space and on planetary surfaces.
- New development utilizing particles in the nanometer range size, having novel properties with applications to high strength, low-mass materials, advanced electronics, and radiation shielding.
- Innovations in polymers, composites, and other materials that incorporate sensory, effector, and self-repair technologies.
- Development of materials for improved sensor technology, leading to the potential for miniaturization and high performance in hostile environments.
- Advancement of the state of the art for the levitation and containerless processing of molten liquid materials including the development of techniques for uniform heating and maintenance of uniform temperature; precise position control of levitated samples particularly in a gaseous environment; measurement and control as well as reduction or elimination of sample rotation in featureless samples; measurement of the emissivity of pure metals, alloys, oxides and ceramics; and measurement of the materials work function over a range of temperatures.
- Microgravity furnace and experiment instrumentation technologies to better monitor sample health (temperature, pressure, etc) and experiment status while minimizing the instrumentation's effect on the sample as well as reducing system impacts on experiment design; additionally, consideration should be given to extending the useful life of instrumentation in order to minimize the need for on-orbit recalibration and refurbishment / replacement.
- Microgravity furnace and experiment thermal technology such as improved insulation for minimizing power, volume, mass and complexity; improved high temperature thermal interface materials for transferring the heat into and out of the sample and furnace components (which move or be stationary relative to each other); heating and cooling approaches that enhance safety, science and resource utilization.
- Advanced sample containment technologies and forms for providing safe, efficient sample containment while enhancing scientific return and minimizing systems impacts on furnace and experiment system design.
- Development of photonics materials of relevance to NASA’s mission including anticipated needs in future space travel that will rely increasingly on automation, minimize power consumption, and accommodate increases in complexity within the limited vehicle habitat volume and mass. Photon-

ics is also inherently less susceptible to electromagnetic pulse (EMP) exposure than electronics and has unique capabilities with regard to parallel data processing. Nonlinear optics, in particular, can play a pivotal role in space communications, remote sensing, engine performance characterization, synthetic vision, rendezvous and docking, laser propulsion, biophotonics, solar cell development, autonomous robotic manipulation, and rover exploration.

B1.03 Bioscience and Engineering
Lead Center: GRC
Participating Center(s): ARC, MSFC

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, models, and/or instruments of use in microgravity and/or for commercial application on Earth in the following areas:

Micro-Optical Technology for Interdisciplinary & Biological Research
Micro- and nano-optical technologies are sought for the measurement and manipulation of 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
- Wireless communication for the transmission and detection of sensor data, Wireless power delivery for sensors and health systems
- Optical quantum technologies for measurement systems including signal detection and transmission
- 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 the NASA's Office of Biological and Physical Research. 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, due to the loss of hydrostatic pressure, and on a longer time scale, due to 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 spaceflight. Furthermore, reintroduction of gravity causes large-scale fluid shifts in the body, which can influence cardiac output and induce faintness. Studies of macro-and micro-scale 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:

- 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

- Understanding the role fluid physics plays in human physiological processes such as cardiovascular flows and its effect on arteriosclerosis, and pulmonary flows and asthma
- Use of the above knowledge to develop effective countermeasures

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. Since 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:

- Understanding of fluid mechanics underlying the operations of microfluidic devices crucial to their successful operation and continued miniaturization
- 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:

- 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
- 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:

- 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
- Imaging hardware that can follow a metabolic process in a turbulent system
- Compact tunneling or evanescent wave microscopes capable of scanning quickly enough to follow metabolic processes

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, plant and microbial systems from the standpoint of physics. Of particular interest are studies that develop theoretical, numerical and/or experimental understanding of the effects of acceleration, radiation 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 of acceleration sensitivity. The knowledge obtained should contribute to related agency activities,

such as the disinfection of water systems, development of self-sustaining ecosystems, treatment of bacterial infection in space, and optimal growth of plants as a food source. Moreover, we expect that the knowledge and technologies derived will also provide ground-based economic and societal benefits. Major research disciplines include the heat, mass and fluid transport in: microbiology, plant and human physiology, hematology, drug delivery systems. Innovations are sought in the following areas:

- Delineation of the effects of acceleration and radiation 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, electroosmotic flows, and cytoplasmic streaming, as well as quantification of metabolic processes and other phenomena that permit the examination of these problems
- Mass, momentum and energy transport in plant development, e.g., transport of nutrients through porous substrates to plant roots
- Effects of bulk fluid flows on biofilms and liposome formation
- Transendothelial transport
- Improved techniques for mixing and separation in microgravity
- Micro- or nanoscale modeling of fluid flows and mass transfer for drug delivery systems
- Development of flexible numerical models to complement experimental and theoretical studies, which may require adaptive mesh refinement, micro/macroscale modeling, and/or treatment of moving boundaries

TOPIC B2 Fundamental Space Biology

Fundamental Biology (FB) is NASA's agency-wide program for the study of fundamental biological processes through space flight and ground-based research. The program has three primary goals: (1) Effectively use microgravity and the other characteristics of the space environment 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 (3) Apply this knowledge and technology to improve our nation's competitiveness, education, and quality of life on Earth. Increased emphasis has been placed on cell and molecular biology and developmental biology, as well as on the growing disciplines of evolutionary biology and genomics. FB will participate in the expanded range of space missions the Agency will undertake in the future. These include the International Space Station, planetary probes, surface studies, sample returns, and planetary bases. The Biological and Physical Research Enterprise also seeks to engage the commercial sector in exploiting the economic benefits of fundamental space biology on Earth.

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. 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.
- Expert control systems for environmental chambers.

The improved understanding of the role of gravity on animals requires innovative instrumentation which 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 non-invasively measure physical, chemical, metabolical and development 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). But, refined and stable measurements 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:

- 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
- Electro-physiology sensors, biotelemetry systems and biological monitors carried on spacecraft

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

The Fundamental Biology Program (FB) is the agency lead for biological research and biological instrumentation/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, 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 desireable.

Biological and biomolecular/microbiological/genomic research is enabling unprecedented insight into the structure and function of cells, organisms, and sub-cellular 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 Fundamental Biology objectives are grouped into the following solicited categories:

- Biological Sample Management and Handling - Technologies for remote, automated biosample and biospecimen collection, handling, preservation/fixation, and processing. 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 nano-technologies, 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 multi-dimensional 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/transfer to advanced bioinformatics and biocomputation systems.
- Integrated Biological Research Systems and Subsystems- Integrated, experiment/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 utilize 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 new methods for purification of living cells; development of space bioreactors for culture of fragile cells that have 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 micro-g research on the International Space Station. Specific areas of interest are:

- New methods for culturing mammalian cells in bioreactors, including advanced bioreactor designs and support systems, miniature sensors for measurement of pH, oxygen, carbon-dioxide, glucose, metabolites, and microprocessor controllers.
- 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, bio-polymers, and molecular bio-processing systems; bio-compatible materials, devices, and sensors for im-

plantable medical applications including molecular diagnostics, in vivo physiological monitoring and microprocessor control of prosthetic devices.
- Methods and apparatus which allow microscopic imaging and biophysical measurements of cell functions, effects of electric or magnetic fields, photoactivation, and testing of drugs or biocompatible polymers on live tissues.
- Quantitative applications of molecular biology, fluorescence image and flow cytometry, and new methods for measurement of cell metabolism, cytogenetics, immune cell functions, DNA, RNA, oglionucleotides, intracellular proteins, secretory products, and cytokine or other cell surface receptors.
- 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. This includes methods for improving the controlled release from transdermal drug devices, ionaphoresis, controlled hyperthermia and new drug delivery systems for inhalation and intranasal administration.
- 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.
- Low -temperature sample storage (-80^{o}C) and biological sample preservation methods.

TOPIC B3 Biomedical and Human Support Research

The goal of the Biological and Human Support Research topic is to ensure the health, safety, and performance of humans living and working in space. This includes life support functions such as a healthy air and water supply, food for the crew in future ultra-long duration missions, health maintenance and in-space medical care, radiation shielding for protecting humans in deep space missions, and unique human factors issues of the space environment.

B3.01 Advanced Spacecraft Life Support
Lead Center: JSC
Participating Center(s): ARC, JPL, KSC, MSFC

Advanced life support systems are essential to enable human planetary exploration. 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, high reliability, minimal use of expendables, ease of maintenance, and low system volume, mass, and power. Innovative, efficient, practical concepts are needed in all areas of regenerative processes providing the basic life-support functions of air revitalization, water reclamation, and waste management, as well as related sensors and controls. Also innovative, cost-effective flight experiment concepts are desired to understand the effect of microgravity and partial-gravity on the operation and performance of advanced life support technologies. 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. Efforts are currently focused on the near term missions ranging from International Space Station through an initial Mars mission. Proposals should include estimates for power, volume, mass, logistics, and crew time requirements as they relate to the technology concepts. Areas in which innovations are solicited include the following:

Air Revitalization
Oxygen, carbon dioxide, water vapor, and trace gas contaminant concentration, separation, and control techniques for space vehicle applications (Space Shuttle, ISS, 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 percent by volume.
- The recovery of oxygen from carbon dioxide with some focus on an approach to deal with the by-products, if any, of the process keeping in mind the above mass, power, and expendables goals.
- Removal of trace contaminant gases from cabin air and/or other 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 lbm of tank weight per lbm 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 upon 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].

Water Reclamation
Efficient, direct treatment of wastewater--consisting of urine, wash water, and condensates--to produce potable and hygiene waters.

- Methods for the phase separation of solids, gases and liquids in a microgravity environment that are insensitive to fouling mechanisms.
- Methods to eliminate or manage solids precipitation in wastewater lines.
- Disinfection technologies, both for potable water storage and point-of-use. Techniques for the elimination of biofilm or microbial contamination from potable water systems. Development of residual disinfectants that can be consumed by crewpersons.
- Methods for the treatment of brine solutions.
- 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.
- 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.
- Methods to minimize biofilm formation on fluid handling components, including flowmeters, check valves, regulators, etc.

Waste Management
Concepts and methods to safely and effectively manage wastes for all future human space missions. 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. However, for sizing purposes, 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), dry human fecal wastes (0.72 kg/day), inedible plant biomass (2.25 kg/day), paper (1.16 kg/day), tape (0.25 kg/day), filters (0.33 kg/day), and water recovery brine concentrates (3.54 kg/day). [These estimates are derived from the Solid Waste Processing and Resource Recovery Workshop Report JSC-40193, with the exception of the water recovery brines]. Wastes can also be assumed to be source-separated, since this requirement has been identified for a majority of waste processing equipment.

- Volume reduction of wet and dry solid wastes.
- Water recovery from wet wastes (including human fecal wastes, food packaging, etc.).
- Stabilization, sterilization, and/or microbial control technologies to minimize or eliminate biological hazards associated with waste.
- Microgravity and hypogravity compatible solid waste management technologies.
- Microgravity compatible technologies for the jettison of solid wastes in space.
- Storage devices needed for the containment of solid waste that incorporates odor abatement technology.

- Other novel waste management technologies for storage, transport, processing, resource recovery, and disposal will be evaluated but must be shown to satisfy a critical need for the referenced near term missions (e.g., recovery of critical resources).

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

- Sensitive, fast response, on-line 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 in water reclamation processes, and atmospheric gaseous constituents (oxygen, carbon dioxide, water vapor, and trace gas contaminants) in air revitalization processes. Both invasive and non-invasive techniques will be considered.

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 human space missions of up to 5 years with crew independence, without re-supply. Specifically, this subtopic's focus is the development of innovations in crew accommodations and equipment; and the development of technologies for assessment, modeling, and enhancement of human performance.

Proposals are solicited that seek to develop technologies that address specific needs:

Habitability factors and working conditions essential for crew well-being
- Human accommodations: Develop design concepts and prototype systems for laundry or dishwashing tasks. The systems should be suitable for operation in micro gravity environments with low water consumption and minimal trace gas emissions.
- Tools to design habitats that include opportunities to vary spatial, visual, acoustic and thermal environments.

Monitoring and maintaining human performance non-intrusively
- Biomechanics and anthropometry data collection and analysis: Develop size or motion measurement systems using wireless or remote sensors. Donning, calibration, and maintenance steps should ensure efficiency and accuracy.
- 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.

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, micro-gravity, 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.
- New technology for illumination modeling with particular attention to real-time displays of shadowing, glare and bloom combined with predicted energy distribution values to quantify surface illumination and reflection. New technology for illumination measurements and evaluations such as "smart" sensor technology for measurement of illumination, color and surface reflectivity.

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 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.

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

Human presence in space requires an understanding of the effects of microgravity and other components of the space environment on the physiological systems of the body. A variety of countermeasures must be developed to oppose the deleterious changes that occur in space or upon return to Earth. This subtopic seeks innovative technologies in two areas: measurement of emboli in the brain, and real time, in vitro, urine chemistry sensors for automated urine chemistry analysis in a "smart toilet."

As launch costs are extremely sensitive to mass and volume, sensors and instruments must be small and lightweight with an emphasis on multi-functional capabilities. Low power consumption is a major consideration, as are design enhancements to improve the operation, design reliability, and maintainability of these instruments in microgravity. As the efficient utilization 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.

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.

Real time, in vitro, urine chemistry sensors for automated urine chemistry analysis in a "smart toilet"
Real time, in vitro, urine chemistry sensors for automated urine chemistry analysis in a "smart" toilet. Methods for measuring urine volume, composition of electrolytes or other urine components should be capable of real-time measurement without withdrawal of samples - that is, measurements must be made online as the urine flows through the waterless toilet in microgravity. The ability to quantitatively measure the excretory products of bone or muscle breakdown are particularly valuable as bone and muscle loss are a persistent problem in the microgravity environment.

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 technologies in food science and food processing will be needed. The impossibility of regularly re-supplying a Mars crew means that the prepackaged shelf-stable food, ingredients, and equipment to provide a complete diet for 6 crewmembers for more than 3 years will have to be carried with them. As the crew remains on the lunar or planetary surface, crops will be grown to supplement the crew's diet especially within the context of experimental advanced life support systems that use plants to revitalize the air and water supply. Hence, methods for processing potential food crops are needed. Areas in which innovations are solicited are:

Long Duration, Shelf-Stable Food

An initial trip to Mars, for example, 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 3 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.

Advanced Packaging
The current food packaging used on Shuttle and the International Space Station is not biodegradable or recyclable and thus represents a significant trash management problem for exploration class missions. Waste packaging in Shuttle missions is returned to Earth for disposal and packaging waste for International Space Station is incinerated upon reentry into Earth's atmosphere. New packaging technology is needed to minimize waste from packaged food. An example might be a biodegradable package that can withstand the retort process or a plastic or other packaging material that can readily be recycled 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 in space should be highly automated, highly reliable, safe, and should minimize crew time, power, water, mass, and volume. Equipment for processing raw materials must be suitable for use in hypo-gravity (e.g., 3/8th-g 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, and radishes. Crops that would require processing would be wheat, soybeans, white potatoes, sweet potatoes, peanuts, dried beans, rice, and tomatoes. Examples of possible food processing equipment that could be used in a long duration space mission include:

- Pressing the oil out of peanuts using an aqueous extraction method.
- Producing a nutritive sweetener source from high carbohydrate baseline crops (e.g., potatoes, sweet potatoes).
- Developing equipment that produces food products from rice, potatoes, soybeans, etc.
- A bread machine that has adjustable speeds and rising/baking times
- Sanitizing salad crops through a highly automated process.

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, on identification and control of microbial agents of food spoilage, including the development of countermeasures to ameliorate their effects. For all food production and processing procedures, HACCP (Hazard Analysis Critical Control Points) 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 fundamental and applied research leading to the development of noninvasive, unobtrusive medical devices that will mitigate crew health, safety, and performance risks during future flight missions. Medical diagnostic and monitoring devices are critical for providing health care and medical intervention during missions, particularly those of extended duration. 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 usage, improved astronaut (patient) comfort, and easy-to-read information displays.

Major research disciplines include: endocrinology, immunology, hematology, microbiology, muscle physiology, pharmacology, drug delivery systems, and mechanistic changes in neurovestibular, cardiovascular, and pulmonary 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 physiologic 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 cardiovascular, musculoskeletal, neurological, gastrointestinal, pulmonary, immunological, and hematological systems.
- Noninvasive, biosensors for real-time monitoring of blood and urine chemistry including, gases, calcium ions, electrolytes, cellular components, proteins, lipids, and hormones.
- In-flight specimen analysis to evaluate physiological, metabolic, and pharmacological responses of astronauts.
- Instrumentation to maintain and assess levels of aerobic and anaerobic physical capability.
- Instrumentation to monitor physical activity and loads placed on different segments of the human body.
- 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.
- Virtual medical instrumentation.

B3.06 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, light to heavy ions, etc.) and 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 the radiation shielding function.
- 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 radiation shielding 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.

B3.07 Biomass Production for Planetary Missions
Lead Center: KSC
Participating Center(s): 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. 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. Areas in which innovations are solicited include the following:

Crop Lighting
- Sources for plant lighting such as, but not limited to, high-efficiency lamps or solar collectors
- Transmission and distribution systems for plant lighting including, but not limited to, luminaires, light pipes and fiber optics
- 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 Delivery Systems
- Technologies for production of crops using hydroponics or solid substrates
- Water and nutrient management systems
- Regenerable media for seed germination plant support
- Separation and recovery of usable minerals from wastewater and solid waste products for use as a source of mineral nutrients for plant growth.

Mechanization and Automation
This system development includes 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
This includes methods to prevent excessive build-up of microorganisms within nutrient delivery systems.

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 non-invasive 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, subminiature and microtechnologies for evaluation of 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 AI data collection systems.

Flight Equipment Support
Innovative hardware and components developed to support research in the Space Shuttle and onboard the International Space Station. Biomass production investigations using flight support equipment will be required to meet the demanding requirements for spaceflight operations, meet the rigorous scientific data collection standards, and produce plants in a controlled environment for research purposes and food. Innovations in whole package design and in component designs will be required.

B3.08 Enclosed Crew Environment Control
Lead Center: JSC
Participating Center(s): ARC, JPL

Advanced Environmental Control in an enclosed crew environment presents a series of challenges as life support goals move 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:

- Distributed network protocols, including support for fieldbus and intelligent controllers
- Development of ontologies for communication among autonomous systems or control agents
- Software development methodologies for autonomous systems,including requirements management, testing, performance metrics and long-term maintenance support, including development for growth and support for model-based simulations
- Approaches for integration of new controls technology (both hardware and software) with existing, legacy systems
- Fault detection, isolation and recovery across multiple systems; sharing of parameters and data between heterogeneous systems
- Control system failure tolerance
- Planning and scheduling, including reactions to system faults, supporting adjustments to operations, inventory, and logistics due to planned and unplanned maintenance
- Development and integration of autonomous system and inter-system control with crew and ground operations
- Development of architectures that support a range of autonomy, from fully autonomous to fully manual, with the corresponding range of support for human interaction
- Distributed Human-Computer Interface, with support for multiple platforms (handheld, head mounted, voice, etc.)

TOPIC B4 Research Integration

BPR seeks to use its research activities to encourage educational excellence and to improve scientific literacy from primary 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 seeks to engage the commercial sector in exploiting the economic benefits of space. We also strive to involve society as a whole in the transformations that will be brought about by research in space.

B4.01 Telescience and Outreach for Space Exploration
Lead Center: MSFC

NASA wants to provide to the general public, schools and industry, access to space and microgravity, and to information about the commercial investigations and results.

Telescience
There are many potential users for NASA services and data located throughout the U.S. There are three general types of users for NASA activities. The first type is the principal investigator (PI) who is responsible for the spacecraft, experiment and attendant science and 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 graduate students to secondary school students. These users will receive either data processed by the PI or unprocessed data. Commercial investi-

gations require the ability to receive, process and display telemetry, view video from science sources, including the ISS, and talk to NASA about 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 in Huntsville, Alabama, or 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. Inputs allow the experimenter to send to their spacecraft 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 on board services like electricity, crew time and cryogenics. This planning process is integral to the entire payload operation and requires the Principal Investigator or his representatives to participate via voice or video teleconferencing. To enable users to operate from their home base, whether it is located at a laboratory, office or home, these services (commensurate to the level of their operation) must be provided at their location at a reasonable cost. Costs include both the platform upon which these services will run and include the communications required to provide these services to the experimenter's location.

Outreach and Education
Another user is the general public observer who is interested in the science that is being conducted. Proposals are sought which provide a system or systems based on commercial solutions. These systems should allow outreach participation in NASA commercial programs, including the science and operational levels. The public should receive data, including voice, video and processed data, but generally would not be allowed to interact with the current investigations. Systems could provide for the general public 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 which promote the use of science and technologies, e.g., museums and space camps.

B4.02 Space Commercialization
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 and microgravity for commercial products and services. The products may utilize information from in-space activities to enhance an Earth-based effort, or may require in-space manufacturing. This subtopic has two goals. First, the commercial demonstration of pivotal technologies or processes; second, 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. Automated processes and hardware (robotics) which will reduce crew time are a priority. All agency activity in microgravity including those in life science and microgravity sciences, which lead to commercial products and services, are of interest. Some specific areas for which proposals are sought include:

Biotechnology and Agribusiness
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. This includes, in particular:

- 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/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 organotypic skin models which simulate physiological changes found in humans under a microgravity environment, 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

- 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 non-linear optical compounds for commercial optical electronic devices and to achieve equivalent performance of space-grown materials in ground processing.
- Innovations using non-linear optical material to be processed in space.
- Innovations for new space-processed glasses for optical electronic applications.

Microgravity Payloads

- Design/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 workloads 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 unique structure 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 Space Commercialization 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. The products may utilize 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 which 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:

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 which 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 utilizing non-terrestrial resources. These resources include propellants, power, and structural materials.

TOPIC B5 Biomolecular Systems, Devices and Technologies

NASA recognizes that biomolecular approaches promise to enable lightweight, convenient, and highly focussed therapies. Three key technologies form the cornerstones of NASA's Biomolecular Systems Program: nanotechnology, information technology, and biotechnology. Investment in these fast-moving fields will provide leading edge advances in health care that will benefit humans on Earth and in space. The program conducts basic research and develops breakthrough technologies to deliver prototype biomolecular micro- and nano- systems for the detection, imaging, recognition and monitoring of biological signatures and processes at the molecular level. This research and development supports NASA's medical, diagnostic, clinical, life support and environmental monitoring, and space exploration/Astrobiology objectives for long-duration space flight, including commercial applications on Earth.

B5.01 Biomolecular Sensors and Effectors
Lead Center: ARC
Participating Center(s): JPL

Emerging technology for micrometer and nanometer scale fabrication, manipulation, and materials characterization enables a new range of technological possibilities. Of particular interest are techniques for miniaturizing biochemical analysis instruments that can interact with life and its constituents at the molecular scale. One of the NASA goals is to seek out and identify biochemicals in minute concentrations in the human body and in extraterrestrial settings. Initially, these microscopic-devices, engineered on the molecular scale, will function primarily to gather data about their environment, with the ultimate goal of actively responding to threats to astronaut health (e.g., by killing tumor cells or by targeted delivery of medication).

Microelectromechanical Systems (MEMS) technology has enabled numerous innovative methods to miniaturize biomedical instruments. Microfluidic platforms are essential to the goals of detecting molecular signatures of real-time biological activities in the human body. Finally, investigations of nanoscale materials, such as carbon nanotubes, and fabrication techniques are needed to develop biochemical devices with new capabilities with implications beyond miniaturization.

Research Topics:

- In vivo sample acquisition and processing
- In vivo device propulsion
- Wireless communications for micro/nano biochemical instruments
- Power sources (biochemical, electrochemical)
- Self-assembled fabrication techniques for biochemical sensor arrays
- Other technologies which would contribute toward integrated prototype nanoexplorers (combining sample acquisition, processing, and sensing).
- Integrated in vivo biochemical sensor and targeted drug delivery device.

B5.02 Biomolecular Imaging
Lead Center: JPL
Participating Center(s): ARC

Cellular structures and functions are a marvel in architecture, engineering, and programming. Currently there are various imaging techniques which allow us to obtain concentration variations, map compositions and monitor transport and transduction mechanisms. Cellular biologists now use molecular imaging to localize and image which biological molecules are where inside a cell and its structures. In addition to where, we can also image when molecules are produced to track temporal changes in cell metabolism. Current technologies for molecular imaging in cellular biology would include the following: FISH, GFP, MRI and spectral techniques that allow spectrally multiplexed probes. Atomic, chemical force microscopies, carbon nanotube and proximal probes are all examples of new approaches to resolving molecular structure at a small enough scale to image individual atoms. Photon based imaging from infrared to x-ray, PET, MRI, NSOM, STM/AFM, photo-acoustic imaging, IR spectral imaging are just some examples of imaging techniques. Proposals sought include:

- New technologies for imaging protein expression in cells at or below the diffraction limited spatial resolution of optical microscopies.
- Nanoscale imaging at a resolution sufficient to provide protein or DNA sequence.
- Image cellular activities such as gene expression at a molecular scale.
- Nanoscale imaging at a resolution sufficient to provide protein or DNA spatial configuration.

B5.03 Biosignatures
Lead Center: ARC

Fundamental to the success of achieving NASA goals is the ability to identify biosignatures to distinguish life from non-life on a planetary scale. Life is a thermodynamic enigma – seemingly violating thermodynamic laws by decreasing entropy. This ability comes from its ability to extract energy from the environment and use this energy to build structures and establish chemistries that are decidedly out of equilibrium. The combination of structural and chemical disequilibria, along with the resulting changes in the environment due to consumption and production of materials, make the technologies basis for the search for life rather straightforward: utilize thermodynamics and kinetics. Search over a variety of scales for structures, measure the chemistry of these structures, and search for metabolites that are disappearing or accumulating on a variety of time scales. Using such an approach, we imagine that life can be sought in a wide variety of environments simply by making simple measurements and asking the right questions of the data. NASA requires technology for in situ life detection that will provide a springboard for the use of similar approaches for detection of "unhealthy" subjects, be they unhealthy due to bacterial or viral infections, or malignancies. From this perspective, one can readily identify specific methods and approaches that will be used in astrobiology (things to be measured, statistical approaches, data handling and analyses, etc.), and how they might be adapted to laboratory, environmental, and in situ studies of life detection, and eventually to laboratory and clinical methods of diagnosis. Technology innovation areas include:

- Tools to assist in the identification of signatures of life via thermodynamic and kinetics of metabolism
- Detection of molecular level structures and anomalies
- Detection of chemical disequilibria and microscale chemical analyses

B5.04 Biomolecular Signal Amplification
Lead Center: JPL
Participating Center(s): ARC

The ability to detect weak signals emitted from molecular interactions has always been a challenge for molecular biologists. Such signals highlight numerous important interactions such as antigen-antibody associations and nucleic acid hybridization reactions. These interactions are often used as assays to detect molecular indicators of disease pathology. As such, increasing sensitivity of these assays without compromising accuracy is of utmost importance. Traditionally, signal amplification in molecular biology has been achieved by one of two approaches- either amplification of the molecule to be detected or intensifying the signal from the detector molecule. Reverse Transcriptase Polymerase Chain Reaction (RT-PCR) is an example of the former. In RT-PCR, one makes a DNA copy of a low copy number transcript to be detected, then amplifies the number of molecules by PCR before detecting the products. To illustrate increasing the signal from a detection molecule, consider the use of labeled secondary antibodies to enhance signal from primary antibody binding. While these techniques have improved detection, methods are still limiting when it comes to detecting molecules in very small quantity or in single copy. More recent examples include catalyzed reporter deposition (CARD), branched DNA signal amplification assays and Fluorescent Resonance Energy Transfer (FRET). Technology innovation areas include:

- Single, specific molecule detection among high background noise.
- Contrast and sensitivity enhancers for non-invasive real time imaging.
- Utilization of biological amplification or self-amplification of target molecules.
- Amplification methods to enhance the probability of finding target molecules.
- Amplification of the precursors of ailments (fever, infections, bone loss, muscle atrophy, etc.)
- Utilization of biological amplification or self-amplification for ailments.

B5.05 Nanoscale Self Assembly using Biological Molecules
Lead Center: GRC
Participating Center(s): ARC

Biomolecular self-assembly is an exciting new discipline lying at the intersection of molecular biology, the physical sciences, and materials engineering. A key feature of biological systems is their ability to undergo self-assembly, a process in which a complex hierarchical structure is established without external intervention. Bridging the gap between organic chemistry and materials synthesis, biomolecular self-assembly combines the powerful specificity of protein and DNA interactions with the more traditional synthetic material synthesis to produce novel materials and sensors. The resulting materials are structured in a way that is characteristic of biological materials, but they are not necessarily of biological origin.

Use of colloids is one route to nanoscale self-assembly. Colloidal particles can serve as substrates for molecularly thin films of biopolymers or other surface-active agents. Extensive use has been made of gold, silica and latex particles as substrates to which antibodies and antigens could be attached for assaying and in drug delivery applications. Lock-and-key protein systems such as the biotin-avidin couple may be used as controllable strong adhesives. Colloidal dispersions have also been used as a solvent for self-assembling lamellar phases of surfactants.

The focus of this subtopic is the applications of biomolecular self-assembly to produce novel sensors or bio-engineered materials that enable technologies relevant to the nation's space program.

B5.06 Nano/Quantum Devices for Space Medicine and Biology Applications
Lead Center: ARC

Participating Center(s): JPL

Nanostructure science and technology is a broad and interdisciplinary area of research and development activity that has been growing explosively in the past few years. It has the potential for revolutionizing the ways in which materials and devices are created and the range and nature of functionalities that can be accessed. Nanodevices or devices based on quantum effects have the potential for higher performance at lower volume, weight, and power consumption. Technology innovation areas include:

- Innovative synthesis and assembly techniques of nanostructured materials for device applications, including semiconductor nanostructures, metallic/magnetic nanostructures, and carbon nanotubes.
- Innovative growth and formation techniques of semiconductor quantum dots with greater uniformity of size, controllable achievement of higher quantum dot density, and closer dot-to-dot interaction range.
- Modeling, simulation and demonstration of innovative sensor concepts based on development of novel applications of nanotechnology and quantum mechanics.
- Innovative nanoscale functional device building blocks based on single electron charging.
- Innovative nanodevices for sensor applications.
- Nanomagnetic devices.
- Molecular electronics.

B5.07 Bioinformatics
Lead Center: JPL
Participating Center(s): ARC

The systematic handling and analysis of biological data to solve scientific problems will involve the development of new computational technologies. Bioinformatics will be important in assessing and modeling physiological conditions. Both pattern recognition and modeling of biological behavior and processes (both at global and local levels) will be crucial to scientific and medical research in space and on Earth. NASA's bioinformatics technology development is divided along the following lines: (1) data acquisition, (2) data handling and curation, (3) hypothesis generation, and (4) hypothesis testing.

Technology innovation development areas to enhance and enable:

- Coarse modeling of smaller scale cell functions
- Data mining/pattern recognition
- Model genomics and kinetics of infections, bone loss, muscle atrophy, etc.
- Complex modeling of large-scale cell functions
- Space information systems - systems for real-time data handling and analysis (types of data include gene chip blood panels, data of spacecraft environment, human body, etc.)
- Pattern recognition for ailments (fever, infections, bone loss, muscle atrophy) combined with model development for predictive use.

9.1.3 EARTH SCIENCE

NASA's Earth Science Enterprise uses satellites and other tools to intensively study the Earth in an effort to expand our understanding of how natural processes affect us, and how we might be affecting them. Such studies will yield improved weather forecasts, tools for managing agriculture and forests, information for fishermen and local planners, and, eventually, the ability to predict how the climate will change in the future. Earth Science has three main components: a series of Earth-observing satellites, an advanced data system, and teams of scientists who will study the data. Key areas of study include clouds; water and energy cycles; oceans; the chemistry of the atmosphere; land surface; water and ecosystem processes; glaciers and polar ice sheets; and the solid Earth. Working together with the nations of the world, Earth Science seeks to improve our knowledge of the Earth and to use that knowledge to the benefit of all humanity.

http://earth.nasa.gov

TOPIC E1 Instruments for Earth Science Measurements

NASA's Earth Science Enterprise 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 biology and biogeochemistry of ecosystems and the global carbon cycle, global water and energy cycle, climate variability and prediction, atmospheric chemistry, and solid Earth and natural hazards. A major objective of the ESE instrument development programs is to implement science measurement capabilities with small or more affordable spacecraft so that the 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 which, 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 Optical
Lead Center: LaRC
Participating Center(s): ARC, GSFC, JPL

High resolution, high accuracy measurements of atmospheric and surface parameters from ground-based, airborne, and spaceborne platforms require advances in the state of the art passive optical technology with emphasis on compactness, reliability, efficiency, low weight, and high performance. Components, subsystems, and complete instrument packages are desired. Emphasis is placed on innovative technologies in the following areas: Atmospheric measurements of climate and meteorological parameters, aerosols, clouds, water vapor, carbon dioxide, methane, and chemical constituents such as ozone, nitrogen dioxide, nitric oxide, carbon monoxide, and hydrocarbons, surface measurements of vegetation index, bi-directional reflectance, biological productivity, chlorophyll fluorescence, 2D and 3D surface terrain mapping, temperatures of water, land and ice, ocean productivity and ocean color. Emphasis is placed on innovative technologies that can expand current measurement capabilities to airborne, spaceborne, or Unmanned Aerial Vehicle (UAV) platforms to benefit multiple measurement needs and applications. Specific measurement and technology needs include:

System Architectures

- Innovative approaches to improved spectral and spatial sampling
- Designs and components to reduce system complexity while improving science knowledge such as multi-spectral imaging and flux radiometers.
- Advanced technical approaches for uncooled detectors, non-moving parts, calibration, tunable filters, environmental stability

Component Technologies

- Optical technologies to enable high spatial resolution (< 10 meter) measurements in LEO (Low Earth Orbit), high-throughput, fast response, and low noise (SNR > 500) to address multi-spectral and hyper-spectral measurement requirements.
- Wedge filters for space applications capable of spectral resolutions of a few nanometers over the visible through short-wave IR portions of the spectrum, and angular (IFOV) resolutions on the order of a milliradian.
- 4K by 4K and larger detector arrays sensitive in near UV (300-400 nm) and Near IR (1-3 micron) with large (> 1 million electrons) well depth.
- Ultra-stable spectral calibration techniques for data quality management and the evaluation of long-term sensor degradation trends in space instruments.
- On-board near real-time processing for atmospheric correction, geolocation, and geometric correction of digital image data, adaptive optics and wavefront sensors for atmospheric sensing correction.

- Optical imager technologies (phased arrays, holographic optics, diffraction optics, etc.) to enable space-based imaging without conventional telescopes and focal planes.
- Adaptive etalon technologies (including MEMS).
- Geiger-mode avalanche photodiodes for 2-micron regime with high quantum efficiency, high speed, and short response time.
- Hyperspectral semiconductor device development covering the range from 280 nm to 1,700 nm with 11 bands.
- Fast, 1-meter diameter lightweight telescope for space application with minimal distortion in the 0.3- 3-micron wavelength range.
- Improved gratings on flat or curved surfaces that maximize efficiency and minimize scatter and ghosts
- Linear variable or electronically variable filters with extended range
- Extremely narrow bandwidth (sub-angstrom) tunable filters.

Innovative Optomechanical Designs

- Development of systems capable of off-nadir pointing for the acquisition of multi-angle data, the acquisition of stereo pairs, the frequent imaging of rapidly changing events from orbit scanning and tilting to remove sun reflection off the ocean, and the frequent imaging of rapidly changing events from orbit.
- Compact, lightweight optical designs that utilize a minimum number of optical surfaces, utilize guided wave optics, are self-aligning.
- Robust low mass and low power scanning drive systems suitable for use in high resolution interferometers.

E1.02 Active Optical
Lead Center: LaRC
Participating Center(s): GSFC, JPL, MSFC

High 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. Components, subsystems, and complete instrument packages are desired. Emphasis is placed on innovative technologies that can expand current measurement capabilities to airborne, spaceborne, or Unmanned Aerial Vehicle (UAV) platforms to benefit multiple measurement needs and applications. Specific measurement and technology needs include:

- Lidar instruments and components for measurement of molecular species (ozone, water vapor, carbon monoxide, carbon dioxide, methane, and nitrous oxide). Emphasis is on measurements from airborne, including UAV's, and spaceborne platforms.
- Lidar instruments and components for cloud and aerosol measurements, with emphasis on aerosol optical properties. Emphasis is on next-generation systems such as multiple wavelengths, high spectral resolution (HSRL), or other advanced measurement concepts.
- Lidar instruments and components for direct-detection and coherent (heterodyne) measurement of wind profiles. Advances are sought for components such as Fabry-Perot interferometers and scanning technologies for direct detection and optics and telescope/scanner technologies for coherent detection. Emphasis is on airborne and spaceborne applications.
- Lidar instruments and components for measurement of meteorological parameters (density, pressure, temperature).
- Lidar instruments and components for measurement of planetary surface topography. Advances are sought for components such as short pulse lasers and signal detection and processing subsystems. Emphasis is on airborne and spaceborne platforms.
- Lidar instruments and components for measurement of vegetation. Emphasis is on measurements from airborne and spaceborne platforms.
- Lidar instruments and components for measurement of sub-surface ocean layers and fluorescence. Emphasis is on measurements from airborne and spaceborne platforms.
- Innovative component technologies addressing the measurement needs above, including:

- Lasers, laser components and optics
- Monolithic optical concepts
- Telescopes and scanners
- Single-element and array detectors
- Data acquisition systems, data processing algorithms, and analysis algorithms
- Solid-state laser materials for diode pumping
- Non-linear optical materials for frequency conversion
- Conductive cooled diode and laser components
- Highly compact, UAV-compatible instrumentation

E1.03 In Situ Terrestrial 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, reusable, GPS-located ocean platforms to measure and transmit to remote terminals upper ocean and lower atmosphere properties including temperature, salinity, momentum, light, precipitation, and biology. Similar sensor packages for use onboard ships while under way.
- Small, lightweight instruments for measuring cloud liquid water or ice content (mass) designed for use on radiosondes, dropsondes, aerosondes, tethered balloons, or kites.
- Instruments for measuring radiation flux (broadband shortwave and longwave), ozone and the bromine and chlorine compounds important to ozone chemistry, and the geomagnetic field. Sensors should be capable of use on Ultra Long Duration Balloons flying at 35 km altitude for periods over 100 days.
- Wide-band microwave radiometers capable of high-speed characterization of cloud parameters, including liquid and ice phase precipitation, that can operate in harsh environmental conditions (e.g., on-board ships and aircraft).
- Compact, lightweight instrumentation for in situ discrimination of biological and inert airborne particles, including genetic identification capability.
- Autonomous GPS-located airborne sensors that remotely sense atmospheric wind profiles in the troposphere and lower stratosphere with high spatial resolution and accuracy.
- Systems and devices for measurement of atmospheric aerosol chemical, microphysical, and radiative properties. Autonomy is desired for ground-station network applications and deployment aboard aircraft.
- 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 meters and areas of at least 100x100 meters.
- 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 (<1% over several months), portable radiometric calibration devices in the shortwave spectral region (0.3 to 3 microns) for field characterization of radiance instruments like sunphotometers and spectrometers.
- Systems for autonomous in situ measurement of atmospheric trace gases relevant to global tropospheric and stratospheric chemistry aboard aircraft.

E1.04 Passive Microwave
Lead Center: GSFC
Participating Center(s): JPL

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 microwave frequency band from, principally, about 1 to 300 GHz, but also with applications outside that band. 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, aerosols; air pollution; and chemical constituents such as ozone, NOX, and carbon monoxide. Earth surface measurements of interest include water, land and ice surface temperatures, land surface moisture, snow coverage and water content, sea surface salinity and winds, and 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 for microwave wavelengths (1 - 500 GHz).
- Large aperture, deployable antenna systems suitable for highly reliable space deployment with RMS surface accuracy of ~ 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. Novel approaches to beam steering for these very large aperture antenna systems are also desired.
- Enhanced onboard data processing capabilities that enable real-time, reconfigurable computational approaches that 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 on-board 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 on-board calibration. Of particular interest are variable correlated noise sources for calibrating correlation-type receivers used in aperture synthesis and polarimetric radiometers.
- New approaches, concepts and techniques are sought for microwave radiometer system calibration over or within the 1-300 GHz frequency band, that 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.
- Focal plane array modules for large-aperture passive microwave imaging applications.

- High power (> 5 mW) signal sources and low noise (< 500 K) heterodyne receivers for operation above 100 GHz.
- Multi-GHz. Low power, 4-bit undersampling analog-to-digital converters and associated digital signal processing logic circuits.
- Low power lightweight microwave radiometers are desired that 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.
- MMIC LNA for spaceborne 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 passive 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 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 that 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.

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/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), scatterometer, sounder, altimeter and atmospheric radar. The life-cycle cost of such radar missions has always been driven by the instrument resource requirements - power, mass, size, and data rate - often making radar uncompetitive on a cost basis 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. On-board 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 timely and frequently, with benefits for science, as well as civil and defense communities. Technologies which 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) and C-band (5.30 GHz). The required bandwidth varies from a few MHz to 20 MHz to 300 MHz to achieve the desired resolution; the larger the bandwidth, the higher the resolution. The application of the synthetic aperture technique is also applied to other radars, including radar ice sounding and wide swath ocean altimeters. The sounder is a low frequency radar (<50 MHz) with a very high percentage bandwidth (100%). Atmospheric radars operate at very high frequencies (35 GHz and 94 GHz) with only modest bandwidth requirements on the order of a few MHz. Ocean altimeters typically operate at L-band (1.2 GHz), C-band (5.3 GHz) and Ku-band (12 GHz).

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

Synthetic Aperture Radar:

- Lightweight, electronically steerable, dual-polarized, phased-array antennas.
- Very large aperture antennas (50 m x 50 m) for geosynchronous SAR applications.
- Shared aperture, multi-frequency antennas.
- Lightweight deployable antenna structures and deployment mechanisms.
- High-efficiency, high power, low-cost, lightweight, phase-stable transmit/receive modules.
- Advanced transmit/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; digital beamforming techniques; time domain techniques; phase correction techniques.
- Innovative radar system concepts to achieve wide swath (>250 km) to enable frequent site revisit and ultra-low-cost radars to enable constellations for global coverage.
- Advanced radar component technologies including high-power low-loss RF switches, filters and phase shifters (MEMS devices are of particular interest); thin-film membrane compatible electronics, high-efficiency power converters; high-speed analog-to-digital converters; low-sidelobe chirp waveform generators and optical chirp generators.
- Distributed digital beamforming and on-board processing technologies.
- SAR data processing algorithms and data reduction techniques.
- SAR data applications and post-processing techniques.

Low-Frequency Radars for Subcanopy and Subsurface Applications

- Lightweight, large aperture (30 m diameter) reflector/reflectarray antennas.
- Shared aperture, dual-polarized, multiple low-frequency (VHF through P-band, 50-500 MHz) antennas (feeds) with highly shaped beams.
- Lightweight deployable antenna structures and deployment mechanisms.
- VHF/UHF SAR data processing algorithms.
- Data applications and post-processing techniques.
- Software and hardware techniques for removal of ionospheric effects at low frequencies.

Radar Ice-Sounder:

- Synthetic aperture processing technique to increase resolution.
- Lightweight, broadband (100% or more) low frequency (<50 MHz), high gain (>10 dB) deployable antennas. Emphasis on antennas between 1-20 MHz (HF systems).
- Highly efficient (>80%), broadband (50-100%), low frequency (<50 MHz), high power (>100 W) transmitters. Emphasis on components between 1-20 MHz (HF systems).
- Low-power, highly integrated radar components (total system mass <1 kg) such as fast-switching CW sweep systems and high isolation receivers.

- Data processing algorithms and data reduction techniques.
- Hardware and/or software development for the ionospheric correction in space-borne radar sounders.
- 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 Ka-band and W-band transmitters (10 kW).
- 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.
- On-board (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.
- High-power (> 1 kW,duty cycle >0.05), wide bandwidth (>10%) Ka band amplifiers.
- Lightweight, low-cost, Ku/Ka band radar system for ground based rain measurements.

Polarimetric Ocean/Land Scatterometer:

- Shared aperture, multi-frequency antennas.
- Large, lightweight, electronically steerable reflectarrays.
- Dual-polarized antennas with high polarization isolation.
- Lightweight deployable antenna structures and deployment mechanisms.
- High efficiency, high power, phase stable L-band, C-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 & Surface Water Monitoring Altimeters:

- Shared aperture, multi-frequency antennas.
- Large, lightweight antenna reflectors and reflectarrays.
- Lightweight deployable antenna structures and deployment mechanisms.
- High efficiency, high power, phase stable C-band and Ku-band transmitters.
- Real-time on-board radar data processing.
- Calibration techniques, data processing algorithms and data reduction techniques.
- Data applications and post-processing techniques.

Bistatic Radar and GPS Science Instruments:

- Deployable, lightweight, 8-beam, independently steerable, dual polarized, 30 dB gain L-band phased array antennas.
- Compact GPS receiver architecture with 6,000 parallel correlators.
- Advanced GPS multipath suppression within receiver.
- Embedded science-quality micro-accelerometer for compact GPS flight receiver.
- Integrated science-quality magnetometer for compact GPS flight receiver.
- Ultra-stable millimeter-wave (~200 GHz) transmitter with >1 watt continuous output.
- Microwave/millimeter-wave received amplitude measurement precision of <0.01 dB
- Continuous Iridium/Globalstar telecom links from low earth orbit
- Miniature, low control authority momentum wheels for sub-10 kg nanosats.

E1.06 Passive Infrared - Sub Millimeter
Lead Center: JPL

Many NASA future Earth science remote sensing programs and missions require microwave to submillimeter wavelength antennas, transmitters, and receivers operating in the 3-cm to 100-micron wavelength range (or a frequency range of 10 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 on the sky(array receivers); small low-power MMIC radiometers, and high-throughput, low power, backend correlators and spectrometers. The focus is on technology for passive radiometer systems that are more spectrally flexible, lighter, smaller, and use less power. These systems must be of durable design for use on aircraft platforms and at remote/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 LN_2 (or higher) temperatures and require moderate noise performance. Advances in cooler technology will enable use of technology presently used in astrophysics receivers, which are 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, broadband, 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 system integration at the circuit and/or chip level is needed to extend monolithic microwave integrated circuit (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 radiometer systems using phased-arrays and MMIC radiometers from 60 GHz, to approximately 400 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 micro-watts at 1 THz; line widths should be <100 kHz. Since 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 micro-watts 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, that are small and lightweight, and that use low direct current power (<5 mW per channel) with high stability.
- Compact and reliable millimeter and submillimeter instrumentation that produces high sensitivity images simultaneously in multiple spectral bands.
- Schottky mixers with high sensitivity at T = 100K and above.
- Superconducting HEB mixers and SIS mixers.
- Receivers utilizing planar diodes or alternative reliable 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 Kelvin with a minimum of 3 temperature settings between 250 and 350 Kelvin.

- 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.
- Large diameter (up to 25-m) deployable antennas suitable for Earth remote sensing at frequencies up to 30 GHz.
- Calibrated radiometer systems that can achieve accuracy and stability of 0.1 K.

E1.07 Thermal Control and Cryogenic Systems
Lead Center: GSFC
Participating Center(s): ARC, JPL, JSC

Future instruments for NASA's Earth Science Enterprises will require increasingly sophisticated thermal control technology. Cryogenic systems have long been used to perform cutting edge space science, but at high cost and with limited lifetime.

In thermal control, existing technology, such as electrical heaters, high emittance paints for radiators, multi-layer insulation, louvers, heat pipes and ambient temperature two-phase loops are inadequate for emerging requirements. For example, optical alignment needs and sensors are requiring ever tighter temperature control (down to +/- 0.5 0C), heat flux levels from lasers and other similar devices are increasing (to >100 W/cm^2), and cryogenic applications are becoming more common. Some applications may require significantly increased power levels while others may require extremely low heat loss for extended periods. The advent of very small instruments may also drive the need for new technologies, particularly since such small instruments will have low thermal capacitance. In general, high performance, versatility, low cost, smaller mass and volume (down to the MEMS level), and high reliability are the prime technology drivers. Furthermore, the drive towards “off-the-shelf” commercial spacecraft buses presents engineering and technological challenges for instruments as such buses may be somewhat limited in resources. Innovative proposals for instrument thermal control systems are sought in the following areas:

- Miniaturized (down to the MEMS level), cryogenic (to 30K) heat transport devices, especially those suitable for cooling sensors and very small electronics.
- Highly reliable, miniaturized Loop Heat Pipes and Capillary Pumped Loops which allow multiple heat load sources and multiple sinks.
- Advanced thermoelectric coolers capable of providing 100s of milliwatts of cooling at 150 K and below.
- Inexpensive radiative coolers for low earth orbit.
- Technologies for cooling very high flux (> $100W/cm^2$) heat sources.

In cryogenic systems, improvements in technology enable further scientific advancement at lower cost and/or lower risk. Both the lifetime and the reliability of the cryogenic systems are critical performance concerns. Mechanical coolers, thermoelectric coolers, radiative coolers, magnetic coolers, and combinations of these will be considered. Of interest are cryogenic coolers for cooling detectors, telescopes and instruments with long life, low vibration, low mass, low cost, and high efficiency. Specific areas of interest include:

- Highly efficient coolers in the range of 4-10 Kelvin as well as 50 milli-Kelvin and below.
- Essentially vibration-free cooling systems such as reverse Brayton cycle cooler technologies
- Highly reliable, efficient, low cost Stirling and pulse tube cooler technologies.
- Highly efficient magnetic and dilution cooling technologies, particularly at very low temperatures
- Hybrid cooling systems that make optimal use of radiative coolers.
- MEMS and miniature solid-state cooler systems.

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 which include 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. That is, they provide the infrastructure for an instrument or suite of instruments. Traditionally, the term 'platform' would be synonymous with 'spacecraft,' and it certainly does include spacecraft. However, 'platform' is intended to be much broader in application than spacecraft and is intended to include non-traditional hosts for sensors and instruments such as airborne platforms (piloted and unpiloted aircraft, balloons, drop sondes), 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 Earth Science data consistent with the future vision of the Earth Science Program and indicate types of platforms for which technology development is required.

E2.01 Structures and Materials
Lead Center: LaRC
Participating Center(s): ARC, GSFC, JPL, JSC

Advanced materials and structures technologies are needed for future Earth Science platforms. These include materials and multifunctional structures that enable significant weight reduction and that possess extended life in the space environment, novel structural concepts for deployment to allow packaging of large structures on small launch vehicles, and innovative materials and technologies to enable dynamically and thermally stable platforms. Specific topics of interest include:

- High strength-to-weight carbon nanotube-based composite materials for application to thrust structure, high-strength booms, thin shells, and membranes;
- Lightweight shielding, self-healing materials, and other countermeasures to protect spacecraft systems from harmful effects of space radiation, including materials development;
- Ultra-lightweight large structural concepts such as deployable and/or inflatable booms, membranes, and apertures for radiometer and synthetic aperture radar missions;
- Concepts, components, and materials to enable large, lightweight, diffraction limited optical systems including membrane optics;
- Dynamically stable structures utilizing integral vibration control and disturbance/payload isolation including spacecraft launch load isolation systems;
- Modular multifunctional structures with flexible imbedded electronics;
- Modular multifunctional structural material with imbedded fluids and control functions;
- Thermally stable materials & components and integrated thermal/structural concepts for high efficiency passive thermal management;
- Low cost, high power-to-weight efficiency deployable/inflatable solar arrays and structures;
- Technologies for mitigating the effects of meteoroids on critical platform components applicable to near-Earth missions;
- Methods for predicting and controlling contamination resulting from the deployment and outgassing of large platforms;
- Unpiloted Aerial Vehicles (UAVs) lightweight material and structure concepts;
- UAV material systems which enable multiple year mission operations.

E2.02 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/orbits. These platforms will include spacecraft, sounding rockets, balloons, and aircraft (both piloted and unpiloted). Advanced Guidance Navigation and Control (GN&C) technology is required for these platforms to address high performance/reliability requirements while simultaneously satisfying low power/mass/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 Earth Science 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 Earth Science spacecraft and/or the management of large fleets of heterogeneous and/or homogeneous Earth Science assets are desired. Proposals that are either directed towards routine engineering enhancements of existing GN&C products, techniques and concepts or not directly related to the mission of NASA's Earth Science Enterprise will be judged to be non-responsive as they do not address the future NASA Earth Science technological challenges that will clearly require a significant leap beyond the current state of the art. Specific areas of research include:

Attitude/Orbit/Trajectory Determination and Control Technologies

- Control techniques/strategies/theories, signal filtering/processing advances, and improved environmental models for platform attitude/orbit/trajectory determination and control.
- Methods for rigid and flexible body control that are robust to parametric uncertainty and modeling error.

GN&C System Technologies

- Innovative GN&C testbed development capabilities and computer aided engineering, simulation and design tools with parallel algorithms for analysis and development of advanced GN&C systems. Open architecture object-oriented simulation tools and testbed systems for modeling and evaluating dynamically complex space systems.
- 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 that address the technologies needed to design and develop closed-loop spacecraft control system architectures that provide the "Drag-Free" precision orbit determination/maintenance capabilities needed for future ES LEO (Low Earth Orbit) formation-flying applications are of special interest. Technology solutions are encouraged which employ Drag-Free sensors (similar to accelerometers), high specific impulse (Isp) thrusters, and low-cost processors with appropriate closed-loop filtering/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 high performance video image processing technology to provide alternative solutions to challenging GN&C problems such as spacecraft relative range/attitude determination while in close formation and/or during proximity operations are of interest.
- 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 for modeling, simulating, and analyzing the inherent dynamics and control of balloon borne-payloads are of interest. Also of interest are innovative concepts, strategies, techniques, and methods for modeling, simulating, and analyz-

ing 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. Non-traditional multi-functional sensor/actuator technology proposals are of particular interest. Proposals that address the GN&C needs for miniature reaction and momentum wheels, miniature star cameras/trackers, precision accelerometer-like sensors for "Drag-Free" spacecraft control and miniature Fine Guidance Sensors (FGS's) are encouraged.
- Low power, low mass, and low cost propulsive actuators, and related subsystem components, for generating attitude/orbit control torques/forces. Propulsive actuators that consume less than one watt of power at three volts, providing impulse bits on the order of one micro-N-sec for 3-axis control or 40 milli-N-sec for spin-stabilized control.
- Innovations in Global Positioning System (GPS) receiver hardware and algorithms that use GPS code and carrier signals to provide spacecraft navigation, attitude, and time:
  - Combined navigation/attitude space receivers, including advanced antenna designs/configurations,
  - Navigation techniques that may employ Wide Area Augmentation System (WAAS) corrections,
  - Navigation, attitude, and control for spacecraft proximity operations, and
  - Innovative uses of GPS which enable new Earth science measurements; for example, the use of differential GPS in repeating aircraft flight patterns and the use of ocean-reflected GPS signals.

Spacecraft Formation Flying Technologies

- Novel approaches to autonomous control of distributed spacecraft and the management of large fleets of heterogeneous and/or homogeneous assets. Submissions should focus on one or several of the following technologies and system-level concepts:
  - Formation self-organization
  - Reconfigurable control laws
  - Robust and fault-tolerant control laws
  - Algorithms for autonomous formation reconfiguration
  - Nonlinear, robust estimation algorithms for relative navigation
  - Integrated, multi-spacecraft formation guidance and control
  - On-board, multi-spacecraft, closed-loop responsiveness to sensed events
  - Low-cost approaches for formation navigation and control exploiting low-cost and existing technologies such as GPS Optimal (e.g., minimum fuel, minimum time) approaches for formation maintenance and maneuvering
  - Unique concepts for dealing with relevant perturbations and disturbances such as J2, solar radiation pressure, etc.
  - New modeling techniques to support the technologies and concepts listed above

E2.03 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. Specific areas for which proposals are being sought include:

Onboard Processing

- Volatile data storage - large capacity solid state storage media and data formatter are required to store instrument data until the next ground contact are currently weight and cost constrained. Development of components and packaging techniques that would allow greater density and lower cost components are necessary to support the higher science data rates higher data volumes and smaller spacecraft of the future.

- General purpose data processing - higher levels of spacecraft autonomy require higher levels of general purpose CISC and RISC processing with fault tolerance & error correction (system and application). Development of spacecraft computers that match or exceed the commercially available desktop computers is essential to meeting the "lights out" spacecraft control requirements.
- Special purpose data processing - higher levels of automated onboard science data processing such as histogramming, feature recognition and image registration are necessary to match the data gathering capabilities of future instruments with the limits of spacecraft to earth communications. Development of technologies such as Digital Signal Processors (DSP) and related hardware is necessary to address these future needs.
- Reconfigurable computing hardware - achieving pure hardware processing capabilities with the flexibility of reprogammability would 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 is necessary to achieve this goal.
- Low-power electronics - in order to provide higher capabilities on smaller less expensive spacecraft, lower power consumption components is essential to reducing solar array and battery sizes, affecting the overall spacecraft design. Development of low voltage, such as 3.3V or 2.5V or lower technologies is essential to achieving the power constraints of smaller spacecraft.

Command and Data Transfer

- Subsystem data transfer - communications between various spacecraft subsystems become increasingly important 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) is currently a limiting factor in achieving higher overall data throughputs. Development of technologies for communications within a box that would replace the conventional passive backplane are necessary to achieve higher science data throughput.

E2.04 Advanced Communication Technologies for Near-Earth Missions
Lead Center: GRC

To realize the Earth Science Enterprise vision of Sensor-Web, a host of in-space and terrestrial communication link technologies and protocols are required. These technologies are likely to perform in an internet-based multi-point to multi-point communication architecture. Furthermore, in this architecture, the spacecraft, as well as the ground systems will be fully capable of interfacing to commercial communication networks to transport data directly to the users. Innovations are sought in space communications technologies and satellite-terrestrial network protocols for data delivery from NASA's future Earth science enterprise near-earth spacecraft, constellations and platforms directly to users. Advanced techniques and products are solicited that support communication among NASA spacecraft and commercial GEO networks for data delivery to users in a cost-effective manner. In addition, ever increasing demands are being placed on missions conserving bandwidth and power resources, while driving up the demands for data transmission and access. Innovative communications technologies are sought at the device, subsystem and system level in such areas as microwave, millimeter wave and optical communications; digital processing, modulation and coding, communications architectures and network technologies. Revolutionary or "breakthrough" improvements in communications technology are required to increase the success potential for planned NASA missions and enable missions for which adequate communications and information technologies do not presently exist. Advances in communications are sought that address provocative, unsolved or unexplored techniques that revolutionize existing methods and paradigms for packaging and communicating data or knowledge through space-time. Specifically, the required products are described below, but are not limited to the following:

Data Communications Technology

- High rate data communication microwave or optical system technologies for supporting multi-Gigabit/sec data rates between and from spacecraft LEO (Low Earth Orbit), MEO (Mid Earth Orbit) or GEO (Geo-synchronous Earth Orbit) orbits to ground networks. Communications include routing, encoding, encrypting of data to allow services on demand to address the need for autonomous spacecraft operations.
- Direct data distribution communication architectures (including multicasting) from LEO spacecraft directly to several users at various data rates and associated communication subsystems. Small, highly efficient, integrated communication receivers and transmitters for inter-spacecraft and constellation communications are needed.
- Communication link technologies to transfer data from an Earth observing balloon or airplane, where the collection and transmission of data is by Internet protocols.

Component Technology

- Innovative approaches to enable higher frequency, miniature, power efficient Traveling Wave Tube Amplifiers (TWTAs) operating at millimeter wave frequencies. Of particular interest is the development of TWTA's that can operate at communication bit rates of 10 Gbps or higher.
- Wide band-gap devices & amplifiers based on III-nitride compound semiconductors for high power, high efficiency microwave power circuits and low noise microwave amplifiers, respectively.
- Low loss MEMS based RF switches are needed that would enable the development of microwave components such as reconfigurable antennas, phase shifters, amplifiers, oscillators, filters for in flight control of the radio frequency bandwidth and power. Photonic band-gap and left-hand meta materials for microwave devices, circuits and components.
- RF component and sub system technologies that enable integration for system on chip packaging type, such as mixed signal (analog/digital/optical) communication systems. Low cost, Ka band flat plate array antennas and low noise block down-converters are desired for small earth terminal applications. Low cost, precision tracking Ka-band earth terminals for OC-3 (155 Mbts/sec.) to OC-12 (622 Mbts/sec.) data rates direct-to-earth downlinks from LEO/MEO spacecraft are also of interest. Wide scan angle (+/-60 degrees), low profile, transmit/receive Ka-band antennas, Ku-Ka band transceivers and closed loop acquisition/tracking algorithms for low-orbit space platforms and communication satellites are desired. Fractal-Element antennas are required for size reduction, broad or multi-band, increased gain and beam agility.
- Digital components enabling space-based networking. Routers, switches, network interface cards, network processors, transceivers, etc. which can lead to integration and implementations in FPGA, ASIC, DSP chip solutions. Internet-based protocol modules and architectures that will provide seamless network continuity between terrestrial and aerospace-based platforms and environments.

Optical communications

High (greater than or equal to 15%) Over all efficiency 1550 nm amplifiers; large (greater than or equal to 250 micron) diameter, high- speed (greater than 2.5 Gbps), In GaAs APD and PIN detectors; simplified acquisition, tracking and pointing architectures for LEO to GEO links; end-to-end optical communications simulation program with emphasis on acquisition, tracking and pointing.

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.
- Advanced network security technologies to assure integrity and authentication of data from the public Internet to protected Space-based networks.
- Adhoc and innovative lightweight networking protocols to support spacecraft constellation, formation flying, and satellite clusters

Breakthrough Communications Technology

- Methods or techniques which demonstrate breakthrough means of effectively "packaging", "storing" and/or "transferring" information or knowledge directly between separate, independent entities using new techniques including, but not limited, "qubit" type devices. Transferring knowledge directly must be suggested or accomplished without first breaking down the information into fundamental "data" transmission elements such as bits, bytes, symbols or other "raw data" types.
- Breakthroughs in quantum information physics to specifically address curious effects and critical unknowns relevant to revolutionary improvements in communicating data, information or knowledge between independent entities across space-time.
- Breakthrough power-efficiency in communications brought about through the use of natural phenomenon, e.g. soliton pulse/wave/energy propagation.
- Verifiable holographic or other multi-dimensional breakthrough communications technologies which enable credible, repeatable communications techniques. Demonstrating functionality is more crucial than theoretical explanations for the effects.
- Enhancements in modulation, coding, protocol development and information or knowledge routing brought about through the inspection or imitation of effective biological, biochemical and other natural and living systems. Examples include cellular "messenger molecules", adapters, aquatic bio-systems and any other communications systems occurring in nature which may demonstrate breakthrough enhancements to existing space communications paradigms.
- Demonstrations of using biological or living systems to successfully, effectively and/or efficiently transfer data, information or knowledge directly, intentionally and controllably between other nonliving (electronic, etc) mediums for use in bio or living networks or systems.
- Provocative, nonstandard uses of radiofrequency spectrum for demonstrating practical yet breakthrough means of communications
- Innovative uses of planetary atmospheres or planetary electromagnetic properties for the breakthrough communication of data, information or knowledge directly between independent entities.
- Enhancements in automated communications carriers through any type of media (including living) where a breakthrough improvement due to the technique can be explained or demonstrated.

E2.05 On-Board Propulsion
Lead Center: GRC
Participating Center(s): GSFC, JSC

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 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/Precision Propulsion

- Propulsion technologies for spacecraft less than 10 kg that emphasize system simplicity, low power requirements, and minimal mass. 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.
- Propulsion technologies to provide high-precision (impulse bit < 100 milliNewton-second) stationkeeping and attitude control.

Thruster Technology

- High-performance, high-efficiency electrostatic and electromagnetic propulsion technologies, including thruster components and advanced power processing, for small, power-limited spacecraft.

- High-performance (specific impulse > 250 s), high-density monopropellant technologies, including propellant formulations, catalytic and noncatalytic decomposition methods, and chamber wall materials.
- High-performance (specific impulse > 360 s) bipropellant technologies for either non-toxic or hypergolic propellant systems

Propulsion System Components:
- Materials compatible with high-temperature, oxidizing, and reactive environments
- Components for fluid isolation, pressure/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
- Components for xenon storage and flow control

E2.06 Storage and Energy Conversion
Lead Center: GRC
Participating Center(s): GSFC, JPL

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 storage and power 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 which 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.

Storage and Energy Conversion Technologies
The energy storage and conversion technologies solicited include photovoltaics, batteries, regenerative fuel cells, alternative high-power-density storage technologies such as dual-use energy storage such as flywheels and structural batteries. Specific areas of interest are:

- Battery and flywheel technologies are needed for spacecraft requiring greater than a 100 watt-hour per kilogram specific energy density and a 10-year lifetime in LEO (Low Earth Orbit) and GEO (Geo-synchronous Orbit). Rechargeable lithium ion batteries with advanced anode and cathode materials and liquid/polymer electrolytes and other advanced battery systems capable of meeting the above performance criteria are of interest. For some terrestrial missions, energy storage is needed which is capable of delivering 30-50% of their ambient specific energy at temperatures as low as -100° C. A 10 AH structural battery is needed for 3.5v spacecraft bus operation. Micro flywheels with high Wh/kg and highly integrated components are needed for spacecraft with 50 Watt bus.
- Regenerative fuel cell technology is of interest to NASA because it is an enabling technology for some robotic terrestrial Earth observation missions. Improvements in specific energy cycle life, cost, and operational overhead are needed for small regenerative fuel cells utilized in balloon and other terrestrial observation missions.
- Micro flywheels for spacecraft FESS or IPACS. Spacecrafts with 50watt bus will require high wh/kg and highly integrated subsystem-to-subsystem components to achieve future Earth Science requirements.
- Future micro-spacecraft require distributed power sources that are integrated with microelectronics devices/instruments. These microelectronic devices/instruments. These microelectronic devices/instruments require rechargeable batteries/fuel cells that can provide power in the micro to milliwatt range. Due to the low thermal mass of the micro-spacecraft in LEO, these spacecraft must operate over a wide temperature range (-100 to 100° C). Long cycle life performance capability is also needed for micro-rechargeable batteries.

- Power systems based on micromachining fabrication techniques and in energy storage components based upon carbon nano-tube, micro, and nano technologies.
- Photovoltaic cell and array technologies with significant improvement(s) in efficiencies, cost, radiation resistance, and wide/low temperature operation are solicited. Potential concepts include rigid arrays, thin film arrays, and various concentrator configurations. Also, technologies for electrostatically clean spacecraft solar arrays.
- Thermal power conversion technologies for orbiting spacecraft and/or orbit transfer vehicles are of interest. Solar concentrators may be rigid or inflatable, primary or secondary and address issues such as manufacturing, coatings, efficiency, packaging/deployment, and pointing/tracking. Receivers may utilize heat pipe or direct absorption technologies to minimize mass and volume. Topics of interest in power conversion include compact heat exchangers, advanced materials and fabrication techniques, and control methods, as they relate to life, reliability and manufacturability. Heat rejection areas include composite materials, heat pipes, pumped loop systems, and packaging and deployment. Also of interest are highly integrated systems that combine elements of the above subsystems to show system level benefits.

E2.07 Life-Cycle Integration, Simulation, Validation, and Collaboration Technologies
Lead Center: JPL
Participating Center(s): ARC

NASA seeks to address all aspects of design development and life-cycle management for Earth Science Missions. In particular, it is desired to improve determination of complete life-cycle requirements early in the design cycle, and the relative effect of each requirement on cost, schedule and risk. As the mission progresses through the life-cycle, it is assumed that modeling, simulation and collaborative engineering technologies would best support integration and validation. A typical NASA mission, project, or vehicle life-cycle could be on the order of 30 years, and over this time, the desired capabilities must be supported across diverse geographic, cultural, and computational environments and be used in and across Earth Science organizations. This subtopic is focused on component design and commercial advanced technologies that support the advancement and integration of engineering tools and processes.

There are many emerging technological concepts that show promise in integrating the life-cycle. Examples of some existing concepts which have not been well incorporated into integrated life-cycle management are: (1) Intelligent data handling (e.g., agents, portals, archiving, documents, mining), (2) Collaborative Analysis and Design, (3) Project Management tools including workflow integration.

Areas of interest include:

- Software system architectures that enable life-cycle simulation systems to be assembled quickly from existing validated models (perhaps using a knowledge base) and tailored for specific vehicles or missions. Such systems must be compatible with legacy software codes and must permit the insertion of research technology by users.
- Intelligent systems for knowledge capture of engineering design and process, and assessment methodologies.
- Technologies that allow intelligent collection, storage, and retrieval of various forms of engineering data (graphical, text, photo, email, sound, etc.) associated with a process life-cycle (full life-cycle greater than 30 years).
- Technologies integrating multi-disciplinary analysis at levels appropriate to the project life-cycle phase, and including multi-disciplinary optimization.
- Technologies for simulating system performance, assessing risk, and estimating cost as the design evolves, and exploring alternatives to aid in decision making.
- Systems and products that reduce the effort required for creating immersive visualization displays of simulations, e.g., to validate real time modeling results.
- Distributed collaboration tools that support the integration of life-cycle analysis in both modeling and simulation.

- Approaches leveraging emerging standards to reduce cost of products, tools, and information services.

E2.08 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, capacity, durability, reliability, modularity, and operational costs. Using advanced materials and components, developing packages and coatings for adverse environments, and using intelligent, system-wide techniques that promote modularity, flexibility, and affordability are the technology challenges this subtopic will address. Advanced technologies for power management and distribution (PMAD) systems are sought in the following areas:

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
Packaging technologies capable of wide-temperature operation or radiation resistance for use in electrical power systems are also of interest. Thermal control technologies that are integral to electrical devices with high heat flux capability and advanced electronic packaging technologies that reduce volume and mass or combine electromagnetic shielding with thermal control are sought.

Electrical Materials and Components
Advanced magnetic, dielectric, semiconductor, and superconductor materials, devices, and circuits are of interest. Advancements in energy density, operating temperature, voltage capability, speed, or efficiency are required. Candidate applications include transformers, inductors, semiconductor switches and diodes, integrated circuits, capacitors, micro batteries, electro-optical devices, micro-electro-mechanical systems (MEMS), superconducting cables and connectors, high voltage connectors, carbon nanotube cables, current sensors, and low-loss soft-magnetic materials.

Power Conversion, Protection, and Distribution
Technologies that provide significant mass, size, low noise, high reliability, efficiency, or integration cost savings in electrical power conversion and protective switchgear components are of interest to NASA. Modular, building block technologies for power conversion/conditioning, battery charging, distribution, and protection are sought that provide higher performance, simple system integration, and greater flexibility through the use of innovative topologies and intelligent controls. Advanced power distribution technologies such as combining power cables with the vehicle structure and advanced connector technologies are sought to reduce mass, increase reliability, and decrease integration costs.

Power Management
Management, control, and monitoring of electrical power systems with autonomous operation to improve safety, reliability, status reporting, operations scheduling and performance of terrestrial and aerospace power systems are of interest to NASA. Candidate technologies include: battery charging, fault detection, isolation, recovery, and system reconfiguration using "intelligent components", autonomous reconfiguration, active impedance and electrical noise cancellation, built-in test, component and system health monitoring, and advanced circuit protection concepts.

TOPIC E3 Advanced Information Systems Technology

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. Information technology is currently employed throughout ESE's space and ground systems and the Advanced Information System Technology theme is soliciting technologies that apply to the end-to-end system functions. The information system functions found in ESE include data acquisition, data transmission, data processing, data management & storage, data distribution, data/metadata/document search, browse and access, data subsetting, knowledge discovery, spatio-temporal analysis, and visualization. The ESE is interested in advanced information technology that can improve any of these functions in isolation or in combination, or is able to support alternative architectures that better address the scientific requirements.

E3.01 Knowledge Discovery and Data Fusion
Lead Center: JPL

NASA's Earth Science Enterprise collects terabyte-scale datasets routinely during its missions, and charges the scientific community with extracting usable and scientifically relevant information from them. These data sets may be images, multispectral images, time series, or field and particle event lists. They may also be engineering time series about spacecraft health collected from on-board sensors. Emphasis has recently been placed on handling and analyzing in situ data from networks or sensorwebs. In addition to the ongoing challenges entailed by handling, analyzing and mining very large data sets, NASA now needs a new framework for performing science data evaluation onboard spacecraft and from in situ sensor networks. New onboard or in situ science capabilities will enable mission activities to be directed by scientists without the assistance of a ground sequencing team, and the constraints of communications links. The science capabilities will be adaptive in nature, and must be efficient in transmission of the usable key data.

This subtopic enlists help in developing a new generation of tools and algorithms for effective acquisition and analysis of data and image sets, appropriate for ground or onboard/in situ use. Of special interest are: 1) the ability to deal quantitatively with uncertainty present in data, perhaps in a statistical framework; 2) development of flexible models through which observables are linked to quantities of scientific or engineering interest; 3) harnessing database technology for organizing the observed data, models, and inferred knowledge, perhaps in onboard or in situ archives; 4) fusion of multiple datasets for enhanced scientific return; and 5) system concepts for handling interactions between onboard science analysis and event detection capabilities and other functions of an autonomous spacecraft or sensor web. One or more of these areas should be addressed by every proposal. Specific subtopics of interest include:

- Automated classification of data.
- Supervised and unsupervised learning methods.
- Knowledge discovery techniques.
- Image analysis and segmentation.
- Statistical pattern recognition.
- Time series feature extraction and analysis.
- Trainable object recognition.
- Automatic image registration and change detection.
- Visualization and rendering techniques.
- Spatiotemporal datamining.
- Intelligent, goal-directed data acquisition and/or compression.
- Science data analysis algorithms designed for scalable computing.
- System concepts for onboard science.
- Adaptive data acquisition techniques.

E3.02 Automation and Planning
Lead Center: ARC

Focus is on technologies that make a spacecraft or system react to uncertainties in a robust fashion while achieving a set of high-level goals or tasks. Technology innovations in automation and autonomous systems to support the high level command collection, processing and efficient and effective techniques for processing large volumes of data into useful information. Intelligent search of large, distributed data stores. Intelligent data discovery and searching over heterogeneous data. Collaboration between Earth scientists and computer scientists is encouraged for these proposals to demonstrate useful results.

Areas of interest include:

- Autonomous agents: Intelligent autonomous mobile search agents to support science applications involving data available on the internet.
- Autonomous data collection: Automatic dynamic reconfiguration of UAV or space on-board data gathering instruments to make effective use of observing conditions, baseline image data priority scheme, history of observations and limited on-board resources.
- Planning and scheduling
- System health and maintenance (space and ground based)
- Distributed decision making (multiple agents, autonomous systems)
- Automated software testing
- Legacy code maintenance and conversion
- Automatic software generation (i.e. processing algorithms)
- Software tools for parallelization; tools for production planning
- Control of FPGA to provide real-time products using hyper-spectral instrument data from airborne platforms
- Verification and validation of automated systems.

E3.03 High Performance Computing and Networking
Lead Center: ARC
Participating Center(s): GSFC

This subtopic focuses on innovations in efficient and effective techniques for processing large volumes of data into useful information. The emphasis is on collaboration between application scientists and computer scientists required for these proposals to demonstrate useful results and the development of the high performance computing required. Areas of interest include:

- High performance processing
- Computing: Distributed computing, Reconfigurable computing, Parallel/cluster computing, Embedded computing, Optical computing.
- Future computing and storage device technologies: quantum computing, atomic chain electronics, molecular computing, nano and quantum device technologies, and carbon nanotube based electronic devices and proposed architectures.
- Innovative node connection networks
- High performance/pervasive networks
- Techniques to enhance performance of wide-area networks supporting highly distributed data production, archive, and access functions.
- High-speed processing architectures/systems; applications of distributed computing environments, especially "pervasive computing";
- Efficient methods/algorithms/systems for warehousing scientific multispectral and hyperspectral data and/or instrument data for automatic and user-directed mining/monitoring of meaningful trends, parameters, fluctuations, etc. to maximize scientific value of TB-sized data sets
- Facilitating portability across architectures
- Advanced Storage and archival techniques (e.g. 3D holographic memory, holographic storage)

- Load balancing techniques
- Standards to simplify data providers' activities while facilitating data usage by a large user community.
- Server side technologies supporting highly responsive user-centric access (e.g., handheld PDAs to large date centers)
- Software development environments and methodologies
- Work scheduling as applied to distributed computer systems

E3.04 Geospatial Data Analysis Processing and Visualization Technologies
Lead Center: SSC

Proposals are sought for the development of advanced technologies to enhance human and machine interaction in support of scientific, commercial and educational application of remote sensing data. An emphasis is on distributed and/or mobile teams in validation and verification exercises and for the commercialization of remote sensing data. Focus areas are to provide tools for interpretation, visualization or analysis of remotely sensed data and to provide qualitative and quantitative analysis tools and techniques for performance analysis of remotely sensed data. Applications can support the commercial remote sensing industry and enhance the commercial or educational application of Earth science data. Areas of specific interest include:

- Unique, innovative data reduction and rapid analysis methodologies and algorithms, particularly for hyperspectral data sets
- Innovative techniques for validation of imaging systems (i.e. thermal and Lidar imaging systems)
- Software tools for mobile computing and efficient data collection and/or presentation
- Innovative approaches for incorporation of GPS data into in situ data collection operations with dynamic links to spatial databases including environmental models
- Innovative techniques to automate quality assurance processes for science data products
- Distribution and sharing of fused science data sets to correlate similar data sets from diverse spacecraft and aerial vehicles and provide unique, commercially useful information products
- Data merge and fusion software for efficient production and real-time delivery of commercial digital products to teams and remote users
- Tools for enabling distributed scientific collaboration
- Software to automate the rapid processing and distribution of sub-setting and presenting RS data over a network
- Software to develop commercial products from digital topography and vegetation canopy data obtained from airborne and space-based active optical sensors
- Innovative approaches to technologies that contribute to the understanding 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
- Visualization of multivariate geospatial data including remotely sensed data from the following: airborne and satellite platforms, vector data from public and private archives; cartographic databases from public and private sources; continuous surface data held as a raster data model; and 3-D data held in a true 3-D raster model.

E3.05 Data Management and Visualization
Lead Center: GSFC
Participating Center(s): ARC

This subtopic focuses on innovative approaches to locating, summarizing and presenting large collections of Earth science data in a highly distributed and networked environment.
Areas of technology innovation include:

- Design and implementation of a virtual reality CAVE for scientific data visualization Ideas can include: 3-D virtual reality environments that will let users 'fly' through the data space; precomputed data fly-throughs that let users search within the fly-through space (i.e. fast forward, reverse, slow motion) to locate specific areas of interest; incorporation of commodity data compression techniques (such as HDTV/MPEG) for reduced storage and transmission requirements; progressive compression and caching techniques that optimize resolution and performance when zooming in for additional detail; techniques for georectification, data overlays, data reduction, and data encoding that work across a distributed environment of widely differing data types and formats; development of integrated object oriented storage and compression techniques that are integrated into search algorithms; novel 3-D presentation techniques that minimize or eliminate the need for special user devices such as goggles or helmets; techniques for high bandwidth collaboration with other users in a distributed environment; development of techniques that invoke integrated visual and auditory presentation cues. Data viewing and real-time data browse, including fast, general purpose rendering tools for scientific applications. Viewing of multi-variate geospatial data including remotely sensed data.

- Tools for enabling distributed scientific collaboration
- Technologies supporting management, storage, search and retrieval of very large, distributed, geospatial earth science data volumes: Tools to facilitate automatic data product legacy, quality assurance and metadata updates. Object relational technologies specific for Earth sciences. Meta-data discovery to facilities the automated use of data from different sources. Automatic metric collection and analysis for data use and data ordering. Smart Objects Dumb Archives (SODA) and storage, archival and retrieval standards applicable to ESE mission requirements.

E3.06 On-Board 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 on-board autonomy and intelligence about the kind and content of data being collected to support rapid decision-making and tasking. Most sensors operate remotely with limited resources; solutions are needed that efficiently operate in these environments to classify or understand the data to support decision and actions on-board or in conjunction with mission operations. This subtopic is interested in developing new methods to autonomously understand Earth Science data in support of making rapid decisions and taking actions.

- Software methods that can identify and select adaptive compression and/or prioritize data for transmission.
- Approaches that can reduce the complexity of data or identify redundant and low priority data in favor of novel or unique data.
- Methods to segment sensor data streams and for compression, analysis and/or summarization.

TOPIC E4 Applying Earth Science Measurements

The Earth Science Enterprise (ESE) continues to search for solutions to how the global environment is changing and the effect these changes have on human societal and economic conditions. The planet's continual environmental change and our increasing human ability to influence the environment are of strong interest to the Enterprise. The Enterprise has equal interest in accelerating the deployment of our science understanding into practical uses by decision makers concerned with stewardship of the Earth's resources. Innovative tools and techniques that are easy to access and use are needed to produce information from Earth science measurements. This information will help guide systemic organizational change in the uses of the planet's resources that can result in a balance of sustainable global economic development with the preservation of the Earth systems' abilities to renew themselves. The goal of this topic is the routine use of Earth science results by a broad user community that works daily with land/biota, air, water, educational, and emergency issues.

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

Technical innovation and unique approaches are solicited for the development of new technologies and technical methods that make Earth science observations easy to use by practitioners in the areas of community growth and infrastructure, disaster management, environmental assessment, and resource management. This subtopic seeks proposals that support the development of end-to-end systems that use remote sensing data and related geo-spatial technologies to produce information for end-user decision makers. Proposals should address technologies of interest: aeronautical, space, sensor technology, computational methods, and distribution capabilities required for the proposed development. Developments should fulfill the operational requirements of the end-users; and take into consideration different operating systems, computing platforms, wired and wireless communications capability and the technical sophistication of the end-user. The following are the specific areas of interest in each of the application themes:

Community Growth & Infrastructure
This area seeks innovation in the application of Earth observation and geospatial technologies to urban modeling. Two aspects of urban modeling are of interest: 1) urban growth and its effect on local/regional environments; and 2) urban growth and its impact on the biophysical characteristics that influence human health. Innovation is needed that contributes to forecasts and strategies for the 'smart growth' of urban areas. Land protection, housing stock assessment, revitalization and in-fill development should be considered important characteristics of the urban landscape.

Innovation is also sought that contributes to forecasts or assessments of urban air quality. Remote detection and monitoring concentrations of ground level ozone, SO_X, NO_X, and particulate matter less than 10 microns, along with the mapping and visualization of trajectory and dispersion are important to protecting human health.

Disaster Management
This subtopic seeks innovation in the application of Earth observation and geospatial technologies to short-lived phenomena in the Earth's atmosphere, land and oceans. Phenomena of particular interests are severe weather such as thunderstorms, tornadoes, and hurricanes, as well as tsunamis, river flooding, plain/coastal flooding, ocean blooms and human-made disasters such as petroleum releases in rivers and oceans. Proposed innovations should increase the understanding of the effects of the short-term event on the physical, chemical and biological processes that interact to affect human safety, the environment, and the economy. Innovations should improve existing capabilities for determining levels of risk and vulnerability assessments. Applications may address human life and property damage, meet the requirements of planners, early warning systems, first responders, and contribute to impact assessments, mitigation, and implementation of relief efforts. Sought after innovations should make improvements in temporal, spectral and spatial responses to the phenomena. Innovation can be at the complete system level, subsystem level or component level.

Environmental Assessment
This subtopic seeks innovation in the application of Earth observation and geospatial technologies to monitoring water quality, to identify the location and magnitude of existing and potential pollution sources and impacts. Both surface and ground water are of importance. Surface water is both flowing water in streams and rivers; and impounded water in natural lakes and man-made reservoirs. Watershed management is important in land use changes that affect pervious and impervious surfaces. 1) In surface water the issue is Total Maximum Daily Loads (TMDLs) which are influenced by surface run off. Pollution from point sources has been well identified and is relatively well characterized. Non-point source pollution locations, intermittent flow and the relation to the variability in stream flow rates are less well understood. 2) For groundwater the issue is aquifer recharge in its location, recharge rate and the potential for leeching surface contaminants. Weather cycles and climate changes can also contribute to the quality of water. Innovations proposed should integrate Earth science observations with current capabilities to improve water quality monitoring and locating pollution sources. Innovation can include improved simulations, visualization, or integration at the system, sub-system and component level.

Resource Management
This subtopic seeks innovation in the application of Earth observations and geospatial technologies in agriculture, fisheries and assessments of water availability. Innovations proposed in these areas should integrate Earth science observations with new and current capabilities that contribute to technical understanding and improvements in the areas of resource management, long-term resource utilization and areas of environmental resource impacts.

Agriculture
The management of crops for water stress, crop quality and/or yield requires the timing of applications of water, fertilizers and other chemical inputs. Crop quality is defined as those characteristics of a commodity, other than yield, which impact the price returned to the grower. In grain crops, for example, quality measures might include oil or protein content. In fiber crops, quality might include color, thickness and strength of fiber. Minimizing crop inputs reduces costs and residuals in the environment. Predicting crop yield allows the growers to assess financial risk and plan their harvest and marketing activities. Predicting crop quality may allow the grower to harvest selectively to maximize return. Optimizing irrigation timing and location returns both economic and environmental benefits.

Fisheries
For fisheries, the interest areas are habitat assessment and stock assessment. In the habitat assessment topics include the carrying capacity of the coastal zone to support increasing human population and economic development and to support estuarine and near shore habitats. Coastal geology, soils, hydrology, shoreline changes, flora and fauna, and bathymetry are important considerations in surveying, characterizing and assessing the health of wetlands, sea-grasses, and reefs. Assessments and predictive capability are needed over large areas with accuracy to prevent significant habitat loss or degradation before the problem is irreversible. In the stock assessment identification and biomass measurement of fish species is needed through the water column in near shore (< 10 meters) waters out to the limit of the Exclusive Economic Zone. Measurement factors of temperature, salinity and plankton influence growth, mortality and recruitment of fish species.

Water Availability
The areas of interest for water availability are soil moisture, water content in snow pack and medium range precipitation forecasting. Soil moisture within a watershed directly influences the timing and quantity of stream flow and the seasonal water volume. Innovation is needed to verify in near real time the soil moisture over an entire watershed. Factors include infiltration, inter-flow and surface runoff. Snow pack measurements are needed to determine total water content and ice content within the overall accumulation of snow. Precise estimates of the water content in snow packs are required to manage water storage available for water supply. Time series data collected in near real time that can show the change in snow pack water content can provide information necessary for accurate estimates of runoff and stream flow. Better volume estimates affect storage; too much storage too early in reservoirs could result in property losses downstream because of high water flows from late snow melts, too little storage in reservoirs can result in losses of water supply and hydroelectric power.

E4.02 Advanced Educational Processes and Tools
Lead Center: GSFC
Participating Center(s): MSFC

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 Earth Science enterprise, 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 3 programmatic areas within the Earth Science Education 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 at www.dlese.org). 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 (for example, specific interfaces for students, park interpreters, TV producers, curriculum developers, etc.)
- Development of interfaces to promote diversity within educational audiences (such as 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.
- 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/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 geo-spatial 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 Integration of Science and Decision-maker Requirements for Ecosystem Health
Lead Center: SSC
Participating Center: KSC

Carbon is important as the basis for the food and fiber that sustain human populations and is the primary energy source that fuels human economies. Carbon is also the major contributor to the planetary greenhouse effect and potential climate change. Natural ecosystems on land and in the oceans sequester over half the CO_2 put into the atmosphere each year through human activities. Scientists believe that changes in land management practices and additions of CO_2 and nutrients (Iron) can enhance terrestrial and potentially oceanic carbon sinks significantly. However significant uncertainties remain about how much additional carbon storage could be achieved through management of ecosystems or engineering approaches, for how long such storage could persist, and just how vulnerable or resilient the global carbon cycle and ecosystems are to human manipulation of sources and sinks.

The capability to monitor local and regional changes in soil/vegetation patterns and ocean biomass and model their response to climate change, has the potential to enhance our ability to forecast the impact of changes. This capability is important to: 1) scientists in areas such as climate change, water cycle, marine ecosystems and carbon sequestration; and 2) local and regional decision-makers in areas such as land management, marine resource management, livestock performance and wildlife habitat management. In the past ten years, the profession of land management has replaced the Climatic Climax Model with a non-equilibrium model of change for most land uses. Central components of these models are the existence of thresholds and irreversible change. Similar dynamics biogeochemical/ecosystem models are being developed for the ocean ecosystems. While these models have not yet included irreversible-change constructs, the ability to monitor the response of the ocean ecosystem and biogeochemistry to large-scale changes is urgently required for development of better models and for monitoring the state of the system. The existence of thresholds in the transition between stable states places a new emphasis on the ability of advisors and managers to detect indicators of change and make a management response before change happens. This detection and response requires:

- Integration of monitoring via remote sensing for large areas
- Accurate models that can simulate vegetation change
- Management responses that are capable of avoiding undesirable change or building on opportunities for desirable change
- Effective non-satellite methods and instruments for measuring ecosystem-atmosphere carbon exchange and ecosystem parameters affecting carbon exchange such as ocean, soil and vegetation carbon stocks and change.

Innovation in technologies and technical methods that can serve the science and decision-making communities are needed that take advantage of space, airborne and in situ instruments, platforms and communications to improve the monitoring and forecasting related to land and ocean management.

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9.1.4 HUMAN EXPLORATION AND DEVELOPMENT OF SPACE

The mission of the Human Exploration and Development of Space (HEDS) Enterprise is to open the space frontier by exploring, using and enabling the development of space and to expand the human experience into the far reaches of space. In exploring space, HEDS brings people and machines together to overcome the challenges of distance, time and environment. Robotic science missions survey and characterize other bodies as precursors to eventual human missions. In using space, HEDS emphasizes learning how to live and work there and utilize the resources and unique environment. In enabling the development of space, HEDS serves as a catalyst for commercial space development. Throughout, this Enterprise will employ breakthrough technologies and ingenious designs to revolutionize human space flight.

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

TOPIC H1 Systems Integration, Analysis and Modeling

The goal of this topic is to enable the optimization of investments made in technology for human/robotic exploration and development of space. This includes identification and refinement of advanced system and architecture concepts that may dramatically increase the safety and reliability -- and reduce the cost -- of ambitious future human exploration missions and campaigns beyond Earth orbit. This topic also encompasses establishing a foundation of relationships with the science community and potential commercial or international partners for future exploration activities. Specific objectives of this topic involve the development and validation of innovative new analysis/modeling tools and techniques for 1) conducting advanced concepts studies to create/identify innovative new approaches to human exploration and the development of space, 2) Conducting detailed, end-to-end architecture studies incorporating the most promising new systems and infrastructure concepts, and 3) Defining and refining strategic research and technology road maps to provide ongoing guidance to technology development efforts

H1.01 Process & Human Factors Engineering Technologies
Lead Center: KSC
Participating Center(s): ARC

Spacecraft launch and payload processing systems have many unique aspects which require development of innovative processes or industrial engineering (IE) technologies in order to obtain the substantial benefits derived from applying IE principles in other industries. Process/Industrial Engineering is a technical discipline emphasizing the interfaces between people, processes, and hardware/software systems in a specific work environment. Process/industrial engineering is devoted to the science of process improvement and optimization of operational phases of complex systems. The Space Shuttle is NASA's first major program with a long-term operational phase. All major current and potential future human space flight programs (the International Space Station, X-vehicles, and extended human exploration) are also projected to have lengthy operational phases. Payload processing activities emphasize repeatable processes and improved customer satisfaction. Therefore, the strategic importance of IE technologies to NASA is rapidly increasing. Advanced spaceport technologies for designing, improving, and managing processes are needed to support spacecraft ground processing at KSC. Process/industrial engineering technologies should support NASA's goal of achieving safe, reliable, and low cost space access. Proposals should also identify potential applications for enhancing the operational phases of new NASA programs and aviation depot maintenance processes. Proposals may address the development of new concepts, methodologies, processes, and/or software support systems which advance the state-of-the-art in one or any combination of the following general areas of interest: operations research; process simulation modeling; statistical process control; planning and scheduling systems; project management risk analysis; decision analysis; cost-benefit analysis; task/work methods analysis; work measurement; human factors engineering; ergonomics; performance metrics; and management information systems. Specific interests for the 2002 solicitation include, but are not limited to, those listed below:

- Simulation tools that assist engineers in process or product design and development while reducing human error risk factors to include the elimination of system safety & efficiency bottlenecks.
- Development of project management tools that identify project or system risk factors while assessing cost and schedule impacts.
- Toolkits for advanced task/methods analysis and procedure design technologies (including process failure modes and effects analyses) for complex, long-duration, and infrequent spacecraft test and checkout activities.
- Development of computer-based training for writing human-centered procedures.
- Development of evaluation methods and metrics for procedure re-design.
- Advanced technologies for generating and delivering effective test and checkout procedures.
- Knowledge-based tools and methods for providing highly effective just-in-time task level training in the operational environment.
- Knowledge-based systems engineering tools for predicting operational technician traps and recommending effective design alternatives.

- Tools to measure and improve human-computer interaction with computer consoles and portable data collection devices.
- Advanced operations research and human factors engineering tools for optimizing utilization of scarce resources and minimizing the potential for human error during depot-level maintenance of reusable launch vehicles and aircraft, expendable launch vehicle test and checkout activities, and payload processing activities.
- Advanced statistical quality control techniques for ensuring high quality, affordable manufacturing and maintenance of unique spacecraft hardware. Automated statistical quality control algorithms that can be applied to data streams generated by space vehicle and ground hardware/software health monitoring systems.
- Advanced modeling and simulation capability for aerospace systems and processes. Capability to assess the effects on operations of proposed changes to designs, processes, or both. Proposed changes could be technological, procedural or both. Effects include but are not limited to changes in task times, resource requirements, such as direct and indirect costs, or both. Advanced capabilities applicable to conceptual, preliminary, early design and detailed design phases of proposed changes.
- Operations research technologies enabling seamless integration of airports and spaceports of the future.

H1.02 Systems Architecture and Infrastructure Modeling
Lead Center: MSFC
Participating Center(s): JSC

This subtopic focuses on the development of innovative computer based tools that can effectively evaluate and analyze competing technologies for future HEDS requirements from a systems point-of-view. These tools should include state-of-the-art breakthroughs and beyond. The tools should be adaptable to various NASA missions as well as to the non-space community. This subtopic should act as a building block to ultimately achieving an end-to-end evaluation tool that identifies the technology development that is required. This will reduce program cost and schedule while increasing the safety and reliability of future missions. The tools developed and matured under this subtopic should embrace the direction that advanced programming has been heading such as virtual reality, neural networks and fuzzy logic. Specific areas of interest include:

- A general purpose concept analysis and design optimization tool that provides the capability to evaluate or optimize a hierarchical system design based on user defined goals, parameters and criteria.
- Graphical user interfaces (GUI) for depicting the hierarchical structure, relationships between systems and friendly user interfaces.
- Automate the input of data or the transfer of output data to other software tools.
- Optimization requirements including user defined goals and interactive changes to design parameters.
- Biologically inspired design optimization algorithms such as automated reasoning, genetic algorithms and neural networks.
- Modeling structure that can accommodate systems and subsystems with their technology options. The model structure should be mission generic, yet capable of capturing HEDS systems elements for assessing specific mission concepts. For example, the model should be capable of assessing the impact of specifying that a particular technology option be used for all elements in a mission architecture, including vehicle, surface and orbital infrastructure subsystems.
- Interfaces for interchange of data, or sharing of capabilities between models, or concurrent execution. This includes the development of standards for subsystem models, and modification or design of hooks within existing models for input/output transfer and use of a common technology database.
- Common databases with technology performance and cost data. The tools should have the capability to ensure that common data is being used appropriately in all models.

- The tools should link the models and databases into a system to allow for trade studies, sensitivity analysis and identify the required technologies that need to be developed.
- Tools with the capability to perform system and technology sensitivities in order to identify mission architecture impacts.
- Tools that model technology performance, analyze competing technologies and then identify promising exploration concepts, architectures, and metrics to focus technology development.

In addition, this subtopic focuses on developing innovative computer based tools that can evaluate and analyze competing technologies from a systems point-of-view and will allow the proposers to have a product suitable for marketing by the end of phase III. The tools should be applicable to a number of different industries.

TOPIC H2 Space Resources Development

The goal of this topic is to drive down the cost of human/robotic exploration missions and campaigns. This includes supporting improved health/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 utilize local resources, such as Regolith / 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/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 photo-voltaic cells and solar arrays, wires, tubes, connectors, etc., and pressurized volumes, 4) Testing key technologies and demonstrate 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.

H2.01 In Situ Resources Utilization of Planetary Materials for Human Space Missions
Lead Center: JSC
Participating Center(s): KSC, MSFC

Significant benefits for future human missions in near-Earth space (Earth-Moon and Earth-Sun libration points and the lunar surface), and to Mars and other planetary bodies may be attained by making maximum use of local, indigenous materials as a source for products such as propellants, life support consumables, radiation protection, and construction materials. By pursuing the philosophy of "make what you need where you need it" instead of bringing it all the way from Earth, In Situ Resource Utilization (ISRU) can result in a reduction of mass requirements for exploration missions, a reduction in mission risk and cost, and expanded human presence in near-Earth space and on extraterrestrial surfaces. It can also enable the long-term commercial development of space by enabling low cost transportation and providing the resources, technologies, and infrastructure required to allow commercial development activities to grow.

In support of NASA's goal of expanding the frontiers of space and knowledge by exploring, using, and enabling the development of space for human enterprise, studies, mission design efforts, and technology and system development activities are being pursued that can significantly reduce mission mass, cost, and risk while enhancing or enabling robotic and human exploration initiatives beyond low Earth Orbit. Key goals are to minimize the mass which must be brought from the Earth (including the equipment required to move or process the resource), minimize power consumption and Earth supplied processing consumables, enable or enhance new mission concepts not possible without the use of space produced products and consumables, and develop infrastructure, resources, and products to promote the commercial development of space.

Proposals may be submitted for ISRU concepts at various destinations, including near-Earth space (Earth-Moon and Earth-Sun libration points and the lunar surface), asteroids, Mars, planetary moons, etc. Areas for investigation of specific methods and processes for in situ resource utilization include the following:

- Methods and systems for digging, sorting, mineral separation, and transporting regolith or other surface materials to a processing reactor in reduced gravity. Such systems should be lightweight, efficient, and capable of operating with minimal human supervision and maintenance in extreme environments.
- Methods for extracting, collecting, and processing in situ materials into mission enabling or enhancing consumables (propellants, oxygen, etc.) or commercially viable products from atmospheric, surface, and subsurface space resources and life support and power system byproducts and waste that are power efficient, minimize the mass and volume of equipment that must be brought from Earth, and require a minimum of Earth-supplied reagents. Emphasis should be placed on innovative designs and processes. Proposals for water/ice extraction or drilling should recognize the uncertainty and potential variability of both the location and abundance of such water
- Methods for processing Moon, Mars, and asteroid surface materials into useful equipment (e.g., solar panels, radio antennas, replacement parts, etc.) and construction materials which require little or no further manufacturing or assembly that enable long-term settlement.
- Methods of packaging ISRU collection, reactor, separation, distribution, and control equipment that significantly reduce total package mass, volume, and power requirements for use in robotic and human mission applications.

H2.02 Human Centered Computing
Lead Center: ARC

NASA is planning to fill space with human explorers, highly trained with scientific and technical skills, to explore our solar system in ways never before possible. To survive years of living and working in space, these astronauts need to be outfitted with life support, data gathering, and spacecraft tools that will enable them to be productive and thrive in harsh and unpredictable environments. Not the least of the astronauts' concerns will be coping with breakdowns and uncertainties in operating the increasingly complex technologies of spacecraft, rovers, and habitats, which will require ongoing monitoring, control, diagnosis, and repair.

To achieve NASA's ambitious exploration goals, researchers must develop robust control systems and exploration tools that can be understood by people, easily learned, maintained, and directed. For example, life support systems for either spacecraft or habitat systems must aid people in diagnosis and repair. Operations assistants, integrated into just-in-time training systems, will be necessary to help people understand the state of the system and help them correct errant inappropriate or unworkable procedures. The design of computer systems necessarily must take into account not only how people will "interface" with the systems, but fundamental aspects of human perceptual-motor coordination, cognitive operations, and group dynamics. Human-centered computing focuses on the "delta" — what is the difference between the best computer systems and people? What are the particular contributions of humans and machines? How can we design machines and operational procedures to complement each other?

Human-centered computing is a design approach that integrates computational systems with human performance and capabilities, such that the total system amplifies, corrects, and leverages the capabilities of both people and machines. The architectural requirements of autonomous systems are required, plus fundamental theories of human perceptual, cognitive, and social systems that anticipate the context and contribution of human behavior in which technologies are utilized and maintained. Beyond this, the harsh realities of working in space environments must be thoroughly understood, so tools such as electronic notebooks, alarm systems, and scheduling systems are adapted to the living and work environment of a space habitat or planetary surface rover.

To advance along these lines, proposals are sought in the following areas:

Perceptual Performance Enhancers

- Visualization tools combining "virtual reality" projection with actual objects in the environment, conveying information about object identity, part relationships, and assembly or operational procedures.
- "Cognitive prostheses" that qualitatively change the capabilities of human perception, pattern analysis, scientific domain modeling, reasoning, and collaborative activity. Such tools could incorporate any of a variety of modeling techniques such as knowledge-based systems and neural networks, and fit tool operations to ongoing human physical interaction, judgment, and collaborative activity.

Robust, Mixed-Initiative Information Systems

- Advanced AI systems/architectures for mixed-initiative system planning, monitoring, and control, with provision for crew oversight. Robust architectures that have predictable behaviors, leave people in control, and expose their workings in ways comprehensible to people with different skills.
- Agent-based tools for information gathering, reminding, and alerting; job performance aids that provide cognitive assistance in the context of the daily activities and interests of operations personnel and crew.

- Computing architectures that address the limitations of knowledge-based systems and neural networks, relative to human capabilities, advancing the state-of-the-art in automated perceptual categorization, non-verbal conceptualization, and coordination across multiple sensory modalities. Applications might include planetary probes and rovers with new kinds of instrumentation, signal processing, and sensing-through-movement.

Collaborative Knowledge Amplifiers for Scientists and Engineers

- Information technology enabling comprehensive sharing of project-related information and data, which supports intelligent organization, access, and presentation of the information. Particularly, tools that fit the human activities of scientific inquiry and engineering design, and relate the contributions of individuals to the developing plans and products of teams.
- "Knowledge management" tools that relate technical models of human knowledge to: a) nonverbal concepts and perceptual skills; b) the daily activities of workers, including especially how databases are actually used in practice; c) informal on-the-job learning; d) social knowledge about what can be said to whom and in what form; and e) the career trajectories of novices, experts, and retiring employees.
- Communication technologies and software tools that enable mission control teams to work together when they are located at different sites and working on several projects.
- Software systems that provide specialized support for collaborative science and engineering tasks, including design, data collection, experimentation, analysis, and model construction to enable scientists and engineers to collaborate as part of distributed project teams at physically separate sites.

Design Tools Grounded in Human Practices

- Tools for software requirements analysis that incorporate and relate models of databases, legacy systems, and work practices.
- Workflow systems that allow teams of users to formalize and routinely reconfigure their own document templates, processing categories, operating procedures, and archival records.

TOPIC H3 Space Utilities and Power

A key goal of the HEDS space utilities and power topic includes working with appropriate NASA and external organizations to identify and establish robust sources for abundant power for in-space, surface and transportation systems for human exploration and the commercial development of space. In additional another key objective is to drive down the cost of human/robotic exploration missions and campaigns. Some selective specific objectives include 1) development and validation of technology for a range of power levels and/or requirements, such as - Large space platforms - Space transportation systems for human exploration and space development - Mobile, piloted or human-supporting lunar or planetary surface systems, and - Various other HEDS systems (e.g., habitats, extravehicular activity (EVA) systems, etc.) 2) Developing a foundation for the future testing and validation of key technologies and demonstrate innovative new human exploration and development of space systems concepts in space, and 3) establishing a foundation for profitable commercial development of space applications of these technologies in the mid- to far-term. Some of the technical objectives targeted by this topic include: - Space Solar Power Systems – Space Nuclear Power Systems -- for surface and in-space power applications - Wireless Power Transmission Systems - Cryogenic propellant depots - Energy Storage Systems

H3.01 Thermal Control Systems for Human Space Missions
Lead Center: JSC
Participating Center(s): MSFC

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. The requirements for human-rating and the specified temperature range (275 K - 310 K) drive the development of enabling active thermal control technologies to support human space exploration. 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). Areas in which innovations are solicited include the following:

- Liquid-to-liquid, liquid-to-air, and air-to-air heat exchangers with improved performance and lifetime over current International Space Station (ISS) and Space Transportation System (STS) types.
- Liquid-to-liquid heat exchangers that provide fault tolerance such that liquids cannot leak from one side to the other.
- Heat pumps capable of acquiring waste heat at near 273 K and rejecting the heat above 300 K.
- Internal heat pumps or alternative technologies to provide cabin dehumidification on-orbit with a fluid heat sink of 288 to 298 K.
- Thermal radiators with fin efficiency 90% or greater at ISS conditions and with improvement over current ISS and STS types in the areas of: lightweight, micro-meteoroid and orbital debris (MMOD) protection, stowed volume, and deployment structures.
- Environmentally friendly, non-toxic single and two-phase working fluids that either freeze below 75 K or do not significantly change density upon freezing or thawing.
- Two-phase thermal control systems and associated control schemes, which require lower power and have less mass compared to current spacecraft systems.
- Microgravity and/or partial gravity thermal energy storage systems for applications at 311 K, 299 K, 277 K, 193 K, and 88 K.
- Lightweight, controllable evaporative heat rejection devices for use with water and ammonia.
- Microgravity compatible food and science sample refrigerator/freezer and cryogenic preservation technologies and systems that provide increased efficiency over current ISS and STS systems, in the temperature range from 277 K to 93 K.
- Insulations or insulation systems for use in creating lightweight, efficiently packaged, rectangular, cold volume enclosures for spacecraft refrigeration/freezer/cryogenic preservation systems, for the temperature range from 277 K to 93 K, and which are comparable to or improvements upon current vacuum wall performance.
- Fluid storage concepts and designs that provide an acceptable alternative to traditional pressure vessels, with the primary benefits of reduced hazards. Concepts should provide function of tanks and/or accumulators and be targeted for fluids such as ammonia, nitrogen, oxygen and refriger-

ants. Possibilities include but are not limited to solid or liquid phase storage, chemically combining with other materials, and use of any materials with an affinity for these candidates.
- Low vibration or vibration isolating fluid components including fans, pumps, compressors, coolers, tubing, fittings, heat exchangers, and valves for use in microgravity processing applications.
- Highly accurate, remotely monitored, in situ, non-intrusive thermal instrumentation for meeting in-space science, manufacturing and safety needs.
- Materials and concepts for thermally efficient containment and processing of hazardous materials and samples in space.
- Advanced analytical tools for thermal/fluid systems design and analyses, which are amenable to concurrent engineering processes.
- Fluid quick disconnects that allow activation without exact alignment of the halves, that have low activation force (approx. 10 lbf) with internal pressures of 500psi, that are not sensitive to level 200 contamination, that leak less than 1x10-6 sccs He at 500psia over at temperature range of -100F to +100F and can be used with ammonia, water or R-134a.

Proposers 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.

H3.02 Spaceport and In-Space Cryogenic Fluids, Handling, and Storage Technologies
Lead Center: KSC
Participating Center(s): GRC, JSC, MSFC

Advanced technologies are being solicited for cryogenic systems for multiple aerospace applications. New and innovative techniques are desired in spaceport technologies, space environment applications, and extraterrestrial applications (lunar & Mars environments). These focus areas include technologies that will increase the performance, operational efficiencies, safety, and reliability of cryogenic systems and provide for autonomous cryogenic operations in earth, space and extraterrestrial environments.

Planetary Spaceport Cryogenic Fluids, Handling and Storage Technologies
Innovative technologies are being solicited for storage, handling, distribution and recovery systems for new spaceport cryogenic facilities. Desired features include: improved operational efficiencies, increased safety & reliability, autonomous loading and off-loading operations and recovery of high value waste gases. Extraterrestrial spaceport systems have an added emphasis for lightweight and highly reliable characteristics. Specific areas of interest include the following:

- New LOX pumping system capable of 75 - 115 liters per second flowrate to support current vehicle loading operations. Highly reliable, variable controlled, parallel pumping system is desired that minimizes the potential for LOX leakage.
- New technology valves for cryogenic applications, including LO_X, LH_2, and LCH_4 that minimize thermal losses and pressure drops across the component. Components should be adaptable to electromechanical activation and in a size range from 1/2 to 5 inches.
- Leak-proof, easy to use cryogenic couplings utilizing robust sealing technology that are compatible with cryogenic temperatures and liquid oxygen.
- Separation and recovery of gaseous hydrogen and/or helium from waste gas streams. Waste stream could contain small amounts of ambient air as well as GN_2, GH_2, and GHe.
- Innovative latching technologies such as shape memory alloy applications and technologies that allow for maximum preload with minimal application loading are also desirable.
- Flowmeters and densitometers for measurement of densified, normal boiling point and/or multiphase cryogen at flowrates from 3 - 115 liters per second.
- Mass on board determination system for cylindrical flight tanks containing normal boiling point and/or sub-cooled propellants. Accuracies of better than 0.5% desired.
- Energy efficient, cost effective distribution systems for transfer of cryogens over long distances (up to several miles in distance).
- Cryocooler systems with cooling capacity greater than 10 watts operating in the 20 - 40 K range.

- Efficient LH_2 storage systems for transporting LH_2 to Mars and storage on the Martian surface.
- Innovative light-weight, thermal and volume efficient liquefaction and cryogenic propellant storage technologies and techniques to minimize overall mission and especially ascent vehicle mass, and to facilitate packaging of Mars robotic and human mission ascent vehicles that utilize in situ produced propellants on Mars landers.

In-Space Environment Cryogenic Fluids, Handling and Storage Technologies
Components or concept proposals are being solicited to improve the performance, operating efficiency, safety and reliability of cryogenic fluid storage and handling in a low gravity (10^{-6} g to 10^{-2} g) environment. Tanks of high energy propellant fluids, stored in their most efficient state (as low pressure sub-critical cryogenic fluids), 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 and unique instrumentation. Innovations are required in the following areas:

- Lightweight, low thermal conductivity cryogenic tank struts and support concepts.
- Low thermal conductivity cryogenic tank penetrations, i.e., instrumentation feed-throughs, feedlines, vent lines.
- Lightweight, insulating thermal protection schemes.
- Robust insulation concepts for multiple launch/landing and ambient/vacuum pressure cycles.
- Devices for vapor-free acquisition of cryogenic liquids.
- Small, low power, lightweight (2 liter/minute) liquid oxygen transfer pumps.
- Tank pressure control (e.g., thermodynamic vent) and/or integrated tank boil-off control and product liquefaction technologies.
- Instrumentation for monitoring cryogens in low gravity including mass quantity gauging, liquid-vapor sensing and free surface imaging.

H3.03 Spaceport/Range Instrumentation and Control Technologies
Lead Center: KSC

The goal of this subtopic is to develop instrumentation, systems and associated sensors required by Spaceports/Ranges to operate future generation space vehicles safely and efficiently. Technologies developed under this subtopic shall support the reduction of vehicle and payload cost per pound to orbit while increasing the safety of ground and flight operations by orders of magnitude.

The vision of the future is that multiple vehicles will be operating simultaneously in various phases of processing, launch, and landing from multiple terrestrial and planetary Spaceports/Ranges. In order to realize this, it will be necessary to have systems that integrate a suite of ground and space based sensors and instrumentation that provide the total Range solution. These systems need to be distributed and capable of supporting multiple sites and operational phases without reconfiguration. This will require autonomous knowledge based expert systems that can be implemented at multiple sites and require minimal infrastructure and personnel to operate.

This subtopic focuses on the development of sensors, instrumentation systems, meteorological and communications technologies that are uniquely suited to Earth and planetary spaceports for the processing, launch, tracking, controlling, and landing of space vehicles. The specific focuses are on sensors, transducers, instrumentation and systems that will be applied to the following areas:

Space Based Range
This focus area includes the development of technologies for satellite platforms or vehicles that provide instrumentation systems that perform or support the following functions: metric tracking, area surveillance, navigation aids, and atmospheric sensing. Each of these functions will require development of one or more of the following technologies; Integrated multi-, hyper-, and ultra-spectral instrumentation and sensors; Multi-channel transceivers. These will provide directors/controllers and vehicles vital real-time data that is necessary to interface with the National Airspace System for all phases of ascent and decent.

Automated Multiple Object Optical Tracking and Recognition System
Develop an automated optical multiple-object tracking and object recognition system to be used during the early stages (first 2 minutes) of a vehicle's ascent. Applying image processing techniques to a wide area view should reduce operational costs compared with radar-based tracking systems and provide more information during a catastrophic event. This system would provide critical position data in near real-time for recovery and analysis of objects of interest. Solutions provided from this capability would be utilized for analysis of nominal or catastrophic events that may occur during a launch operation.

- Minimum object size: ~ 1 m^2
- Maximum number of objects: up to 50
- Position accuracy: 10 m
- Field of view: 10 km^2 at 70 km

Decision Models and Simulation
New and innovative methods to ensure safe and cost effective real-time decision models that safely reduce conservatism and provide the necessary fidelity. Improvements in real-time computational capability and code development can significantly improve assessments. Specific technologies needed:

- Range Dispersion Monitoring Instrumentation: Develop ground-based and airborne time-resolved real-time instruments to measure atmospheric chemical species associated with spaceport propellants and combustion products. Deployable instruments, both physical sampling and remote sensing, shall be capable of being networked to provide real-time data to a central processor for formatting and ingestion into a spaceport decision model. Sensors will be capable of identifying specific chemical species including hydrogen chloride, nitrogen dioxide, hydrazine (anhydrous, monomethyl, and unsymmetrical dimethyl), hydrocarbons, sulfur hexafluoride, and particulate matter.
- Conflagration Decision Model: Heat and mass emission factors from solid propellant burning under water needs to be assessed and modeled. In addition to heat quenching, the chemical interaction of burning solid propellant and associated combustion products needs to be known as a function of water depth and salinity. The model output should yield mass and heat content of gaseous products including hydrogen chloride, solid products including particulate aluminum oxide and ammonium perchlorate, and liquid products including hydrochloric acid for unit mass of solid propellant involved, Unburnt propellant mass should also be assessed. Assessments are to be based on empirical studies using Space Shuttle-like solid propellants.
- Decision Model On-Screen Editor: Develop methodology to enable on-screen editing of graphical outputs, such as meteorological parameters utilized in spaceport decision models. Shapes, slopes, and uncertainty bandwidths of curves should be automatically digitized based on operator on-screen inputs. This editing capability must allow the user to make changes to the forecasted toxic corridor in near real time. Methodology must execute with sufficient speed to accommodate user inputs, decision model reevaluations, and input refinements to assess decisions, consequences, and uncertainties.

Miniature Mass Spectrometers for Hazardous Gas Detection
Development is needed for small, lightweight, rugged, inexpensive, mass spectrometers or other technology capable of measuring one part per million to 100 percent of hydrogen, helium, nitrogen, oxygen, and argon in a high-vibration environment. These instruments will be used on and around space launch vehicles for leak detection during ground processing, test firings, pre-launch propellant loading, launch, ascent, and descent (post reentry). The primary improvements in technology and performance over current instruments are size and weight reduction, cost reduction, and operation in a high vibration environment. Current instruments typically fill one or more equipment racks, weigh several hundred kilograms, and must be operated in an air conditioned, vibration free environment, typically several hundred feet from the potential leak locations. Their cost, size, and complexity mandate that each instrument must sample multiple leak locations on a time-shared basis. The target cost of an operational version of the desired instrument is \$5,000-\$20,000 each. The needed instrument accuracy is plus or minus ten parts per million or 5 percent of

reading, whichever error is greater. The instrument should possess mass resolution capable of meeting the desired accuracy goals for hydrogen in the presence of 100 percent helium and for oxygen in the presence of 100 percent nitrogen. The instrument should be less than 3500 cubic centimeters total volume and have mass less than ten kilograms, including high-vacuum pump. The instrument should be able to withstand an 18 G vibration over a range of 5-2500 Hz. for 15 minutes on each axis without damage. The instrument should be capable of meeting the specified accuracy requirements for twelve hours without calibration. It should be capable of analyzing all five specified gases and providing the concentration of each within one second. While advances are primarily sought in development of complete instruments, advances in key enabling technology such as vacuum pumps, ionizers, and detectors are also sought.

H3.04 Electromagnetic Physics Measurements, Control, and Simulation Technologies
Lead Center: KSC
Participating Center(s): JSC

Spacecraft launch operations involving toxic and explosive vapors, liquid and solid propellants as well as the operation of electronic components on the ground, in space, and in extra-terrestrial environments have created special concerns for understanding the electromagnetic dynamics of surfaces in contact with each other as well as the production and dissipation of electrostatic charge due to this interaction. These concerns are of crucial importance to NASA in the fabrication, processing, launch, and safe operation of unique and expensive spacecraft launching from earth as well as from other planetary surfaces. Specific interests for the 2002 solicitation include, but are not limited to, those listed below:

- Development of instrumentation to study the electromagnetic dynamics of surfaces in sliding contact with each other and its effects on the generation of electrostatic charge under a wide range of atmospheric conditions. Frictional contact between surfaces generates energetic electrons, ions, and photons. NASA is interested in instrumentation to measure the number and the type of the particles transferred as well the amount of mass transferred between surfaces after breaking contact. These instruments should be compact and lightweight and capable of working under ultrahigh vacuum conditions (10-12 Torr).
- Develop techniques for measuring the charge-to-mass ratio and the speed of dry particles (1 to 100 micrometers) in ambient and high vacuum conditions (10-12 torr) over a broad range of temperatures. These techniques must be capable of supporting the future development of the electromagnetic characterization of materials during exposure to dust impingement in a vacuum, atmospheric, and non-terrestrial atmospheric environments.
- Develop improved triboelectric charge measurement and decay test devices that will become part of new testing standards for protective clothing and other materials to be used in space, hazardous ground processing, and extra-terrestrial environments. Performance of the devices should be compared to similar data already collected by the Kennedy Space Center using existing technology. Instruments and devices proposed for demonstration should be light weight, small in size, and suitable for operation in a vacuum with temperature ranges from -160^{o} C (- 250 ^{o} F) to 200 ^{o} C (400o F), in various gaseous environments with pressures from 100 millitorr to 5000 torr and temperatures from -160 ^{o} C (- 250 ^{o} F) to 200 ^{o} C (400 ^{o} F) as well as terrestrial environments with temperatures from - 75 ^{o} C (-100 ^{o} F) to 65 ^{o} C (150 ^{o} F) and humidity from 0.5% to 100%.
- Develop miniature sensors for detecting and measuring the electrostatic potential and charge distribution generated on payloads, spacecraft, and landers. Develop software for modeling the electric potentials of payloads, spacecraft, and landers based on previous flight experiment data and models.
- Develop dust generators that would deliver 1 to 40 micrometers uncharged particles at speeds ranging from 10 to 30 m/s at atmospheric pressures ranging from 100 mTorr to 760 Torr and at temperatures ranging from -100 ^{o} C to 50 ^{o} C. Proposed devices should provide particle counts as well as particle velocities.

H3.05 Wireless Power Transmission
Lead Center: MSFC

The goal of this activity is to conduct research for Space Solar Power Wireless Power Transmission (WPT) technology development to reduce the cost of electrical power and 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 microwave 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; and space-based sites for spacecraft and space vehicle propulsion.

Technology Elements

- Transmitting elements, both microwave and laser
- Transmission power systems
- Relay stations, if any
- Receiving stations
- Distribution systems
- Thermal management
- Interference
- Legal issues
- Land use
- Public perception
- Economics
- Power management and distribution
- Safety
- Robotic assembly of on-orbit elements…

Objectives

- Develop advanced laser and/or microwave power transmission concepts
- Identify small-scale technology demonstrations, both land and space based
- Identify research and technology activities, concentrating on "tall poles" and promising concepts
- Develop a methodology for discriminating and choosing the most promising systems and methodologies

Tasks

- Develop advanced candidate wireless power transmission concepts and systems designs
- Perform trades on the concepts and designs, and identify the most promising by means of a quantitative selection process
- Identify required and beneficial technology demonstrations, and recommend solutions
- Conduct research and advanced development work

H3.06 Propellant Depots
Lead Center: MSFC
Participating Center(s): GRC, JSC

The focus of this subtopic is to develop and advance enabling technologies required to build and operate a propellant depot near Earth or in deep space. Cryogenic propellant storage depot technology is a unique area, in that it has been studied in detail but little research has been accomplished in space, where the unique effects of low gravity come into play. The propellant depot will provide affordable propellants and similar consumables as needed in the development of space. A propellant depot not only requires technology development in key areas such as cryogenic storage or 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. Specific areas of interest include:

- 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.
- 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 utilizing 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; health monitoring and smart systems.
- Light-weight structures including inflatables, deployables and advanced composites.
- Micrometeoroid and space debris protection schemes and associated technologies including advanced light-weight 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 chilldown including spray nozzle configurations, liquid flow rate and duration, number of gas venting steps and performance in a low gravity environment.
- Stratification / 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/disconnects with small or no fluid and heat leakage. The connects/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 micro-g condensation and fluid mixing.

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 micro-g fluid transfer by performing an orbital experiment.

H3.07 Space Nuclear Power For Human Missions
Lead Center: GRC
Participating Center(s): JSC, MSFC

NASA is interested in the development of highly advanced systems, subsystems and components for use with both nuclear reactors and radioisotopes for future robotic and manned missions. Principally these systems of interest are non-nuclear, however they may operate in close proximity to nuclear sources. Anticipated power levels range from 100's of watts to multi-megawatts. Applications include: electric power for in-space propulsion, vehicle housekeeping, and science payloads, and on planetary surfaces; surface and atmospheric mobility, science stations, resource production, robotic outposts and human bases.
Major technologies being pursued are:

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

Supporting technology includes:

- High temperature materials/coatings >1300 K
- Deployment systems large radiators, surface mobility
- Systems to mitigate planetary surface environments. Dust, wind, planetary atmospheres, (CO_2, etc.)

In addition to overall system mass, volume and cost reductions, safety and reliability are of extreme importance. It is envisioned that these technologies will be used on robotic and eventually human missions and it is to the Agency's advantage to develop those technologies that transcend the robotic and human mission set 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.

H3.08 Vibroacoustic Prediction and Simulation Technologies
Lead Center: KSC

The launch acoustic and vibration environment induced by a rocket engine imposes severe conditions on the launch pad infrastructure. Nearby structures and equipment subjected to these intense environments must be designed to withstand them. The problem is that the environments are non-stationary and random while existing design methods attempt to utilize stationary models of the worst conditions to describe them. An important consideration in the development of all foreseeable future launch vehicles is cost. Yet the inherently conservative design approaches used lead to costly structure and equipment designs. This problem is compounded by a lack of knowledge of the environment induced by a launch vehicle being designed at the same time as the launch facility. This has in many cases lead to overbuilt facilities and poor design due to improper accounting for the launch environment.

Specific interests for the 2002 solicitation include developing tools for analytically simulating the launch acoustic environment and its vibration effect on launch pad structures and equipment. The response of the types of structures normally encountered on launch pads such as open trusses, frames, concrete slabs and beams, and corrugated metal enclosures are of particular interest from the response viewpoint. From the acoustic and potentially overpressure environment determination viewpoint, tools that can be used to analytically predict the environment for any generalized launch pad design are sought. Typical launch pad designs will look at issues like covered versus uncovered exhaust ducts or trenches, active and passive acoustic and overpressure suppression systems, and exhaust plume deflector geometries, so the prediction tools should address one or more of these.

In conjunction with the analytical tool developments described above, it will be necessary to verify tool results. These verifications can take advantage of either full or sub-scale data. Technologies for generating sub-scale test data to verify analytical tools and assess their applicability to full scale problems are also sought.

H3.09 Spaceport Command, Control, and Monitor Technologies
Lead Center: KSC

The goal of this subtopic is to promote the development of intelligent command, control and monitoring systems, vehicle health monitoring systems and associated sensors required by Spaceports to operate future generations of space vehicles safely and efficiently. Technologies developed under this subtopic shall support the reduction of vehicle and payload cost per pound to orbit while increasing the safety of ground and flight operations by orders of magnitude.

The vision of the future is that multiple vehicles will be operating simultaneously in various phases of processing, launch, and landing from multiple terrestrial and planetary Spaceports. In order to realize this, it will be necessary to have systems that integrate a suite of ground resources and instrumentation that provide the total Spaceport solution. These systems need to be distributed and capable of supporting multiple sites and operational phases without reconfiguration. This will require autonomous knowledge based expert systems that can be implemented at multiple sites and require minimal infrastructure and personnel to operate.

This subtopic focuses on the development of highly flexible and reliable command and control system architectures, sensors, and instrumentation systems, that are uniquely suited to and used at Earth and planetary spaceports for mission planning, processing, launch, controlling, and landing of space vehicles. The specific focuses are on sensors, transducers, instrumentation and control and monitor systems hardware and software that will be applied to the following areas of command, control, and monitoring:

- New and innovative technologies that include real-time advisory systems
- Data reduction, analysis, and archiving
- Configuration validation and management
- Low cost high fidelity training capabilities that minimize impact to operational systems
- Simulation tools which provide new front-end interfaces and promote low overhead, quick and accurate model generation and operation, in addition to COTS products that can interface with KSC simulation products and new technology
- Technology areas which provide solutions to deterministic real-time performance of commercial switched based networks, and operating system and driver effects on network performance with various Real-time Operating Systems are of interest.
- Technologies that minimize software change and re-test associated with end-item configuration changes are also of interest.
- A system which serves as an advisory system incorporating payloads testing knowledge with existing test and support system capabilities to enable payload test personnel to more quickly solve payload test and integration problems.

H3.10 Solar Power Generation and Power Management
Lead Center: GRC

Over the last thirty years NASA has periodically investigated the feasibility of large-scale space solar power systems including possible solar power satellites that could deliver power to space and terrestrial locations by wireless transmission for both government missions and commercial markets. "Large-scale" is defined as providing power to a user in the range from 1 megawatt (MW) to approximately 1 gigawatt (GW) or more. Previous concept definition efforts have determined that Space Solar Power (SSP) system performance goals (for space science and exploration as well as commercial applications) could potentially be accomplished through pursuit of focused strategic technology development efforts. A similar approach is intended with this effort.

Dramatic advances in a wide range of space technologies are needed in order to achieve the necessary breakthrough improvements in diverse space systems needed to make SSP systems feasible. New systems concepts must be created and refined which incorporate existing and new technologies in revolutionary ways. This opportunity has the intent to explore options for, and the viability of, highly innovative new concepts and technologies that might dramatically lower the cost and increase performance of critical SSP technologies/systems in the areas of Solar Power Generation and Power Management and Distribution.

Power Generation
Photovoltaic Cells and Arrays: Proposal efforts could include technology development, studies and demonstrations in the areas of innovative solar cells, solar array blanket technology and array structural and deployment methods. Concepts are sought which, at the multi-kilowatt level and in the near term, could enable total array specific powers to exceed 500W/kg. High voltages are required with sustaining operating voltages up to 1000 volts dc. Array designs should have the potential to achieve total array specific powers of 1000 W/kg or more at the multi-hundred kilowatt to MWe output level. Cell and blanket technology shall have the potential for significant cost reduction compared to state-of-the-art space qualified arrays at these sizes. Technology advances needed to achieve multi-MWe output levels at costs consistent with the economic viability of a large SSP system should be identified. For example, innovative processes for thin film solar array manufacture.

Other areas of interest include demonstration of high efficiency, lightweight concentrator cell and array designs, multi-bandgap cells, advanced spectrum splitting concentrator concepts (with up to 100x concentration), multi-quantum well and multi-quantum dot concepts, advanced multi-band gap schemes, and thermophotovoltaics.

High-Voltage Arrays/Arc Mitigation: Lightweight, high power, high efficiency solar arrays are absolutely necessary for SSP; most concepts also require high voltages. However, high power, high voltage arrays in various Earth orbits are subject to continuous arcing, which can destroy lightweight substrates. Therefore, enabling research and technology development and/or demonstrations are needed that leads to the following:

- Lightweight, high-voltage arrays. These arrays should be resistant to radiation damage and yet have high efficiencies, and be resistant to arcing in plasma chambers to at least the 1000 v string voltage level. Provisions for plasma testing should be addressed;
- Design concepts/guidelines for very high voltage power distribution systems in GEO and other Earth neighborhood environments. Voltages up to 100 kV should be considered. Arc mitigation strategies in the space plasma, ambient or self generated, should have the highest priority. Proposals should have provisions for verification in ground-based plasma chambers and/or space flight experiments.

Power Management
Power Distribution: NASA is interested in components and systems for distributing megawatt levels of electric power in large satellite systems. Preliminary studies have identified the following key technology studies and demonstrations:

- High-Voltage Cabling, Switches and Distribution Units: Current-limiting switches, housed in distribution units are required. Switches should be remotely controlled, and shall incorporate digital system interfaces for data and control. System voltage level is expected to be up to 100k volts. NASA is interested in initially investigating designs for accommodating at least 1000-volt distribution with a clear evolution path for growing to 100k-volt systems. The distribution units should allow for all system interfaces: data, thermal, and electrical, and should accommodate transferring loads among separate sources.
- High-Voltage DC-to-DC Converters: Converters must be capable of being remotely controlled, and should incorporate digital system interfaces for data and control. NASA is interested in initially investigating designs for accommodating at least 1000volt distribution with a clear evolution path for growing to 100k-volt systems. Proposed designs should consider a modular switch and

transformer combination that allows for multiple increments of input voltage and current as well as multiple increments of output voltage and current, a modular building block approach.

High-Temperature Semiconductors for PMAD Systems: NASA is interested in high-temperature, power semiconductors for use in high-voltage DC-DC converters. To reduce the weight of heat rejection systems our studies have indicated that 300^{o}C chassis temperatures are required. NASA is seeking proposals to demonstrate technology readiness in both silicon carbide and gallium nitride semiconductors. Topics include, but are not limited to defect-free epitaxy, dynamic characterization, space radiation hardness, device packaging to sustain simultaneous high voltages and temperatures, life prediction and thermal management.

Intelligent Power Controls and Health Management: Fault management through autonomous control will be necessary for future SSP systems. Concepts and demonstrations of such components and systems are requested to enable development of intelligent controls which will sense/detect faults, shut down affected regions and re-route power to maintain operations. Self-healing concepts are sought which allow the system and components to maintain high reliability. Detection and reporting of failures due to the environment (micrometeoroids) or component breakdown will have to be a part of the system. Materials that can recognize failures and initiate self-correction are of interest.

TOPIC H4 Habitation and BioAstronautics

The goal of this topic is to assure robust and reliable capabilities to support 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 extra-vehicular 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 far-term

H4.01 Extravehicular Activity Productivity
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.
- Thermal insulation suitable for use in vacuum and low ambient pressure.

EVA Mobility

- Space suit low profile bearings that maximizes rotation that 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 crew-member 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 which will provide flow for a space suit but can be stacked to give greater flow for a vehicle.
- CO_2 and humidity control devices which, while minimizing expendables, function in a CO_2 environment.
- 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/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 crewmember and public and are integratable into a spacesuit that is light weight and low power.
- Mini-mass spectrometer that detects N_2, CO_2, NH_4, O_2, and hydrazine partial pressures.
- Radio/laser communications that provides good communications among crew and 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.
- Work tools that assist the EVA crewmember during operations in zero-gravity and at worksites. Specifically, devices that provide temporary attachments, that 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.

H4.02 Crew Habitability Systems
Lead Center: JSC

Advanced habitation systems includes the overall habitat system and its crew supporting habitability functions within. Habitability systems technology 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, and logistics, maintenance and repair systems are being sought out for innovative solutions with reliability, durability, repairability, radiation protection, packaging efficiency and life-cycle cost effectiveness. Integration of workstations, integrated sensors, circuitry, automated components, integrated outfitting and advanced workstation 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 food heating, preparation, dining 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 enable a habitable environment for the crew.

The Space Station and Space Launch Initiative are of most interest and consideration of flight-testing in space should be considered. The Near-Earth missions such the Moon and Mars are also of interest. Areas in which advanced habitability system innovations are solicited include the following technologies for use in space (zero gravity) and/or the 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 (Conduction, Convection, Microwave)
- Wardroom, Deployable Outfitting
- Trash Management, Recycling, Dual Use

Crew Hygiene Systems: Create crew hygiene systems that are lightweight, low power, low volume systems to support on-orbit crew waste and hygiene activities.

- Waste Collection, Gas/liquid separator, Urine Separator
- Crew Hygiene, No-rinse Hygiene Products, Non-foaming gas/liquid separator (handle soaps)
- Integrated Systems & Outfitting

Crew Rest Systems: Create crew rest systems that are lightweight, low power, low volume systems to support on-orbit sleeping and privacy activities.

- Crew Quarters, Radiation Protection, Acoustic Control, Quiet Air Ventilation
- Relaxation/Recreation, Interactive VR Systems
- Integrated Systems & Outfitting

TOPIC H5 Space Assembly, Inspection and Maintenance

One goal of the space assembly, inspection and maintenance topic is to enable a much more robust set of options for affordable implementation of ambitious new modular space exploration systems and missions. Another goal is 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 tele-presence 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 impact 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, and 7) establishing a foundation for profitable commercial development of space applications of these technologies in the mid- to far-term. The space program can enrich society by directly enhancing the quality of education. Terrestrial applications of technologies developed for space have saved many lives, made possible medical breakthroughs, created countless jobs, and yielded diverse other tangible benefits for Americans. The further commercial development of space will yield still more jobs, technologies, and capabilities to benefit 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.

H5.01 Automated Rendezvous and Docking and Capture
Lead Center: JSC
Participating Center(s): MSFC

In support of future robotic and human missions, the need for automated 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 to dock two vehicles from initially large distances (> 1000 kilometers). The "chaser" vehicle will begin the rendezvous after completing orbital insertion. The "target" vehicle may be orbiting for several years prior to the rendezvous. There can be differing levels of cooperativeness, from actively supporting the rendezvous by utilizing powered subsystems to being completely passive, devoid of rendezvous-enhancing retroreflectors.

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. To provide a generalized capability useful for future missions beyond LEO, solutions should not rely on GPS capabilities.

Innovations are sought to solve the following technology challenges:

- Automated techniques for orbit determination of chaser and target spacecraft during the initial phase of rendezvous operations when spacecraft to spacecraft ranges exceed hundreds of kilometers.
- A minimum relative navigation sensor suite addressing spacecraft-to-spacecraft ranges of 100 kilometers through docking, including relative attitude control during the final 100 meters of the approach. Providing capability for circumnavigation of the target at 100 meters is desirable.

H5.02 Robotics Assistance, Assembly, Maintenance, and Servicing
Lead Center: JSC

Proposals are solicited for innovative concepts that improve robotic capabilities as well as the humans ability to interact with and control robotic systems while minimizing the workload to EVA and IVA astronauts, as well as ground operators.

Robotic Manipulators, End-Effectors, and Joints
Proposals are sought which include improvements to robotic joints, actuators, end-effectors, tools, and mechanisms. Proposals should address issues associated with space compatibility. Specific areas of interest include the following:

- Technologies or systems that provide a reduction to the weight and or volume of robotic systems such as:
    - Reduced scale high power-to-weight ratio actuators including but not limited to magnestostrictive motors and synthetic muscles.
    - Miniaturized actuator control and drive electronics.
    - Miniaturized sensing systems for manipulator position, rate, acceleration, force and torque.
- Robotic systems that accommodate existing EVA tools including but not limited to anthropomorphic systems and multi-fingered dexterous end-effectors.
- Planetary robotic mobility systems and devices; Robots will be needed to work with and transport humans and equipment on a planetary surface. Examples include novel rover drive systems, suspension systems, and manipulator systems.
- Compact low power devices for site setup, operation, and planetary surface exploration. Novel mechanisms are needed to enable human exploration and habitation of planetary bodies. Examples include site clearing and setup devices, equipment deployment devices, sample collection and manipulation devices, and the actuation components for these devices.

Human/Robotic Interface
Proposals that improve operator efficiency via advanced displays, controls and telepresence interfaces, and improve the ability of humans and computers to seamlessly control robotic systems are sought. Specific technology requirements include the following:

- Tactile feedback devices that provide operator awareness of contact between work space objects and the robot structure. Key aspects of this technology are ergonomics and safety.
- Force feedback devices that provide operator awareness of manipulator and payload inertia, gripping force, and forces and moments due to contact with external objects. Key aspects of this technology are ergonomics and safety.

- Stereo graphic display systems that provide high-fidelity depth perception, field of view, and high resolution.
- Tracking position and orientation of user appendages (i.e., head, arms, fingers, eyes) for the purpose of providing motion commands to the robot. Key aspects of this technology are to free the operator of any exoskeletons or devices attached to the body which impede or restrict the operator's movements.
- Innovative miniaturized display hardware for use with Helmet Mounted Display (HMD) systems that project data in a Head Up Display (HUD) format. Emphasis is placed on compact, low mass hardware that can be used with HMD displays and efficiently display data (graphical and alphanumeric) without detracting from the HMD displayed video.

Intelligent autonomous systems

- Artificial intelligence based systems and architectures, with provision for crew oversight.

Robotic EVR Systems

Proposals are solicited for innovative concepts which will increase the functionality and robustness of extravehicular robotic (EVR) systems for science and operations. One example of such a robot is an EVA Robotic Assistant for planetary surface exploration. This robot should be able to follow a geologist, carry his tools and samples, provide video documentation of his activities plus real-time video for remote viewing and be commandable via a combination of gesture/voice by the geologist. Innovative concepts in machine vision, as well as in other non-vision forms of sensing and perception, which can provide the necessary input for the robotic system to function under a wide variety of operating conditions are required. Some specific technology needs to enable this EVA Robotic Assistant are:

- Small, low power machine vision systems for tracking a moving, articulated object, such as a geologist exploring a planetary surface on foot. The tracker should not encumber the geologist by requiring him to wear special targets or beacons.
- Aided dead-reckoning and landmark navigation to keep a record, referenced to the terrain, of where the geologist is now and where he has been. Systems which do not require emplacement of external beacons are needed.
- Machine vision techniques for real-time image registration to create mosaics suitable for human viewing are needed. Mosaic construction must take into account camera motion and changes in lighting over extended periods, either several hours of EVA activity or a subsequent return to a previously visited location. This is intended to let the crew back in the habitat see what the geologist sees or to look around as if they were there.

Another example of an EVR is a mobile, remotely controlled video camera platform capable of transmitting video to its operator. For planetary surface exploration this could be a scout intended to locate sites for follow-up EVA. For in-space operations, this could be an AERCam used to provide video views on demand of the exterior of the International Space Station or a future Space Solar Power Satellite to inspect for damage, plan or supervise repair work, etc. Specific technology needs include:

- Supervised and traded control systems which allow for seamless human/robot interaction. The ability to accommodate both planned and unplanned human and autonomous operations within a task is essential.
- Model based landmark navigation to allow a mobile camera platform to find its way around the outside of a large satellite without requiring the addition of expensive external beacons including the ability to update the model of the satellite exterior as it changes.
- Machine vision techniques, including the construction of image mosaics, for detection of unspecified changes in objects being inspected under changing lighting and viewing conditions.
- Virtual reality interfaces that make it practical to operate such a robotic camera platform in close proximity to a large satellite when the operator has the view from the camera platform but no views of the platform.

H5.03 Non-Destructive Evaluation, Health Monitoring and Life Determination of Aerospace Vehicles/Systems
Lead Center: LaRC
Participating Center(s): ARC, JSC

Innovative and commercially viable concepts are being solicited for the development of resilient space qualified non-destructive evaluation (NDE) and health-monitoring technologies for on-orbit inspection and maintenance of aerospace systems. Advancements in integrated multi-functional sensor systems, autonomous inspection approaches, distributed/embedded sensors, roaming inspectors, and shape adaptive sensors are sought. Concepts in computational models for signal processing and data interpretation to establish quantitative characterization and event determination are also of interest. Evaluation sciences include ultrasonics, laser ultrasonics, optics and fiber optics, shearography, video optics and metrology, thermography, electromagnetics, acoustic emission, X-ray, management of digital NDE data, biomimetic, and nano-scale sensing approaches for structural health monitoring.

Technologies may be applied to:

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

Technologies may be used for:

- Characterizing material properties;
- Assessing effects of defects in materials and structures;
- Evaluation of mass-loss in materials;
- Detecting cracks, porosity, foreign material, inclusions, corrosion, disbonds;
- Detecting 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,
- Micro-meteor impact damage assessment,
- Electronic system/wiring integrity assessment;
- 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;
- In situ monitoring and control of materials processing.

Structural applications to be considered for NDE and health monitoring development include a variety of high stress and hostile aero-thermo-chemical service environments projected for complex structural aerospace vehicle systems. There is additional specific interest in autonomous, non-contacting, remote, rapid, and less geometry sensitive technologies that reduce weight and acquisition costs or improve system sensitivity, stability, and operational costs.

TOPIC H6 Human 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 sub-surface knowledge and access -- both remotely and through sampling – ranging down to 1000s of meters, 2) enabling safe and affordable human exploration of other planetary surfaces -- locally but over global distances involving traverses of up to 1000s of kilometers, 3) 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 4) establishing a foundation for profitable commercial development of space applications of these technologies in the mid- to far-term.

H6.01 Crew Training and On-Board Crew Support
Lead Center: JSC
Participating Center(s): MSFC

Dramatic improvements will be needed in crew and ground operations performance and productivity as NASA develops new operational capabilities to support multiple manned missions, and long duration and long distance missions. Robotic, vehicle and support systems will be required to be more robust, autonomous and intelligent, and more maintainable. These capabilities will allow operators to "buy time" by increasing system mean time between failures, predicting when intervention will be needed, managing degraded operations, and using functional redundancy. Advanced capabilities for information and data analysis and presentation, onboard planning, execution and fault management will be needed to assist the crew. Sophisticated training and maintenance support systems and a robust knowledge base will be needed onboard, and will need to be well integrated with increasingly advanced control and maintenance systems. Ground support operations will need to be redesigned to support the increasing autonomy of space systems and onboard crew. There will need to be advanced support for distributed and adjustable command responsibility, and distributed and flexible training. Significantly more productive and intuitive approaches are needed for updating, adapting, testing and certifying advanced distributed operations software and knowledge bases during missions. Specific areas of interest in the areas of crew training, and in flight and ground operations, include:

Crew Training and Maintenance Support Systems

- Flexible training and tutoring systems for mission operations support, including distributed cooperative training, virtual reality training, intelligent computer-based training, and authoring tools.
- Integration of training with advanced control and maintenance systems.
- Tools to collect/capture and tailor design-time information for use in developing training materials.
- Procedures or technology for evaluating effectiveness of innovative training methods.
- Data Management, Data Analysis, and Presentation and Human Interaction.
- Methods for selecting and summarizing vehicle systems and payload data relating to status and events, to support crew and ground awareness, operational decision-making, and management by exception and opportunity rather than by continuous or scheduled monitoring.
- Human interaction methods for collaboration, cooperation and supervision of intelligent semi-autonomous systems.
- Goal-driven collaborative data analysis systems capable of adaptation and learning.
- Simple systems for notification and coordination, including natural language interfaces.
- Immersive environments: real-time environments to enhance a human operator's ability to interact with large quantities of complex data, especially at distant locations.
- Intelligent data analysis techniques: capabilities to interpret, explain, explore, and classify large quantities of heterogeneous data.

Robust Planning, Operations, Fault Detection, and Recovery with Distributed Adjustable Command Responsibility

- Algorithms for network security that will protect networks at the gigabit and terabit throughput with minimal degradation to throughput
- Onboard planning, sequencing, monitoring, and re-planning of activities, including systems and crew activities.
- Flexible management of the actions of subsystems within the larger context of system flight rules and constraints.
- Flexible and robust fault management approaches that use system models, "buy time" for human intervention and maintenance, and learn from human operators during and after the interventions.
- Approaches to distributed and adjustable command responsibilities among systems, crew and ground.
- Model-based continuous estimation of the likelihood of critical events, including human errors, to provide warnings of potential events and their consequences, and to suggest appropriate counter-measures.
- Integration of systems for fault management, maintenance and training.

Operations Knowledge Management and Software Updating.

- Systems and processes for crew and ground operators to quickly and effectively define, update, test and certify operational knowledge and rule bases before and during missions, designed for re-use in autonomous systems and in training.
- Tools for incorporating and using engineering data and specifications (about equipment and its operating modes and failures and about operations procedures) into operations knowledge and model-based autonomous systems.
- Tools and environments to support modification and validation of knowledge bases (models of activities, equipment and environment)in intelligent autonomous software by operators, to capture methods and knowledge used by operators during interventions and to collaboratively adapt to unanticipated circumstances.
- Simulation environments and tools for use in designing and testing intelligent semi-autonomous systems.

H6.02 Distributed/International Ground Operations
Lead Center: JSC
Participating Center(s): MSFC

As the operations for the International Space Station evolves and the International partners become more integrated into the Operations of the ISS, new methods of information sharing and team interactions will be required. The current virtual team tools will not be sufficient to support the distributed international operations team interaction. Operations will also evolve in the ISS to allow the expertise of the Flight Controller to be distributed outside of the facility in order to reduce the need for constant monitoring in the Mission Control Center. Additionally, new methods for distributed functionality of the Mission Control Center in the event of an emergency are needed. Specific areas of interest in the areas of distributed/international operations include:

Distributed Architecture

- The capability to command and control and access an orbiting vehicle telemetry from a single computer
- The capability to remotely synchronize storage and central servers miles away and to switch operations to the distant servers without any loss of data

Distributed Operations

- The capability for a distributed immersive virtual environment where 3D models could be manipulated at any location and would result in the model being manipulated at all locations (e.g. rotated) and any annotations or pointing to a segment of the virtual model would be displayed at all locations.

- The capability for a virtual meeting presence, where instead of a video teleconference, you are able to have the other meeting attendees sitting around a table as if they are at that location, but are actually remotely located. (e.g. across the table would be a 3 dimensional image of the other meeting participant reacting and interacting as if they were in the same room)
- Wireless access to voice, video and data in a hand held device
- International communication tools that would allow real time translation of spoken word from one language to another.

TOPIC H7 Space Transportation

The goal of the HEDS Space Transportation topic is to identify and develop specific new space transportation technologies that can significantly increase the safety and reliability of ambitious future human exploration missions and campaigns beyond Earth orbit, while dramatically reducing the transportation-related cost of human exploration initial missions and sustained campaigns. This includes both systems and infrastructures associated with Earth-to-orbit transportation, in-space transport, and excursions from space to and from targets in space (including the Moon, Mars and asteroids). The objectives under this topic include 1) developing and demonstrating selected, highly innovative technologies needed to assure that future human exploration space transportation systems and infrastructures are safe and "robustly" reliable, 2) developing and validating technologies for the affordable transportation to - and from - targets in space beyond low Earth orbit, 3) enabling reliable and affordable transportation to all points of interest globally on the Moon or Mars, 4) establishing a foundation for profitable commercial development of space applications of these technologies in the mid- to far-term, 5) revolutionary propulsion systems and advanced space transfer technologies with application to mid- and far-term space exploration missions. Propulsion technologies that push the state-of-the-art in electric, electromagnetic, thermal and chemical systems, and 6) fission propulsion systems technologies that enable rapid and affordable in-space transportation, potentially leading to ambitious exploration of the solar system and beyond.

H7.01 High Power Electric Propulsion For Human Missions
Lead Center: GRC
Participating Center(s): JSC, MSFC

High-power (> 100 kW) electric propulsion technologies are a critical component of orbit transfer and planetary insertion in the HEDS missions. High-power electric propulsion can reduce propellant mass requirements (compared to all-chemical propulsion) to the extent that it allows a reduction in launch vehicle class or an increase in payload. In either case, the mass savings result in significant cost savings for HEDS missions. For interplanetary missions, high-power electric propulsion will provide quicker trips times (depending on available power) than all-chemical propulsion since its high specific impulse (Isp) allows for direct transit to planetary bodies.

Innovations in high-power electric propulsion technology are sought that will increase high-power electric thruster efficiency, increase thruster life, reduce total system mass, reduce system complexity, and reduce trip time. Thruster parameters of interest include power levels of 100-kW to several megawatts; Isp values of 2000 s for earth-orbit transfers to over 5000 s for planetary missions; thruster efficiencies in excess of 50%; and system lifetimes commensurate with mission requirements (typically 10,000 hours of operation). Proposals that seek to investigate and resolve, either theoretically or experimentally, the fundamental lifetime and performance limiting mechanisms of high-power electric thrusters are of particular interest.

Several propulsion devices are being considered for high-power HEDS missions including Hall, Ion, magnetoplasmadynamic (MPD) thrusters, pulsed inductive thrusters (PIT), and VASMIR. The specific technology challenges for high-power propulsion devices include:

Hall and Ion

- Scaled up in power (100 kW class)
- Use of alternate propellants such as krypton or argon

- Maintain high efficiency of today's lower power systems (>55 to 70% efficient)
- Long lifetimes (>10,000 hours)

MPD

- Long lifetime components >10,000 hours
- Improved efficiency (>60%)
- Simpler, higher efficient, continuous (not pulsed) power processing systems (>90%)
- Lighter thermal control (most of the inefficiency results in waste heat not removed by the exhaust, e.g. almost 400 kW of heat must be removed for a 1 MW MPD) (<2 kg/kWt)

Pulsed Inductive Thrusters

- High efficiency >60%
- Simple, efficient and light pulsed power processing systems (>90%, <1 kg/kW)

VASMIR

- High efficiency stages and processes (total efficiency >60%)
- Light components including superconducting magnets
- Advanced, long-term fuel storage (e.g. hydrogen and helium) [years on-orbit, <20% tankage]

Specific Impulse Throttling

- Techniques to allow for throttling of Isp at constant power (~2500 sec to 10,000 sec)
- Other innovative propulsion concepts providing the above Isp's, >60% efficiency, at power levels from 100 kW to multi-megawats

Support Systems

- Light, inexpensive, throttleable propellant feed systems for various fuels
- Radiation-resistant components to resist cosmic and power system radiation
- Safety and redundant systems to ensure crew member safety and mission success
- Gimbaling systems: (2DOF >+/- 20°)

H7.02 Unmanned Autonomous Rendezvous Systems
Lead Center: MSFC

In support of future unmanned missions in Earth orbit, the need for an autonomous rendezvous and docking system has been identified as a critical enabling technology.

This subtopic addresses hardware and software technologies necessary to develop a robust autonomous guidance, navigation, and control (GN&C) capability to allow an unmanned autonomous rendezvous and docking of two vehicles in Earth orbit. This subtopic also addresses the technologies necessary to perform precision station keeping for capture and/or inspection of one vehicle by another vehicle. The primary objective is a low cost and highly robust system. The mission begins at launch vehicle main engine cutoff and includes autonomous orbit transfer, rendezvous, on-board mission planning and replanning, autonomous proximity operations and docking/capture.

Because of the absence of humans, the rendezvous and docking capability must be low risk with high robustness, ensuring a very high level of mission success. The proposed system should be modular and adaptable to wide range of missions and vehicles.

Specific innovations are sought to solve the following technology challenges:

- Spacecraft self determination of orbits. Innovative concepts may include ground tracking methodologies, land based or orbiting navigation and communication aids.
- Low Earth orbit, geostationary Earth orbit, and highly elliptical orbit rendezvous.

- Autonomous on-board mission planning and replanning algorithms and methodologies. Algorithms should include constraints inputs and optimization variability for mission time and propellant use.
- Relative navigation methods and sensors. A minimum relative navigation sensor suite addressing spacecraft-to-spacecraft ranges of 100 kilometers through docking, including relative attitude control during the final 100 meters of the approach.
- Light weight, low cost docking mechanisms which may include data, power, and fluid transfer capability.

Alternative strategies and supporting technologies are additionally sought.

H7.03 Propulsion Systems Ground Test Operations
Lead Center: SSC

Proposals are solicited for innovative technologies applicable to ground testing of rocket engines. The goal is to reduce overall propulsion test operations costs (recurring costs) and/or increase reliability and performance of ground test facilities.

Specific areas of required technology innovation include the following:

- Improved cryogenic high-pressure/high-flow rate instrumentation. Temperature sensors that are exposed to the high pressure (up to 12,000 psi) and high flow rates (up to 2000 lb/sec, 333 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 sub-millisecond response times that can withstand the aforementioned rocket engine testing environment.
- Improved low-cost cryogenic insulation. A requirement exists for more durable insulation materials for cryogenic (liquid oxygen and liquid hydrogen) tanks, pipes, and valves. This insulation must be resistant to deterioration in an environment of intense sunlight, high humidity, and frequent, heavy rainfall. It must also be resistant to detachment during thermal contraction and expansion cycles of the insulated components.
- 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. Statistic analysis must be supported.
- Model-based and knowledge-based methods to capture features from one dimensional sensor signals. The features of interest should help identify behaviors indicative of operating conditions (health) of sensors and the processes they monitor.
- Improved cryogenic propellant conditioning methods. New propulsion systems using cryogenic fueled rocket engines are designed with advanced propellant requirements, which includes propellant densification through sub-cooling. Improved methods are sought to meet these cryogenic propellant conditioning requirements for production and storage of densified propellants, such as sub cooled and slush hydrogen.
- 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. Reduced interference with aircraft flying overhead is a desirable feature.

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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 nine years to five 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 four years. Our technology program encompasses three primary goals. First, we develop new and better technical approaches and capabilities. Then we validate these 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/strategy/2000/

TOPIC S1 Sun Earth Connection

The goal of the Sun-Earth Connection (SEC) Theme in the Space Science Enterprise is an understanding of the changing Sun and its effects on the Solar System, life, and society. SEC's strategy for understanding this interactive system is organized around four fundamental Quests, designed to answer the following questions: 1) Why Does the Sun Vary? 2) How Do the Planets Respond to Solar Variations? 3) How Do the Sun and Galaxy Interact? 4) How Does Solar Variability Affect Life and Society? SEC's challenging science program involves: 1) seeking breakthroughs in understanding by making measurements from new vantage points within and outside the Solar System; 2) making simultaneous, system-wide measurements with constellations of spacecraft that resolve existing space-time ambiguities; 3) applying new scientific knowledge strategically to produce direct and immediate benefits to our increasingly space-dependent society.

S1.01 Particles and Fields Measurements for Missions to the Heliosphere, Planetary Magnetospheres and Upper Atmospheres
Lead Center: GSFC
Participating Center(s): JPL

The Sun-Earth-Connections theme studies 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/ionosphere systems. Remote sensing of photons and neutral atoms are required for the physics and chemistry of the Sun, the heliosphere, magnetospheres, and planetary atmospheres and ionospheres. Since 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:

Photon Remote Sensing (Radar to Infra-red through x-ray and gamma-ray wavelengths)

- Advanced light weight diffraction limited mirrors.
- Advanced optical spectrograph components.
- Advanced detectors for visible through X-ray wavelengths.
- Improved techniques for spectrometric imaging of IR emissions from planetary atmospheres and ionospheres, such as large array (8 Megapixel) CCD cameras (0.35^{-2} micron), holographically enhanced Fabry-Perot interferometers, and tunable IR lasers (2^{-5} micron) based on, e.g., quantum cascades.
- Improved techniques for spectrometric imaging of visible and UV emissions from regions of energetic plasma phenomena interacting with atmospheric gases, such as aurora and day-glow cameras.
- Improved techniques for spectrometric imaging of X/Gamma-ray emissions from planetary and cometary atmospheres and ionospheres, such as solid state photomultiplier devices for use in combination with scintillation detectors.

Plasma Remote Sensing (e.g., neutral atom cameras)

- Advanced neutral atom imagers for energies from a few eV to 100 keV to remotely sense ion populations in the heliosphere and in the magnetospheres of the planets. 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.

In situ Plasma Sensors

- Improved techniques for imaging of charged particle (electrons and ions) velocity distributions.
- Improved techniques for the regulation of spacecraft floating potential near the local plasma potential, with minimal impacts on the ambient plasma and field environment.

- Low power digital time-of-flight analyzer chips and waveform generators with sub-nanosecond resolution and multiple channels of parallel processing.
- Miniaturized, radiation-tolerant, autonomous electronic systems for the above.

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.

Electromagnetic Radiation Sensors

- Radar sounding and echo imaging of plasma density and field structures from orbiting spacecraft.

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

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/ascent. Innovations are needed to reduce spacecraft propulsion system mass, volume, and/or cost. Applicable propulsion technologies include nuclear and solar electric propulsion, low-thrust chemical rockets, and solar sails.

Nuclear and 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 6000 seconds, while utilizing 50 to 100 kilowatts or more of electrical power from a nuclear energy source. Another area applies to propulsion technologies capable of delivering Isp greater than 3500 seconds, using electrical power from radioisotope or solar energy sources. Thruster technologies include, but are not limited to, ion engines, Hall thrusters, Magnetoplasmadynamic (MPD) thrusters and pulsed electromagnetic devices. Other subsystems of interest include the power source, propellant storage and feed, 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. They are enabling for several strategic missions in the Sun-Earth Connection (SEC) 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 (ESS) 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. 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 areal 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 leviated orbits, high delta V, and for use in leaving solar system at high speed). Closest solar approaches may range from 1 AU down to 0.1 AU. Areal densities for a solar sail subsystem (excluding payload) may range from 1 to 15 g/m^2.

Low Thrust Chemical Propulsion Systems
Innovations in low thrust chemical propulsion system technologies are being sought for space science applications. Technologies of interest include, but are not restricted to, bipropellant engines with Isp greater than 360 seconds. Another area includes lightweight, compact and low-power propellant management components, such as valves, flow control/regulation, fluid isolation, and lightweight tankage. Innovations considered here may focus on the component, subsystem or system level, and must ultimately result in significant reductions in spacecraft system mass, volume and/or cost.

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

NASA seeks innovative concepts for multifunctional or integrated structure and sensor/electronic systems to reduce spacecraft size and mass, and to enable lower-cost and more capable aerospace vehicles, instruments and structures. A multifunctional system combines several functions, which are usually performed by separate subsystems, into a single highly integrated system. Additionally, multifunctional systems would enable more effective health monitoring where, in this case, "health monitoring" refers to the state of the spacecraft, subsystem or structure. To achieve this will require revolutionary advances over the capabilities of traditional spacecraft systems. Microspacecraft systems (as small as 10 kg, using 10 W, or less) of all varieties will enable new missions that are currently impractical. These systems will include, but are not limited to, orbiters, landers, atmospheric probes, rovers, penetrators, aerobots (balloons), planetary aircraft, subsurface vehicles (ice/soil), and submarines. Also of interest are distributed sensor systems integral with structural elements for the monitoring of the state of those elements or for the construction of new classes of scientific instruments based upon the unique features of the integrated system. New technologies are needed in the areas of integration and packaging of MEMS sensors and actuators integral with advanced lightweight materials for structure and propulsion or thermal control.

Potential mission applications for the technology products developed in this area include micro/nano-spacecraft, thin-film gossamer spacecraft, adaptive large-aperture telescopes, antennas, and airframes. High-priority technology development needs include the following:

- Techniques for the structural integration of low-volume electronics packaging such as chip-on-structure, chip-on-flex (flexible substrate), and imbedded electronics.
- Concepts for integrating electronics, MEMS, power distribution, energy storage, thermal management, and radiation shielding with ultra-lightweight composite structures.
- Multifunctional membranes that incorporate thin-film electronics and MEMS sensors, photovoltaic cells, or electrochromic materials.
- Adaptive and reconfigurable structures that can respond reactively to environmental stimuli for self-repair of damage.
- Avionics, including highly integrated "systems-on-a-chip" technologies that integrate areas such as telecommunications, power management, data processing and storage, on-chip energy storage, on-chip magnetics or data sensors with structure and/or actuators.
- Micro-Electro-Mechanical Systems (MEMS) including: microactuation, navigation sensors, health-monitor sensor systems, low power and low-mass on-chip communication systems, and micro fluid storage and control systems.
- Thermal management, including active and passive techniques.

- Integration of functions such as engineering sensors and science instruments, structure, thermal, cabling, propulsion, etc.
- Technology for integrating three-dimensional VLSI, chip stacking, multi-chip-module stacking and other advanced packaging techniques with stuctural elements.
- Concepts and designs for test and validation of design integrity and performance of IP based ASICs, mixed signal ASICs and MEMS.

S1.04 Spacecraft Technology for Micro/Nanosats
Lead Center: GSFC
Participating Center(s): JPL

NASA seeks research & 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/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, cost), list the assumptions for 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/output, formatting, encoding, processing, storage, and A to D 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/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 two-hour 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.
- Systems 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/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 Spacecraft and Space Environment Interaction
Lead Center: MSFC
Participating Center(s): GSFC, JPL

This subtopic is concerned with the effect on spacecraft systems and materials by the ionizing radiation, electromagnetic fields, plasma and thermosphere, and thermal and solar components of the environment. Innovative systems and components are sought that are compatible with the harsh environment of space, or that mitigate its effects. Materials sought include advanced in thermal control coatings, multi-layer insulation materials, polymeric films, optical materials, seals, marker/astronaut visual aid coatings, and radiation shielding.

New processing and application techniques are sought that reduce the cost or increase the performance reliability of current space-qualified materials and coatings, as are low cost, lightweight materials and protective coatings that mitigate environmental effects.

Specific areas for which proposals are sought include:

- Cost-effective methods for improving radiation tolerance of microelectronics, reducing single-event upsets, and eliminating latch-ups.
- Cost-effective shielding and other mitigation of radiation effects.
- Techniques for electrically grounding spacecraft to mitigate spacecraft charging.
- Techniques for controlling spacecraft potentials actively or passively.
- Other methods to mitigate harmful effects of space plasma and spacecraft charging.
- Preventing or mitigating the effects of space plasma electrical discharges on solar arrays and surfaces.
- Stable, electrically conductive but thermally advantageous coatings for spacecraft surfaces.
- Electrically insulating materials with the capability of "bleeding off" buried charge.
- Flexible materials capable of withstanding ultraviolet and particulate radiation without embrittlement
- Development of mitigation design guidelines for ultraviolet radiation for missions closer than 1 AU to the sun.
- Study of synergisms between the natural and induced environments around an active space station.
- Advanced materials for fasteners, including thread, hook-and-loop fasteners, structural adhesives with minimal outgassing characteristics, and EVA tethers.
- Cost-effective methods for ground-based simulation of the environment.

S1.06 UV and EUV Optics and Detectors
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)

Detectors

- Large format (4K x 4K 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)

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 chemicals elements where 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
Participating Center(s): GSFC

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 will allow the Filled Aperture Infrared instrument (FAIR) to extend HST observations into the mid and far infrared (40-500 µm) region; the

MicroArcsecond 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 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/Submillimeter
Future space-based observatories in the 10 to 40 micron spectral regime will be passively cooled to about 30K. 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 superconductng electronics are applicable areas. Future space observatories in the 40 micron to 1 mm spectral regime will be cooled to even lower temperatures, presumably < 10K, 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 operating in the same frequency range near the quantum limit are desirable.

X-ray/Gamma-ray
Large format gas micro-structure detectors for use with "lobster eye" X-ray optics are needed. Desirable characteristics include any of the following: low energy band-pass (0.25 - 4 keV), large area (> 10 cm), good spatial resolution (< 300 microns), integrated read-out (e.g. micro-structure detector manufactured on or bonded to two dimensional thin film transistor arrays). Also of interest are detectors that can be extended to 3-dimensions and large volumes (meter scale) for gamma-ray tracking. Applications for detectors are expected in low rate environments, making background suppression important. For soft X-ray detectors, the capability of distinguishing X-ray interactions from particle tracks is essential, while for gamma-ray applications the ability to reconstruct events via track recognition is required.

Space 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 to serve as primary receiving instruments.

Mm/Submm Heterodyne Receivers, Antennas, Arrays
Proposals for this wavelength of sensor and detector technology are requested under subtopic E1.06 for the Earth Science Enterprise. If the application envisioned is primarily for astrophysics it may be proposed under this subtopic.

S2.02 Terrestrial and Extra-Terrestrial Balloons and Aerobots
Lead Center: GSFC
Participating Center(s): JPL

Innovations in materials, structures, and systems concepts have enabled buoyant vehicles to play an expanding role in NASA's 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. Balloons 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 extra-terrestrial balloons and aerobots in the following areas:

Materials

- Membranes for terrestrial applications having strengths in excess of 7600 N/m and areal densities less than 40 g/m^2. Also desired are films, fibers, and innovative construction techniques that would lead to composite membranes achieving these strength and density goals. Additional material design considerations include resistance to UV degradation, operating temperatures between 180K and 300K, resistance to fracture and creep, low helium permeability, low absorptivity to emmisivity ratio, and high toughness along with good handling, folding, and seaming characteristics. Material must be producible in a lay flat width of at least 1.53 meters.
- Membranes for extra terrestrial applications having yield strengths in excess of 150-200 MPa and areal densities less than 10-12 g/m^2. Also desired are films, fibers, and innovative construction techniques that would lead to composite membranes achieving these strength and density goals. For planetary applications, operating temperatures of the membranes are 70-90K (Titan), 140-300K (Mars) and 250-750k (Venus). Cold brittleness point of the membranes should be below the operating temperature range.

Support Systems

- Trajectory control techniques for maneuvering terrestrial and extra-terrestrial aerobots both horizontally and vertically.
- Low weight power systems for terrestrial balloons that produce 2 kW or more continuously.
- Power systems that enable long duration, polar night missions.
- Innovative, low cost, low power, low weight, precision pointing systems that permit arcsecond or better accuracy.

Design and Fabrication

- Efficient and cost-effective balloon envelope seaming, fabrication, and inspection techniques that lower costs and increase quality.
- Innovative balloon design concepts that reduce material strength requirements, increase reliability, enhance performance, or improve mission flexibility.

Deployment and inflation of planetary balloons

- Low weight systems for controlled deployment of balloons during atmospheric descent with mitigation of deployment shocks for Mars applications
- Low-weight high pressure tanks for gas storage
- Automatic inflation and launch from the planetary surface

S2.03 Multiple Coordinated Observatories
Lead Center: GSFC
Participating Center(s): JPL

A revolution is taking place in the way we conduct a range of space science missions. Specifically, the next decade will bring over 20 missions which involve formations of coordinated, observing platforms, or virtual platforms (VPs) in order to enable very long baseline imaging systems, high resolution interferometric imaging of extended scenes, time-synchronous observation of phenomena in space, and complex communications networks to name a few. These distributed systems will operate under virtual infrastructures capable of responding to changing needs and conditions while evolving over time to introduce new capabilities. Representative mission scenarios include maintaining a specified satellite formation geometry at key points in the trajectory, maintaining the relative motion among co-orbiting spacecraft throughout the orbit, or maintaining relative positioning and attitude for targeting starts and other points distant in this or other solar system. Some of the more challenging scenarios involve the measurement of gravity waves and the imaging of black holes. These missions have relative measurement and/or control requirements on the order of nano- or even picometers, sometimes at tens, thousands, and even millions of kilometers apart.

Frequently, these requirements go beyond the capability of current technology in the ability to sense and control position and orientation. Additionally, distributed spacecraft concepts of collective pointing and phasing of a number of observing systems relative to a target of interest or coordinated pointing (pointing the formation to collect related data from different selected angles) are critical to many of these mission scenarios. In addition to the dynamic behavior of each individual spacecraft, the collective behavior of all the spacecraft in the formation will determine the quality and the magnitude of the science return.

The requirements for coordinating these platforms have necessitated a major change in how we analyze, design, operate, and maintain space-based observatories. In particular, in many cases, several of the spacecraft bus components, which were at one time virtually decoupled from the payload or science sensor, are now fully integrated and fully coupled together operationally. This is the case for a wide range of interferometry missions where the interferometric measurements, which provide the primary science product, are the only measurements available at the precision required to maintain the spacecraft formation. This concept, fitting largely into a category of "real-scene wavefront sensing," is the primary technology focus for this call.

In this subtopic we invite proposals consistent with the end-to-end problem of distributed space systems, from an integrated scientific and engineering standpoint. The problem will divided into six key functional areas. Of particular interest will be proposals that cover several of the areas in an integrated fashion. Necessarily the proposal must cover problems that are unique to multiple spacecraft missions. The areas include:

Formation Sensing and Control
This area covers the sensing systems, actuation systems, and associated algorithms required to maintain and/or understand vehicle position or orientation in absolute or relative sense, but unique to distributed space systems. Also included are the analytical and design techniques for understanding the dynamic behavior of the DSS. Lastly, this includes integration between the science collection and the maintenance of a virtual aperture as in real-scene wavefront error sensing and control and phase diversity techniques as well as the use of optical path delay lines in the end-to-end problem of maintaining the synthetic aperture.

Constellation Management and Mission Operations
The management of distributed space systems including constellation-wide status and control to enable affordable operation of the constellation in a unified and coordinated fashion. This includes telemetry, tracking and command & control (TT&C), health and safety management, mission planning, scheduling and execution, resource management, flight dynamic product generation and analysis, high-level fleet configuration and safekeeping employing increasing levels of automation and possibly autonomy cost effectively. This area also includes collaborative multi-spacecraft science data collection, storage, and downlink; automated data management and data delivery.

Intersatellite Communications
Hardware, software, and advanced coding and compression algorithms, are developed to address the unique communication needs of distributed multi-spacecraft systems. Prototypes of RF and optical communications and coarse (cm level) ranging hardware are developed to support distributed systems. This area would include the spectrum management and allocation, and will provide the physical layer connectivity among the spacecraft. Also encompasses communications infrastructure around the Earth-Sun L2 Lagrange point.

Data Processing, Fusion, and Analysis
The DPFA thrust emphasizes the data operations aspects of the DSS end-to-end system in fulfilling the scientific objectives of DSS missions. Data operations include data handling, processing, analysis and management. Automated science data analysis capabilities, including event recognition and feature detection, are required to increase knowledge extraction and enable automated response/action for opportunistic science. Rapid tasking of instrumentation or other sciencecraft can enable more dynamic science data measurements/observations. Advanced capabilities will be developed to increase interaction between modeling/forecasting systems and science instruments. For example, noteworthy science features or events can autonomously trigger additional desired science measurements or observations. This area covers:

- Information-based system engineering of the mission hardware and software components
- Evaluation of the methodologies and techniques to produce the final science products from the science and engineering data acquired by the science instruments and sensors
- Examination of the efficiency of data and information flow in the processing, fusion and analysis of science and engineering data

Miniaturized Spacecraft Technology
Approaches to reducing spacecraft bus infrastructure requirements in the areas of cost, mass, volume, and power. Low-power, radiation tolerant electronics and systems are developed to satisfy the stringent constraints of packaging and power for tightly integrated miniature spacecraft architectures. Examples include MEMS thermal control, integrated power systems, RF or optical communications and ranging, attitude sensing, multifunctional structures, and propulsion functions are developed.

Mission Synthesis, Design, and Validation
This area represents the end-to-end view of the DSS as a whole (pre-, during, and post- mission), including the analytical tools, hardware and software testbeds, systems engineering concepts and tools, advanced simulation techniques including improved methods for stochastic integration and high precision requirements, interface control for integrating components together, as well as special processing requirements and protocols. Lastly, this area includes methods for modeling and simulating distributed systems, including associated mission and observation planning tools based on observed data, and scientific validation and verification.

Most importantly, proposals in this area should show clear application to the fundamental goals of the SEU theme or to the SEU roadmap DSS missions. These include the Laser Interferometer Space Antenna (LISA), the Micro-Arcsecond X-ray Imaging Mission (MAXIM), MAXIM pathfinder, Constellation-X, Orbiting Wide-angle Light Collectors (OWL), and any future concept or reference missions which bring out the technologies that enable these "Cosmic Journey" missions.

S2.04 Thermal Control and Management
Lead Center: GSFC
Participating Center(s): ARC, JPL, MSFC

Future spacecraft and instruments for NASA's Space Science Enterprise will require increasingly sophisticated thermal control technology to meet the demands of tight control with minimal mass and power resources. Cryogenic optics, instrumentation, and structures (down to a few Kelvin) and large-scale spacecraft/instruments are clearly an emerging trend. These require ever more sophisticated cooling techniques for stringent optical alignment and thermal noise abatement purposes. Tight temperature control (too less than +/- 1 0C), high heat flux levels from lasers, and integration of instrument and spacecraft subsystems are emerging trends. Large, distributed structures such as mirrors will require creative techniques to integrate structural, mechanical alignment, and thermal control functions in very light weight structures. In general, high performance, low cost, low weight, and high reliability are prime technology drivers. Technologies incorporating self-diagnostic and repair techniques would be very useful. Specific areas for which innovative proposals are sought include:

- Advanced thermal control coatings such as variable emissive surfaces that permit adaptive intelligent control.
- Cryogenic (3 K to 40 K) heat transport devices for sensor and /or optics cooling which incorporate a diode function.
- Integrated structural, alignment, and thermal control concepts for very large structures.
- Advanced analytical techniques for thermal modeling, focusing on techniques that can be easily integrated with emerging mechanical and optical analytical tools.
- Advanced high conductivity materials, such as diamond films, which may be suitable for cryogenic applications.

S2.05 Optical Technologies
Lead Center: GSFC
Participating Center(s): JPL, MSFC

The NASA Space Science Enterprise is studying future missions to explore the Structure and Evolution of the Universe (SEU), which will require very large space observatories. In order to understand the structure and evolution of the universe, a variety of 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 (30K) and at a substantial distance from the Earth. Apertures for normal incidence telescope optics are required in the range of 20 - 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 will have effective apertures in the 100 - 1000 m diameter range. Low mass of critical components such as the primary mirror and support and/or deployment structure is extremely important. It is also essential to develop actuators, deformable mirrors and other components for operation in a cryogenic environment. 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 bandwidth. The following technologies are sought:

- Large, ultra-lightweight optical mirrors including membrane optics for very large aperture space telescopes and interferometers
- Large, ultra-lightweight grazing incidence optics for x-ray mirrors with angular resolutions less than 5 arcsec.
- 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; image stabilization systems
- Advanced, wavefront sensing and control systems including image based wavefront sensors
- Shape measurement and control of large aperture membrane optics.
- Wavefront correction techniques and optics for large aperture membrane mirrors and refractors (curved lenses, fresnel lenses, diffractive lenses).
- Cryogenic optics, structures, and mechanisms for space telescopes and interferometers
- Nanometer and picometer metrology for space telescopes and interferometers
- High-precision pointing and attitude control systems for large space telescopes and interferometers
- Space-fabricated optics and techniques including fabrication from raw materials or blanks, coatings, assembly of components, metrology, and system testing.
- High-performance materials and fabrication processes for ultra-lightweight, high performance optics.
- 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, and structural performance of large space telescopes and interferometers.
- Advanced, low-cost, high quality large optics fabrication processes and test methods including active metrology feedback systems during fabrication, and artificial intelligence controlled systems.
- Technologies for testing new mirror materials and shapes in relevant environments including cryogenic testing.
- New coatings and methods for applying them.
- Long path length measurement techniques.
- Innovative solutions to detect and correct errors in deployed optical systems.
- Deployable optical benches to achieve reference baseline dimensions greater than those of the payload envelope.
- High resolution (2 nm) long stroke (6mm) cryogenic actuators.
- Wide field of view optics using square pore slumped micro-channel plates or equivalent

- Coded masks for 5 mm x 5 mm x 5 mm pixels of high-Z passive metal (Pb or W) and ~4 m^2 area.
- Grazing incidence focusing mirrors with response up to 150 keV
- 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).

Novel optical materials, specialized optical fabrication techniques, and new optical metrology instruments and components for Earth- and space-based applications are needed, as follows:

- 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 silicon carbide optics and structures are also desired.
- Develop optics for focusing EUV and x-ray radiation, where reductions in fabrication time and cost are sought. Developments are also needed in the areas of surface roughness and figure characterization of EUV and curved x-ray optics, especially Wolter systems.
- Develop novel materials and fabrication techniques for producing cryogenic optics. Testing techniques, including both full- and sub-aperture testing, for cryogenic optics are needed. Also desired are techniques for testing the durability of and stress in coatings used in harsh environments, particularly cryogenic optics.
- Develop novel techniques for producing and measuring coatings and polarization control elements. Optical coatings for use in the EUV, UV, visible, IR and far IR for filters, beamsplitters, polarizers, and reflectors will be considered. Broadband polarizing- and non-polarizing cube-type beamsplitters are also needed.
- Perform development related to fabrication of x-ray, gamma-ray, and neutron collimators that have the precision necessary to achieve arcsecond or sub-arcsecond imaging in solar physics and astrophysics when used in stationary multi-grid arrays or as rotating modulation.
- Develop portable and miniaturized state-of-the-art optical characterization instrumentation and rapid, large-area surface-roughness characterization techniques are needed. Also, 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 optic from the polishing machine. Techniques for testing the figure of large, convex aspheric surfaces to fractional wave tolerances in the visible are needed.
- Develop efficient, analytical, optical modeling and analysis programs capable of determining the ground-based and space-based performance of complex aberrated optical telescopes and instrument systems will be considered. Also, simple, well documented, flexible programs which generate commands to operate a numerically controlled polishing machine, given the tool wear profile and surface error map are desired.
- Develop very low scattered light optical material thin film mirror coatings or mirrors for broad-band white light applications to planet detection space telescopes.
- Develop a novel material for producing doubly curved, ultra-thin, unsupported shell optical quality telescope mirrors which are capable of being rolled for storage and transport. These mirrors will exceed one meter in diameter, have an areal density of < 1.5 kg/m^2, and have sufficient "memory" to enable it to return to its original configuration when unfurled. Fine adjustment will be achieved using actuator material embedded within the shell mirror or with a two-stage optics system or both. The reflective surface would not be damaged when the mirror is rolled. This material must tolerate the space environment without dimensional changes, stiffness changes, or loss of mechanical integrity.

S2.06 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/millions of resultant spatial resolution elements.

Innovative technologies are sought to enhance the scope, efficiency and resolution of instrument systems at all energies/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 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 super-conducting 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 keV to 10 keV,
    - 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 en-

ergy). 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 to 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.

TOPIC S3 Astronomical Search for Origins

NASA's Origin's Program seeks the answers to two broad questions related to life on earth as we know it. How we got here and are we alone? The answers lie in an understanding of how galaxies, stars, and planetary systems formed in the early universe. We must determine whether planetary systems and earth like planets are typical companions of average stars and if life beyond earth is a rare, possibly nonexistent, occurrence or if it is robust and has spread throughout the galaxy. Origin's primary mission goals are to study the early universe, find planets around other stars, and search for life beyond Earth.

S3.01 Ultralight Adaptive Large Telescope Systems
Lead Center: MSFC
Participating Center(s): GSFC, JPL

The long-range goal of the Astronomical Search for Origins and Planetary Systems (ASO) theme in the Space Science Enterprise is to detect, characterize, and ultimately image extra-solar planets in orbit around nearby stars. Results from these efforts may provide clues as to the existence of life on these planets and the nature of life within our own solar system. The level of image resolution needed to accomplish these observations requires the development of telescopes with light gathering apertures that are many times the size of NASA's planned 8-meter Next Generation Space Telescope (NGST). Such large aperture requirements have recently stimulated the development of new and unconventional telescope design concepts; ranging from single light collection stations employing a myriad of distributed reflective mirrors to constellations of large telescopes flying in formation and operating as interferometers.

In addition to a large aggregate aperture requirement, these new observatories must maintain a low areal density (including the optics, reaction structure, actuators, and wiring). 100 kg/m^2 is typical for conventional telescopes, and NGST is striving to achieve between 10 and 15 kg/m^2. However, for ASO missions and other future telescope programs, areal densities of ~1 kg/m^2 or less are required to enable affordable and launchable system architectures. Other system design considerations include; the ability to deploy components from a stowed launch configuration to a final on-orbit configuration without degrading the system's optical quality, the need for precise structural and system control mechanisms used to maintain diffraction-limited imaging capabilities, and the ability to successfully endure and perform within the harsh space environment.

Specifically, this subtopic is soliciting concepts and enabling technologies for large space-based telescope systems designed to accomplish either near-term objectives (i.e., ~10m apertures and 1-10kg/m^2 areal densities) and/or far-term objectives (i.e., 20-40m
apertures and <1kg/m^2 areal densities). Specific areas of interest include:

- Novel concepts for space telescope system design and implementation.
- Active/adaptive wavefront sensing and control at ambient and cryogenic temperatures.
- Large lightweight cryogenic optical materials.
- Large transmissive optics and optical materials.
- Large reflective optics and optical materials.
- Low cost, in situ metrology techniques for space-deployed optics.
- Low areal density precision structures.
- Pliable structures with shape memory.
- Low weight, low cost actuators for optical surfaces.

- Deformable, controllable optics.
- Membrane mirrors
- Non-contacting shape control actuation for membrane mirrors
- Integral membrane mirror and shape control actuation subsystem
- Membrane mirror packaging and deployment
- Large aperture telescope structures, materials, and deployment

S3.02 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 one 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 to 3 orders of magnitudes improvement on top of the S/C control requirements. The spacecraft also require onboard capability for optimal path planning, and time optimal maneuver design and execution.

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

- Integrated optical/formation/control simulation tools.
- Distributed, multi-timing, high fidelity simulations.
- Formation modeling techniques.
- Precision guidance and control architectures and design methodologies.
- Centralized/decentralized formation estimation.
- Distributed sensor fusion.
- RF/optical precision metrology systems.
- Formation sensors.
- Precision micro-thrusters/actuators.
- Autonomous re-configurable formation techniques.
- Optimal, synchronized, maneuver design methodologies.
- Collision avoidance mechanisms.
- Formation management and station keeping.
- Six degrees of freedom precision formation testbeds.

S3.03 Astronomical Instrumentation
Lead Center: JPL
Participating Center(s): ARC

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. However, the performance and observing efficiency of these instruments 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 near-infrared to past 100 microns. Measurement techniques include imaging, photometry, spectroscopy, coronography, and polarimetry. Of particular interest are:

Advanced Detectors
These efforts should propose breakthrough capabilities in spectral coverage, large array size with uniform high quantum efficiency, ultra-low dark current, elevated operating temperatures, spectroscopic capabilities, or their ability to operate effectively and reproducibly over long periods (ex. 5-10 years of space observations at low power, extreme temperatures, etc.).

Cryogenic Readout Electronics
Proposed space observatory sizes require driving analog detector signals over ever increasing distances to the warm (> 250 K) readout electronics. Novel, low power components which can be located near the detector are sought to either 1) drive long (> 5 m) signal cables with excellent fidelity (~16 bit accuracy) or, 2) move more of the signal chain, perhaps including the A/D converters, into the cold area (< 50 K).

High Performance Filters
There is a critical need for new sources of custom infrared bandpass filters with good in-band transmission and very low out-of-band transmission at wavelengths longward of 1 micron and extending to approximately 30 microns. Desirable passbands range from 50% to less than 1% of the central wavelength with in-band transmissions > 70%. Both fixed and tunable filters operating at temperatures < 50 K are desirable.

Other Optical and Opto-mechanical Instrument Components
Given the call for multiple capability instruments, there is a growing need for breakthrough concepts in instrument optics which minimize the volume requirements while adding capabilities (spectral, or otherwise) to the instrument. These elements may include gratings, prisms, dichroics, or other novel components.

Mechanical Coolers
The best detectors for wavelengths > 5 microns usually need to be cooled to < 10 K. There are a number of proposed Origins missions which have cooling requirements ranging from 50 mK to 20 K; highly stable (both mechanical and temperature stability), long life coolers are needed for these. Efforts may address the component level such as materials for magnetic refrigerants or novel heat switches, or they may address entire systems such as pulse tube, J-T, sorption, or sub-kelvin coolers.

S3.04 High Contrast Astrophysical Imaging
Lead Center: JPL

This subtopic addresses the unique problem of imaging 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 less than one arcsecond 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 and phase fluctuations in the optical train severely reduces the effectiveness of any star light cancellation scheme.

This innovative research focuses on advances in coronagraphic instruments, interferometric star light cancellation instruments, and potential occulting technologies that operate at visible and infrared wavelengths. For infrared applications, operation at cryogenic temperatures is required. The ultimate application of these instruments is to operate in space as part of a future observatory mission. In some architectures, both the telescope and instrument package need to be optimized for high contrast imaging. Any auxiliary instrumentation secondary to high contrast imaging must not compromise the high contrast optimization of the telescope.

There is interest in component development, innovative instrument design, as well as in fabrication of subsystem devices:

- Aspheric mirror fabrication processes (2 m or larger) that maximize suppression of mid-spatial frequency (100 mm to 500 mm) figure errors without increasing high frequency surface errors (0.5 nm rms goal).

- Ultra-low scatter optics on moderate to large spherical and aspheric mirrors (1 m class and above).
- Ultra-low scatter and high throughput optical coatings.
- Validation of optical surface uniformity at the beginning and end of mission life.
- Advanced apodization mask or occulting spot fabrication technology controlling smooth density gradients to 10^{-4} with spatial resolutions ~ 1 um.
- Small stroke, high precision continuous face sheet deformable mirrors and electronics driving 10^{4} or more actuators.
- High precision wavefront error sensing techniques.
- High performance wavefront controllers.
- Advanced starlight coronagraphic instrument concepts.
- Advanced aperture apodization and aperture shaping techniques.
- Interferometric starlight cancellation techniques.
- Pupil plane masks for interferometry.
- Aperture synthesis and beam combination strategies.
- Single mode fiber filtering from visible to 20 um wavelength.

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

Achieving the Solar System exploration goals requires innovative miniaturized science instruments and instrument components that offer significant improvement over the state of the art in terms of size, mass, power, cost, performance, and robustness. This subtopic supports the development of advanced instrument technology that has potential for scientific investigation on future planetary missions. New measurement concepts, advances in existing instrument concepts, advances in critical components such as detectors, sample handling techniques and technologies that enable integrated instrument architectures are all of interest. Proposers are encouraged to relate their proposed technology development to future planetary science goals as much as possible. Information on planetary science goals may be found at the NASA website http://solarsystem.nasa.gov.

While both remote and in situ sensing instruments are of interest, NASA’s space science missions will increasingly rely upon in situ characterization of the atmosphere, surface and subsurface regions of planets, satellites, and small bodies. These instruments may be deployed on surface landers and rovers, subsurface penetrators, cryobots, and airborne platforms. These instruments must be capable of withstanding operation in space and planetary environmental extremes, which include temperature, pressure, radiation, and impact stresses. A reasonable target for an in situ science instrument concept is 1-kilogram mass, 1-liter volume, and 1 watt-hour of energy, although for mission critical capabilities, additional resources might be available.

A wide range of in situ instruments is of interest: geological, chemical, biological, physical, and environmental. Particular emphasis is needed for astrobiology related measurements seeking to understand the origin and evolution of life and pre-biotic processes. New in situ analysis techniques are desired to identify and quantify biogenically important elements (C, H, N, O, P, and S) and their compounds (e.g., CH4, NOx, H_2O) within extraterrestrial atmospheres, soils, ices, sedimentary rocks, and minerals.

Future Mission Needs
The following future mission needs will receive emphasis during proposal selection:

- Mars Surveyor Missions: Missions to Mars will include both orbiters and landers with launches occurring approximately every 26 months. The high-level science drivers for Mars include determining if life ever arose on Mars, characterizing the ancient and present climate as well as climate processes, determining the evolution of the Martian surface and interior, and characterization of the environment in preparation for human exploration.
- Outer Solar System Missions: Future outer planet mission opportunities might include a Europa lander, a Titan lander, and/or a comet nucleus sample return. Instruments for Europa and Titan are particularly challenging because of the extreme environmental constraints. Europa measurement needs include characterization of the near-surface composition, determination of the compositional, geophysical, and geological context for the surface site, and a search for indications of Europan biology. Titan drivers include a determination of the distribution and composition of organics, and atmospheric dynamics.
- Discovery Program Missions: Discovery program missions represent a series of competed focused missions to a variety of solar system objects. They may include orbiters, landers, flybys, balloons, and airplanes to study a wide variety of science goals involving geology, geochemistry, geophysics, atmospheres and climates, and particles and fields. Instrumentation and instrument concepts that address this broad range of needs will be considered.

Example Measurement Needs
Meeting the needs for the Solar System exploration goals requires a significant arsenal of advanced scientific instrumentation. Examples of instruments that might meet some of the above goals include, but are not limited to, the following.

- Chemical sensing instrumentation for the surface and subsurface chemical, mineralogy, and isotopic analysis of soils, rocks, and ices. Examples include Raman spectrometers, laser-induced breakdown spectrometers, water/ice detectors, age-dating systems, electrochemical systems, thin film sensors, liquid and gas chromatography systems, gas chromatograph-mass spectrometers and other mass analyzing systems.
- Instrumentation focused on exobiological assessments for the identification and characterization of biomarkers of extinct or extant life, or prebiotic molecules. Examples include ultraviolet-Raman, infrared reflectance and transmittance, fluorescence microscopy, total organic carbon analyzers, microcalorimetry concepts, NMR spectroscopy, chromatography systems, CHONS isotope analysis, biosensor concepts, ion mobility spectrometers or other molecular identification instrumentation capable of operating alone or as part of a gas chromatograph system.
- Sensing instrumentation that integrates such functions as separation, reagent addition, and detection, especially using emerging "lab-on-a-chip" technologies.
- Suboptical microscopy instrumentation to characterize morphology, elemental and mineralogical composition, such electron microscopy techniques and atomic force microscopy.
- Instrumentation for the chemical and isotopic analysis of planetary atmospheres.
- Physical and environmental sensing systems, such as seismic and meteorological sensors, humidity sensors, wind and particle size distribution sensors.
- Particles and fields measurements, such as magnetometers, and electric field monitors.
- Enabling in situ instrument component and support technologies, such as 2–10 micron laser sources, miniaturized pumps, sample inlet systems, valves, and fluidic technologies for sample preparation.
- Advanced detectors and focal plane arrays in the regimes of radar/sub-mm through IR/Vis/UV.

S4.02 Planetary Mobility and Robotics, Sub-Surface Access, and Autonomous Control Technologies
Lead Center: JPL
Participating Center(s): ARC

During future exploration of planetary, lunar, small solar system body (such as comets and asteroids) surfaces, new tools in the areas of surface robotics systems, sub-surface systems, aerial systems, and autonomous software need to be developed. These technology tools and software are required for advanced scientific exploration to provide access to challenging surface sites, collect sub-surface samples, investigate a site through an aerial survey, and provide long-duration survival on planet surface. In particular, this subtopic seeks technology innovations that are in the following areas:

- Airborne Systems including autonomous fixed-wing aircraft, airships or blimps for long-duration scientific investigations, and aerobots and balloons for atmospheric and surface exploration.
- Surface Systems including science rovers for detailed in situ investigation, advanced surface mobility systems for access to high-risk terrain, manipulation and sample-handling systems for precision placement of instruments and sampling systems, and multiple, cooperating robotic systems for the development of a sustained robotic presence through robotic colonies and sensor webs.
- Sub-Surface Systems including shallow sampling systems for robust collection of rock and soil samples from less 1 meters in depth, deep drilling systems for exploration of sub-surface strata including the search for possible sub-surface water aquifers, low-cost, low-mass penetrator systems that are capable of conducting limited scientific discovery over a wide terrain area, sub-surface mobility systems that allow for the autonomous exploration of sub-surface material including soil, rock, and ice, and autonomous underwater robotic systems for exploration of possible sub-surface oceans on the moons of Jupiter.
- Autonomous Software Technologies including autonomous navigation techniques, algorithms for multiple cooperating systems, behavior-based control systems, advanced path planning techniques, software for intelligent systems, robotic reconfiguration strategies, and autonomous scientific data collection.

S4.03 Detection and Reduction of Biological Contamination on Flight Hardware and in Return-Sample Handling
Lead Center: JPL
Participating Center(s): ARC, JSC

As solar system exploration continues, NASA remains committed to 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. Thus, one of the great challenges is to develop or find the technologies 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. 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 that will support its needs in the areas of cleaning (non-destructively and without residues), cleaning validation, maintenance of biologically clean work areas, encapsulation and containerization, and archival preservation of organic and inorganic samples. Examples of such technologies include:

- Low temperature, non-corrosive sterilization techniques (room temperature and below)
- Non-abrasive cleaning techniques for narrow aperture occluded areas

- Non-abrasive cleaning techniques for fragile surfaces such as optics
- Ultra clean assembly processes for non-assembly line (unique and/or limited production) hardware
- Direct and rapid in situ monitoring of particles and biological contamination on surfaces with various shape, finish, electrical conductivity, etc.
- Effective new sampling methods with improved precision and accuracy for use on spacecraft surfaces to provide samples for detection of biological contamination
- Rapid cleaning validation methods with high sensitivity for the major classes of biological molecules: proteins, amino acid, DNA/RNA, lipids, polysaccharides
- Containerization and encapsulation of samples to be returned to Earth, including innovative mechanisms for isolation, sealing, and leak detection.

With regard to Mars sample handling, a leading concept for sample handling is based on Biosafety Level Four (BSL-4) laboratories. However, current technology does not adequately address the need for decontamination measures to destroy more resistant microbes than those commonly studied in BSL-4 labs. Sterilization techniques are needed for suits, laboratory cabinets, tools, and containers. Optimized cleaning techniques and cleaning verification are also areas requiring advances in technology.

To the extent possible, sample operations should be done with robotic or teleoperated systems. The use of robotic sampling devices could result in the elimination of gloves in glove boxes, which are known sources of leaks and contamination. We seek robotics devices that include the following:

- Offer great dexterity at scales ranging from micrometers to tens of centimeters
- Are constructed of clean and cleanable materials
- Function without lubricants
- Are extremely reliable
- Can be repaired without loss of sample integrity.

Finally, we seek technology to advance the state of the art in seals. The repeated operation of seals on airlocks between cabinets creates a significant opportunity for failure of the seals. Mechanical and robotic systems for sample handling will require the development of highly reliable seals to maintain the integrity of the containment systems.

S4.04 Materials and Systems for Future Planetary Exploration
Lead Center: JPL
Participating Center(s): LaRC

Two Important areas for future planetary exploration are covered in this subtopic:

Lightweight Materials for Planetary Aerocapture and Spacecraft Structures and Deployables

The desire to launch deep space mission payloads at lower cost, on smaller launch vehicles has increased as projects become more constrained due to budget pressures. In light of these factors, new concepts of using thin film structures or space systems to accomplish mission critical functions such as mobility (balloons), aerocapture (ballutes), and deployable multifunctional structures (radiators, receptors, antennas, struts, etc.) are gaining importance. Low mass, low volume space asset functionality is critical to enabling new missions to withstand the harsh environments (temperature and atmospheric conditions, at Venus or Titan for example) if we wish to dramatically reduce the cost of in situ science or to extend life expectancy of systems exposed to the challenges of atomic oxygen, radiation effects, and debris and micro-meteoroid impacts on orbit or in deep space. We wish to identify, evaluate, and develop thin film materials, systems and associated technologies that will be compatible with ballute, balloon and the low-mass multifunctional-structure requirements listed below. A systems engineering perspective is encouraged. Proposals should address how materials/configurations are compatible with expected preflight configurations, subsequent in-flight configurations, and attendant environments. Technology areas for innovation include:

- Ballute materials for aerocapture missions with high temperature capability > 400° C, high emissivity e > 0.8, low mass-areal density < 10 gm/m^2, thin films with appropriate stability and dynamics response. The ability to withstand aerodynamic stresses/temperatures during deployment and aerocapture sequences.
- Balloon and aerobot materials and associated seaming technology with capability to withstand acidic (sulfuric acid) atmosphere and high temperatures (withstand up to 500° C - Venus or in the case of Titan down to -170° C) at areal densities of < 10gm/m^2. Low packing density is needed for the launch and cruise phase of missions to Venus or Titan. Issues to address are mass, material strength (thin films/composites, metallization, rip stop properties), space environment durability and longevity; resistance to micro-cracks due to high strain, retention of properties after tight packing; and manufacturing issues including edge capture, joint concepts, and prelaunch repair.
- Low mass multifunctional structures or membranes integrated with electronics, power sources, thermal control or communication capabilities, with areal densities under 0.1 kg/m^2 such that they would be applicable to large area ultra-lightweight deployable or inflatable structures. Specific areas of interest are thermal technologies for thin films and membranes; development of active or passive thermal control systems and models for the electronics integrated with membrane structures; development of substrate thinning and bonding processes; development of materials with controllable surface properties that, when combined with integrated control electronics, could adapt to changing environments or mission needs; space rigidizable thin films or structural components; and shape memory thin films/low density polymeric materials for deployable structures.

Planetary Entry, Descent and Landing Technologies
Entry, Descent, and Landing (EDL) systems are an enabling component of future planetary surface and airborne explorations. EDL systems are naturally comprised of a wide variety of tightly integrated subsystems. These subsystems can include, but are not limited to: entry body, thermal protection, entry guidance avionics, super-sonic parachute, sub-sonic parachute, terrain sensors, and touch-down sub-system. In addition to these hardware specific sub-systems, guidance and hazard detection algorithms are an integral element of future EDL systems. Innovations are sought which provide benefits in the following general areas, increased payload delivery mass, improved delivery accuracy, and improved hazard detection and avoidance approaches. The intended outcome of these improvements is to deliver larger payloads with greater targeting accuracy to planetary landing sites with significant terrain hazards. In particular, this subtopic seeks technology innovations that are in the following areas:

- Entry body systems, and sub-systems including lightweight aeroshells, and thermal protection.
- Parachute decelerator systems including supersonic and sub-sonic parachutes. Particular areas of interest include approaches that can lead to increased supersonic parachute deployment criteria, i.e. increased Mach-Q space. Also of interest are para-guidance techniques.
- Terrain hazard detection approaches that provide real-time three dimensional terrain mapping capability during parachute descent and powered terminal descent.
- Lightweight touchdown system terrain hazard tolerance approaches including airbag, shock struts, and structural crush zones. In future EDL systems the touchdown system, i.e. the lander, are intended to be tolerant to landings in moderately cratered terrains with their incipient surface rock distributions.
- EDL telecommunication innovations are sought which facilitate real time EDL engineering telemetry either via a direct to earth link or to an overhead cruise/relay stage.

S4.05 Advanced Miniature and Microelectronics, Nanosensors, and Evolvable Hardware
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/soil), and submarines. Also of interest are delivery of distributed sensor systems consisting of networks of tiny (<<1 kg) individual elements which combine sensors, control, and communications in highly integrated packages, and which are scattered over planetary surfaces, atmospheres, oceans, or sub-surfaces. 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.

Advanced Miniature and Micro Avionics and Electronics
Advances in microelectronics, avionics architecture, packaging and thermal control are sought. Applicable technology areas include:

- Avionics, including highly integrated, ultra low power and extreme long life components.
- Avionics components including sensors, actuators, communication, and micropower sources, able to operate in extreme environments: low temperature, high temperature, high radiation.
- Thermal management for electronics, including active and passive techniques.
- Three-dimensional VLSI, chip stacking, multi-chip-module stacking and other advanced packaging techniques.
- Low power, COTS-based radiation tolerant and advanced power management techniques.
- Radiation hard, high density, non-volatile mass memory.
- Radiation hardness microelectronics and Integrated Circuits.
- Fault tolerance and onboard maintenance design and analysis techniques for severely constrained environments and extreme long life missions.
- Concepts and designs for test and validation of design integrity and performance of IP based ASICs, mixed signal ASICs and MEMS.
- High resolution, high sampling rate, low power and radiation-hardened analog-digital converters, and digital signal processing hardware components with algorithm design environments for rapid design and prototyping.

Nanotechnology
The nanosensing and the bio-nanotechnology for 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, such as high-Q RF signal processing, single molecule sensing and manipulation, on-chip biomolecular analysis, harsh environment operable nanosystems, and semiconductor laser diodes and detectors in the 2-5 um wavelength range. Of particular interest are carbon nanotube-based sensors and actuators, quantum dots based opto-electronics devices, quantum sensors and measurements, magnetic field sensors and nanocrystal based evolvable computing and memory architectures.

Evolvable Hardware
We are also interested in novel and innovative technologies for evolvable space systems. The main focus is on a complete system approach, which would lead to demonstrations of autonomously evolving systems using reconfigurable recourses such as Field Programmable Gate Arrays (FPGA) or Field Programmable Transistor Arrays (FPTA).

S4.06 High Rate Telecommunications for Deep Space and Local Planetary Networks
Lead Center: JPL
Participating Center(s): GSFC

This subtopic seeks innovations for long distance optical and RF communication technologies.

RF Communications
- Ultra-small, low-cost, low-power, innovative deep-space transponders and components, including integrated circuits such as microwave monolithic integrated circuits (MMICs) and Bi-CMOS circuits. Signal processing circuits for receivers that provide carrier tracking, command and ranging capabilities. Low-voltage, multi-function MMIC designs to provide low-noise down-conversion, automatic gain-control, up-conversion, and transceiver functions at (Ka-band (32 GHz). MMIC

modulators with drivers to provide large linear phase modulation (above 2.5 radians), high-data rate BPSK/QPSK modulation at X-band (8.4 GHz) and Ka-band. Miniature, ultra-stable and voltage-controlled oscillators for deep space communications and GPS applications. Miniature, low-loss X-band and Ka-band switches and diplexers.
- Advanced Ka-band MMIC and photonic packages for high data rate (1 Gbps) applications.
- Miniature, high-efficiency power amplifiers and RF power devices operating in the X- and Ka-band, transmitters with output power levels up to 20 watts that can survive the space environment with a minimum mean-time-to-failure of ten years.

Optical Communications
- Efficient (greater than 20% wall plug), lightweight (less than 1 kg including drivers), flight-qualifiable actively pulsed high repetition-rate, high peak power laser transmitters (diode-pumped based) with 1 to 3 W of average output power. Pulse generation time delay uncertainty should be less than 1 nsec with pulse-width no greater than 30 ns. High (>1000) modulation extinction ratio is highly desirable.
- Novel schemes for stray-light control and sunlight mitigation. Also, transmit/receive isolation methods providing at least 130 dB of isolation.
- Acquisition and tracking technologies including algorithms for sub-micro-radian laser beam pointing from deep-space ranges.
- Low power consumption, high quantum efficiency and fill factor and compact acquisition and tracking focal plane array detectors incorporating on-chip processing for window control, pixel gain/offset correction window, background/pattern noise calibration, bright spot location for initial acquisition, and pixel summation mode. Multiple windowing capability with different integration times for each window is also highly desirable.
- Lightweight high precision (<0.1 micro-rad over 1-500 Hz) inertial reference sensors for use on-board spacecraft) inertial reference sensors (gyros,) for use onboard spacecraft.
- Avalanche Photodiode Detectors (APD) with > 3 mm active area diameter, bandwidth > 200 MHz, QE > 40% at 1064 nm, very low noise (k factor < 0.0.02) and gain >100.
- Large diameter (250-300 micron) receiver detector with sufficient bandwidth for 2.5 Gbps communications with at least -30 dBm of sensitivity at 1E-9 BER and high (at least 2 KHz) bandwidth AGC control or limiting amplifier. Also of interest is a single free-space receiver with multiple channels (detectors) for WDM.

S4.07 Deep Space Power Systems
Lead Center: GRC
Participating Center(s): JPL, JSC, MSFC

Innovative concepts utilizing 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 several kilowatts. NASA Space Science missions require energy systems with high energy density, reliability and low overall costs (including operations). Advanced technologies are sought in the following areas:

Energy Conversion
Advances in photovoltaic technology are sought, including rigid arrays, thin film arrays, and concentrator arrays with substantial increases in specific power (w/kg) and decreased cost. Must accommodate radiation resistance, low temperature/low intensity, and high temperature/ high intensity operation,

Advances in radioisotope power conversion to electricity (tens of milliwatts to hundreds of watts with efficiencies > 20 %). Includes advances in AMTEC, thermophotovoltaics, thermoelectrics, Stirling, and microfabricated power systems.

Energy Storage
Includes advances in primary and secondary (rechargeable) battery technologies. Technologies include lithium ion batteries, lithium polymer batteries and other advanced concepts providing dramatic increases

in mass and volume energy density (w-hr/kg) and (w-hr/liter). Must be able to operate in harsh environments, including high radiation and low/high 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/recharge (anywhere from hours to days).

Power Electronics
Advanced electronic technologies with reduced volume and mass capable of high-temperature, low-temperature (cryogenic), or wide-temperature operation, radiation resistance, and/or electromagnetic shielding with thermal control.

Thermal control integral to electrical devices capable of > 100 W/cm^2 heat flux.

Advanced electronic materials, devices and circuits including transformers, integrated circuits, capacitors, ultra capacitors, electro-optical devices, micro electro-mechanical systems (MEMS), sensors, low loss magnetic cores, motor drives, electrical actuation.

Advanced PMAD control technologies including fault detection, isolation, and system reconfiguration, including "smart components", built-in test, health management, and power-line or wireless communication.

Power System Materials
Advances are sought in materials, surfaces, and components that are durable for atomic oxygen, soft x-ray, electron, proton, and ultraviolet radiation and thermal cycling environments, lightweight electromagnetic interference shielding, and high-performance, environmentally durable radiators.

S4.08 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 distinguish microorganisms and biologically important molecular structures within complex chemical mixtures. For example, gaseous biomarkers, produced by microbial communities, are among our targets in current search strategies for life in the atmospheres of extrasolar planets. Both gaseous and mineral biomarkers produced by these communities are profoundly affected by internal biogeochemical cycling. The small spatial scales at which these biogeochemical processes operate necessitate measurements made using microsensors. Microbial ecology research at NASA could benefit enormously from collaboration of sensor technologists and microbial ecologists. 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 the effects of gravity on the evolution of living systems is a fundamental question of substantial, inherent scientific value in our quest to understand life. In addition, radiation of varying levels is assumed to have varying effects on the development and evolution of life. Knowledge 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. These interactions can be seen in carbon cycles and nitrogen cycles. Some examples of rapid changes that affect these microbial processes are increases in UV, increases in average and seasonal temperatures, and changes in the length of the growing season, all which are key issues in both Earth Science and Astrobiology. Additional areas include Controlled Environment Sustainability Research (CESR), growth chambers and monitoring capabilities. This research requires unique instrumentation and information science technologies that are not covered in the Earth Science program.

NASA seeks innovations in the following technology areas:

- For Mars exploration, 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 in situ and laboratory based microbial sensing/monitoring system capable of providing quantitative spatial and temporal visualization of material and functions in selected specimens.
- Advanced miniaturized biological in situ 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) embodies 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.
- In order to address the imperative to understand gaseous biomarker production, we desire technologies capable of measuring a range of volatile compounds at small spatial scales, possibly through the coupling of gas diffusion sensors to portable mass spectrometers. 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.
- Nondestructive structural characterization of micro-areas of microsamples of rocks and minerals by diffraction (1-100 micron scale). Tools to Support Gravity and Radiation Studies of Biological Systems over Multiple Generations These technologies must be miniaturized to minimize weight, volume and power requirements and must operate autonomously for extended periods of time to accommodate monitoring multiple generations of organisms. Thus, instrumentation must be self-calibrating, require no or minimal consumables and be remotely controlled.
- 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/imaging technology with high resolution and low power requirements.

- Habitat support - technologies for supporting miniature ecosystems isolated from their support environments, data collection and transmission technologies in concert with the automated chemical instrumentation described above. Candidate technologies include sensor and telemetry systems as well as variable-spectrum, low power light sources for simulating conditions on the early Earth.
- 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 <1nm 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/alkaline hot springs, Antarctic climates or boreholes into the Earth).
- High resolution, high sensitivity (femtomole or better) methods for the isolation and characterization of nucleic acids (DNA/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 system designed to provided access to terrestrial and extraterrestrial environments such as deep ocean hydrothermal vents.

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9.2 STTR Research Topics

To reduce overlap and streamline administrative and programmatic functions, NASA has established areas of excellence for each of its field installations. The most significant, as noted in NASA's management plan, are termed Centers of Excellence (CE). There is one CE for each NASA installation. Each CE represents a focused, Agency-wide leadership responsibility in a specific area of technology or knowledge. CE's are charted with a clear definition of their capabilities and boundaries. They are chartered to be preeminent within the Agency, if not worldwide, with respect to the human resources, facilities, and other critical capabilities associated with the particular area of excellence. Each CE must maintain or increase the Agency's preeminent position in their assigned area in line with the program requirements of the Strategic Enterprises and the long-term interests of the Agency. The NASA STTR Program is aligned with the CE's. This year four CE's are participating. Research topics rotate each year among the different CE's. The topic will be focused on some of the product areas or challenges faced by the CE.

Topic 1 Information Technology
NASA Installation: Ames Research Center (ARC)

This NASA Center of Excellence for Information Technology is based on three cornerstones: Automated Reasoning for Autonomous Systems, Human-Centered Computing, and High Performance Computing & Networking. For this Solicitation, the focus is on software tools and methods to support these cornerstones. The target domains for these capabilities should be of high relevance to NASA. Primary areas of interest are as follows:

Technologies for Autonomous Spacecraft, Rovers, and Other Complex Systems

- An on-board capability for synthesizing operational plans from high-level goals, rather than from low-level sequences of actions sent by a ground operations team.
- On-board methods that use explicit component-based models to diagnose system health and then automatically re-configure to respond to failures.
- Integrated software capabilities that allow automated science rovers to respond to high-level goals such as "advance to a nearby interesting rock and analyze it." This could include perception of camera and other sensor data, position determination and path planning, science planning, and automated analysis of resulting science data.
- On-Board Real-Time Vehicle Health Management systems that perform quickly enough to monitor a flight control system (including spacecraft and fixed/rotary wing aircraft) in a highly dynamic environment, and respond to anomalies with suggested recovery or mitigation actions.
- Software generation tools which 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.
- Application of automated reasoning and formal methods for high-assurance tools for program synthesis and program verification. Of special interest are tools for synthesis and verification of new kinds of software capabilities, including autonomy software, software that learns and adapts, and software for distributed systems such as air traffic control.

Technologies for Augmentation of Operations Performance

- Algorithms, software, and workflow processes that allow ground operations teams to perform at the same level with greatly reduced personnel, and to respond faster and better to any unexpected contingency.
- Tools that allow spoken language interaction with automated systems. Of special interest are tools targeted towards use by astronauts in an orbiting or planetary habitat as well as for interaction with planetary vehicles and science rovers.
- Innovative hardware and software systems that improve operator efficiency for tele-operating robotic systems via advanced displays, controls and telepresence interfaces as well as technologies to enhance teleoperations applications. Teleoperations, in this context, includes telerobotics, telescience, telepresence, and distributed collaborative virtual environments. Application areas include flight and ground operations development, analyses, training, and support.
- Innovative concepts for augmenting the simulation and 3-D visualization capabilities of advanced airport/ spaceport facilities like Future Flight Central (FFC) at Ames Research Center. Specific interest areas include 3-D visualization of aircraft noise, wake vortices, and dynamic weather conditions. Creative concepts that enable alternative uses of FFC-like facilities (e.g., aircraft carrier operation visualization) are also of interest.
- Advances in the ability of globally distributed control centers to cooperate in the control of fleets of spacecraft or multiple satellites occupying the same orbital slot.

Technologies for High Performance Computing and Networking

- Technologies to monitor the resources and services that make up a large-scale, heterogeneous, distributed computation system (a computational grid, or Grid), analyze the operation of such a system, and attempt to automatically resolve failures of the system.
- Capability-based authorization and access control techniques based upon public key cryptography to allow users to gain access to Grid resources and services.
- Techniques for efficiently scheduling scientific applications on the many high-performance computers that make up a Grid.
- Techniques for scheduling simultaneous access to Grid resources such as instruments, networks, storage systems, and computer systems. These techniques should maximize Grid resource utilization and minimize the amount of time applications wait for resources.
- Grid portal technologies that implement single sign-on access to Grid resources, and Grid problem solving environment (PSE) technologies, which provide a single interface for access to and interaction with problem-specific data, computation codes, data analysis codes, and visualization/steering codes.
- Integration of Web Services with Grid Services and portals using WSDL, UDDI, WSI, and WSFL.
- Advancements in Grid based global file systems.
- Techniques to execute application workflows on Grids.

Topic 2 Atmospheric Flight Operations

NASA Installation: Dryden Flight Research Center (DFRC)

Accurate simulation of aerospace vehicles' flight characteristics is of great importance for both initial design and subsequent flight-testing. This topic focuses on R&D for multi-disciplinary modeling and simulation and for development of efficient software tools for aero-structures-controls-propulsion interaction simulation of flight vehicles. The benefit of this effort lies in ensuring flight safety, particularly during flight tests.

This topic solicits proposals for innovative, linear or non-linear, aerospace vehicles' dynamic systems modeling and simulation techniques. In particular:

R&D in finite element based numerical simulation algorithms in 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 interaction simulation software and correlation of such analysis results with flight test data.

Topic 3 Earth Science and Physics and Astronomy

NASA Installation: Goddard Space Flight Center (GSFC)

This STTR is divided into both passive and active remote sensing concepts and technologies to enable future both Earth Science and Physics and Astronomy measurements.

For Earth Science, this primarily will include soil moisture, ocean salinity, ocean mixing layer depth, carbon dioxide, atmospheric chemistry in both troposphere and stratosphere, aerosols, hydrological cycle, earthquakes, and other natural disasters such as volcanic eruptions, fires, and spreading of various vector diseases.

Physics and astronomy related goals seek to solve mysteries of the universe, explore the solar system, discover planets around other stars, search for life beyond Earth, chart the evolution of the universe and understand its galaxies, stars, planets, and life. NASA seeks to understand the universe from the beginning of time, looking ever deeper with increasingly more capable telescopes to scan the entire electromagnetic spectrum from gamma rays to radio wavelengths.

Microwave Measurements Using Large Aperture Systems

Breakthrough technologies are sought to support 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. Antenna concepts may include large single apertures or apertures composed of multiple elements that are operated synergistically so as to product the desired performance.

Active Optical Systems and Technology

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 either enable a new measurement capability, enhance an existing measurement capability by significantly improving the performance (spatial/temporal resolution, accuracy, range of regard), or substantially reduce the resources (cost, mass, volume or power) required to attain the same measurement capability.

Systems and approaches will be considered which demonstrate a capability that is scalable to space or can be mounted on a relevant platform (UAV, long duration balloon, or aircraft) for calibration/validation of a spaceborne system.

Passive Remote Sensing Detector Systems and Components

Innovative developments are being sought that incorporate new architectures, new technologies and advanced remote sensing techniques to make physics and astronomy measurements. Emphasis on low weight, small volume and low power is very important. The innovations sought include:

- Far infrared detector systems for operation at temperatures less than or approximately equal to 80 K
- 3D (2 spatial 1 energy) photon counting detectors for spectroscopic imaging in the visible & UV

- Energy resolving sensors that operate above 4K. These should have at least 4 energy bands and can operate anywhere between X-ray and Sub-mm
- High spatial resolution (0.1 arc second or better), light weight, ground testable optical systems for visible, UV, and EUV solar investigations
- Widely tunable(> 60 nm), single frequency, compact (< 1 cubic inch volume) semiconductor lasers
- High quantum efficiency (> 10%), photon counting, near infrared (1- 2 micron) detectors for use in laser systems
- Devices permitting the measurement of DC/AC electric and magnetic fields
- High speed, low power, low signal analog electronics for high energy detector systems
- Precision lightweight optics (precision defined as surface figure <0.01 waves rms @633nm, surface roughness <2 angstroms, lightweight defined as approaching NGST metric 15 kg/m^2) for application to astronomical investigations
- Inflatable structures and antennas
- Lightweight x-ray telescope optics
- Lightweight, low power cryogenic coolers for miniature systems
- Superconducting devices with increased performance for cooling, detection, electronics, or other novel remote sensing applications

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 are sought as are increases in performance and serviceability of system components. The overall goal is to develop an instrument with increased performance in the areas of improved collection, detection and measurement. Specific area of interest include:

- Miniaturized and ruggedized Gas Chromatograph columns
- Micro-valves
- Improved stability and performance of secondary electron multipliers
- Performance increases in the areas of size and conversion efficiently of high voltage DC/DC converters
- Rigid miniature vacuum pumps

Unmanned Aerial Vehicle Technologies for Remote Sensing
Innovations to support Unmanned Aerial Vehicles' (UAV) basic and applied science and application demonstrations are sought in at least one of the following areas:

- Low cost avionic's instrumentation for precise navigation and aircraft control, must have an attitude sampling rate greater than 25Hz and an accuracy greater than .2 degrees in roll and pitch.
- Real-time sensor fusion algorithms that combine low-cost inertial, GPS, magnetometer and other sensor inputs to deliver aircraft state vectors at a rate greater than 50Hz.
- Uncooled infrared/thermal spectral imager instrument of less than 2 lbs. and no larger than .05 cubic meters in volume. Must operate autonomously in coordination with the on-board flight plan. It must have a built-in data acquisition system. The spectral bands must all be co-registered 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 .6 microns. Quantization bit resolution should be 10-bit minimum.

Topic 4 Rocket Propulsion Testing Systems
NASA Installation: Stennis Space Center (SSC)

Proposals are sought for innovative technologies and technology concepts in the area of propulsion test operations. Proposals should support the reduction of overall propulsion test operations costs (recurring costs) and/or increase reliability and performance of propulsion ground test facilities and operations methodologies. Specific areas of interest in this subtopic include the following:

Facility and Test Article Health-Monitoring Technologies

- Innovative non-intrusive 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. Sub-millisecond response time is required. Temperature sensors must be able to measure cryogenic temperatures of fluids (160R for LO_X and 34R for LH_2) under high pressure (up to 12,000 psi), high flow rate conditions (2000 lb/sec – 82 ft/sec for LO_X, 500 lb/sec – 333 ft/sec for LH_2). Flow rate sensors must have a range of up to 2000 lb/sec (82 ft/sec) for LO_X and 500 lb/sec (333ft/sec) for LH_2. Pressure sensors must have a range up to 12,000 psi. Rocket plume sensors must determine gas species, temperature, and velocity for H_2, O_2, RP1, 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 (160R for LO_X and 34R for LH_2) under high pressure (up to 12,000 psi), high flow rate conditions (2000 lb/sec – 82 ft/sec for LO_X, 500 lb/sec – 333 ft/sec for LH_2). Response time must be on the order of a few milliseconds to the sub-milliseconds.
- On-line (real-time) sampling of percent concentration of pressurizing nitrogen in liquid oxygen systems. Instrumentation must be capable of sub-millisecond sampling of nitrogen percent concentration at cryogenic temperatures (160R for LO_X and 34R for LH_2), pressures up to 12,000 psi, and high flow rate conditions (2000 lb/sec – 82 ft/sec for LO_X, 500 lb/sec – 333 ft/sec for LH_2).
- On-line (real-time) sampling and analysis of high pressure, high flow liquid oxygen-nitrogen mixtures. There is a significant need for real time, totally non-intrusive instrumentation for high pressure, high flow rate LO_X systems, having the capability to detect the presence of other chemical species present in the LO_X, which may have been introduced through the pressurization process. An example would be the detection of N_2 in a LO_X flow, where N_2 is used to pressurize the LO_X delivery system. The technology should be expandable to include other propellants.
- Model-based and knowledge-based methods to capture features from sensor signals. The features of interest should help identify behaviors indicative of operating conditions (health) of sensors and the processes they monitor. Signals of interest are one-dimensional.

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 (160R for LO_X and 34R for LH_2) under high pressure (up to 12,000 psi) high flow rate conditions (2000 lb/sec – 82 ft/sec for LO_X, 500 lb/sec – 333 ft/sec for LH_2). Components must be able to operate in the elevated temperatures associated with a rocket engine testing environment. Response time must be on the order of a few milliseconds to 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 minus 320° F to 100° F or minus 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 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 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 inputs and outputs.

- 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 methods are required that can accurately predict the acoustic levels using fewer measurements. New, innovative techniques based on energy density measurements rather than pressure measurements show promise as replacements for the older models.
- 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 Science 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. Statistic analysis must be supported.
- Digital simulation techniques to support decision making processes to address reliability, availability, and return on investment. Requirements exist to develop and apply statistics, operations management, operations research, decision theory to the management and operations of rocket engine test decision process, operations approaches, data analysis, and measures of effectiveness development.
- Techniques to reduce required sample size to maintain acceptable levels of confidence in cost data. In order to leverage appropriate models and to manage the cost of data acquisition and maintenance, the minimization of required data sample sizes is critical.

Topic 5 Space Propulsion

NASA Installation: Marshall Space Flight Center (MSFC)

This Center of Excellence seeks development of propulsion technologies that will enable dramatic improvements in space transportation safety, reliability and cost. Key to this goal is the application of innovative, non-traditional propulsion technologies, devices and systems that could significantly increase the structural margins of future launch systems and substantially reduce the mission times for interplanetary and deep space spacecraft. Development of such technologies is sought to enable ambitious commercial, robotic and human exploration missions in the future.

The following are some specific technology innovation areas that would provide significant advancements in space transportation capability and lead to development of safe, affordable, high-performance propulsion technologies:

- Propulsion applications of technology innovations in fission, fusion and other advanced energy production methods. Of special interest is research leading to application in commercial transportation and energy markets, and techniques for economical and environmentally acceptable testing.
- Research and technology advancement in high efficiency fission electric propulsion systems. Mid-term research and technology should enable system specific masses below 20 kg/kWe at specific impulses greater than 5000 s. Far-term research and technology should enable system specific masses below 1 kg/kWe at specific impulses greater than 5000 s.
- Research and technology advancement in antimatter production, storage, transportation, and utilization for application as a propulsion energy source. Of special interest is research leading to methods for convenient, low-cost antiproton production and robust, high-containment density storage devices.
- Enhancements to or development of new propulsion systems utilizing electromagnetic fields or solar interactions, such as solar/magnetic sails, solar thermal propulsion and electrodynamic tethers.

Appendix A: Phase I Sample Table of Contents

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Appendix B: Example Format for Briefing Chart

NASA SBIR/STTR Technologies

Title of Proposal

PI: PI's Name / Firm – City, ST
Proposal No.: 02-I

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