National Aeronautics and Space Administration

SBIR:
Small Business Innovation Research
Program Solicitation

A searchable version of this document is located at:
http://sbir.nasa.gov

Opening Date: April 24, 2000
Closing Date: July 14, 2000

The cover is designed by James Kalshoven and Jay Friedlander using the facilities of the Space Science Data Operations Office of the NASA Goddard Space Flight Center in Greenbelt, Maryland. It exhibits reusable launch vehicle (RLV) flight demonstrators being developed under the auspices of the Advanced Space Transportation Program at NASA's Marshall Space Flight Center. At the top and the bottom of the cover are the X-37 and X-34 Pathfinder class of small experimental testbed vehicles. The larger X-33 in the cover center demonstrates technology for a single stage to orbit RLV concept.

TABLE OF CONTENTS

2000 NASA Small Business Innovation Research Program Solicitation

1. Program Description

1.1 Introduction

The National Aeronautics and Space Administration (NASA) invites eligible small business concerns (SBCs) to submit Phase-I proposals for its 2000 Small Business Innovation Research (SBIR) Program. NASA seeks innovative concepts addressing the program needs and offering commercial application potential as described in the Solicitation subtopics.

This Solicitation contains program background information, outlines eligibility requirements for participants, describes the three SBIR program phases, and provides information for submitting responsive proposals. The 2000 Solicitation period for Phase-I proposals begins April 24, 2000 and ends July 14, 2000. Unsolicited proposals will not be accepted.

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 by a subtopic in this Solicitation. Proposals involving high risk are encouraged when the anticipated payoff is great. Proposals submitted in response to this Solicitation must include all relevant documentation as required in Section 3. 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.

Subject to the availability of funds, NASA plans to select about 290 proposals in mid-October 2000 for negotiation of Phase-I fixed-price contracts. NASA anticipates that about 40 percent of these Phase-I projects will be selected for Phase-II. The FY 2000 NASA SBIR Program budget is approximately $92.1M.

1.2 Program Background

1.2.1 Legislative Basis. This Solicitation is issued pursuant to the authority contained in P.L. 97-219, as amended (Small Business Innovation Development Act of 1982) (15 U.S.C. 638). SBIR policy is provided by the Small Business Administration (SBA) through its Policy Directive dated January 26, 1993. The current law authorizes agencies participating in the SBIR Program to expend with small business concerns not less than 2.5 percent of their extramural Research/Research and Development (R/R&D) budgets in FY 2000.

1.2.2 Program Purposes. The purposes of the SBIR program as established by law are: to stimulate technological innovation in the private sector; to strengthen the role of small business concerns 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.

1.3 Program Management

The NASA Office of Aero-Space Technology provides overall policy direction for the SBIR program. The Program Management Office is hosted at the Goddard Space Flight Center. The NASA Installations identify R&D needs, evaluate proposals, make recommendations for selections, and manage individual projects. All NASA Strategic Enterprises and Field Installations participate in the Program. NASA installations are:

Ames Research Center, www.arc.nasa.gov
Dryden Flight Research Center, www.dfrc.nasa.gov
Glenn Research Center, www.grc.nasa.gov
Goddard Space Flight Center, www.gsfc.nasa.gov
NASA Headquarters, www.hq.nasa.gov
Jet Propulsion Laboratory, www.jpl.nasa.gov
Johnson Space Center, www.jsc.nasa.gov
Kennedy Space Center, www.ksc.nasa.gov
Langley Research Center, www.larc.nasa.gov
Marshall Space Flight Center, www.msfc.nasa.gov
Stennis Space Center, www.ssc.nasa.gov

1.4 Three Phase SBIR Program

The NASA SBIR Program is a three-phase program utilizing the entrepreneurial talents of the SBC for meeting the needs of both NASA and the commercial marketplace.

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. NASA funding for each Phase-I contract is limited to $70,000. Contractors have up to 6 months to submit their final report. 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 of this Solicitation. 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.

1.4.2 Phase-II. The objective of Phase-II is to continue the R/R&D effort from Phase-I. Only SBCs awarded Phase-I contracts are eligible for Phase-II SBIR funding agreements, and only at the Federal Agency which awarded the Phase-I project. The Government is not obligated to fund any specific SBIR Phase-II proposal. Funding for each Phase-II contract will be limited to $600,000. Contractors have up to 24 months to complete the effort and submit their final report.

Phase-II projects are chosen as a result of competitive evaluations based on selection criteria provided in Section 4.2. Phase-II proposals are more comprehensive than those required for Phase-I and are to be prepared in accordance with instructions provided in the Phase-I contract.

1.4.3 Phase-III. NASA may award Phase-III contracts for products or services with non-SBIR 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 to Participate in the SBIR Program

1.5.1 Small Business Concern. Only firms qualifying as SBCs as defined in Section 2.1 of this Solicitation are eligible to participate in the SBIR program. Socially and economically disadvantaged and women-owned SBCs are particularly encouraged to propose.

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 2.7).

1.5.3 Principal Investigator. The Principal Investigator (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 SBIR 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 apply personally on the project. The amount of time the PI proposes to spend on the project must be acceptable to the NASA 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.

Primary Employment. 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. Primary employment means that the PI will average a minimum of 20 hours per week with the SBC, and 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. If the PI does not 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.

Employees of Academic and Non-Profit Organizations. An offeror proposing a PI who is also to be employed concurrently in any capacity by an academic or non-profit organization must include, as part of the proposal, a written release statement. The PI release statement shall approve concurrent primary employment with the SBC as defined above, and agree to less than half-time employment by the organization beginning no later than the time of NASA SBIR contract award and continuing thereafter during contract performance. The organization must specifically release the employee from all duties, responsibilities, and activities required by or implied by employment in that position as much as or more than half-time. Proposals that do not include the required written release statement may be rejected.

Co-Principal Investigators. Co-PI's are not acceptable.

Misrepresentation or Substitution. Substitution of a PI by the offeror at any time without NASA's advance written approval, or misrepresentation of PI qualifications and eligibility, will result in rejection of the proposal or termination of the contract.

1.6 General Information

1.6.1 Solicitation Distribution. This 2000 SBIR Program Solicitation is available via the NASA SBIR/STTR homepage **(http://sbir.nasa.gov)**. If the SBC has difficulty accessing the Solicitation, contact the Help Desk (Section 1.6.2).

SBCs are encouraged to check the SBIR/STTR homepage for program updates. Any updates or corrections to the Solicitation will be posted there.

1.6.2 Means of Contacting NASA SBIR Program

1. NASA SBIR/STTR Homepage: **http://sbir.nasa.gov**

2. Each of the NASA field centers has its own homepage including strategic planning and SBIR 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 to:

   Paul Mexcur, Program Manager
   NASA SBIR/STTR Program Management Office
   Code 710, Building 3, Room 108
   Goddard Space Flight Center
   Greenbelt, MD 20771-0001

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 Small Business Concern

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

1. Is 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.

2.2 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.

2.3 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.

2.4 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.

2.5 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).

2.6 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.

2.7 United States

Means the 50 states, the territories and possessions of the United States, the Commonwealth of Puerto Rico, the Trust Territory of the Pacific Islands, and the District of Columbia.

2.8 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.

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.*

End Deliverables. The deliverable item at the end of a Phase-I contract shall be a professional quality report that justifies, validates, and defends the experimental and theoretical work accomplished. Delivery of a product or service with the Phase-I report may be desirable, but it is not a requirement.

Deliverable items for Phase-II contracts shall include products or services in addition to professional quality reports 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.

> **Note:** As part of the Phase-I and Phase-II deliverables, a non-proprietary technical abstract of findings shall be submitted by the offeror via the SBIR/STTR homepage.

3.2 Phase-I Proposal Requirements

3.2.1 General Requirements

Page Limitation. A Phase-I SBIR proposal shall not exceed a total of 25 standard 8 1/2 x 11 inch (21.6 x 27.9 cm) pages. A page is defined as a single side of a piece of paper. All four 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). Samples, videotapes, slides, or other ancillary items will not be accepted. Offerors are requested not to use the entire 25-page allowance unless necessary**. Proposals exceeding the 25 page limitation will be rejected during administrative screening.** The program would prefer proposals prepared on both sides of the paper, if possible.

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.

Brevity and Organization. The proposal should be focused, concise, and organized in accordance with the Solicitation requirements.

Classified Information. NASA does not accept SBIR 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 in the order presented:

1. Proposal Cover (Form 9A), signed in ink, as page 1.
2. Proposal Summary (Form 9B), as page 2.
3. Technical Proposal (11 Parts), including all graphics, and starting at page 3 with a table of contents.
4. Summary Budget (Form 9C), signed in ink.

3.2.3 Proposal Cover and Proposal Summary

Page 1: Proposal Cover (Form 9A). A copy of the Proposal Cover is provided in Section 9. 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 9B). A copy of the Proposal Summary is provided in Section 9. The offeror shall provide complete information for each item and submit Form 9B 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 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:** Forms 9A and 9B, the Proposal Cover and the Proposal Summary, 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 and numbered. A proposal omitting any part will be considered non-responsive to this Solicitation and may be rejected during administrative screening. 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.

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 what will be done, where it will be done, and how it will be done. 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.

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 principal investigator 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. Key personnel are the principal investigator and other individuals whose expertise and functions are essential to the success of the project. Provide bibliographic information including directly related education and experience.

This part shall also establish and confirm the eligibility of the principal investigator (Section 1.5.3), and indicate the extent to which other proposals recently submitted or planned for submission in 2000 and existing projects commit the time of 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 SBC team to carry out the proposed Phase-I and projected Phase-II and Phase-III 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 SBIR Phase-I contracts as a direct cost (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 and its principals in marketing-related products or services or in raising capital should be presented.

If an offeror proposes the use of unique or one-of-a-kind Government facilities, a statement, describing the uniqueness of the facility and its availability to the offeror at specified times, signed by the appropriate Government official must be included with the proposal. Proposals lacking this signed statement may be rejected without evaluation. If the proposer does not require the use of Government facilities or equipment, the proposer shall so state in this part of the proposal.

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 provided such arrangements do not exceed one-third of the research and/or analytical work (amount requested including cost sharing if any, less fee, if any). The offeror must describe all subcontracting or other business arrangements, and identify the relevant organizations and/or individuals with whom arrangements are planned. 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.

The expertise to be provided by entities other than the SBC must be described in detail, as well as the functions, services, number of hours and labor rates, and their extent of the effort. The proposal must include certifications by each participating organization and individual 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.

Part 10: Commercial Applications Potential. The commercial potential of the proposed SBIR project is a significant evaluation factor (Section 4.1.2). Therefore, offerors will discuss in this section the broad commercial applications for their project results and plans to bring the technology to commercial application. Offerors should discuss the following:

1) The specific commercial products or services contemplated and the corresponding target market niche;
2) Expected unique competitive advantage of the commercial products or services;
3) Nature of the corresponding contemplated commercial venture;
4) Importance of the contemplated commercial venture to the offeror's current competitive position and to its strategic planning; and
5) The offeror's capability and plans to bring the necessary physical, personnel, and financial resources to bear, in a timely way, to result in a viable commercial venture in the near term subsequent to Phase-II (if awarded).

Part 11: Similar Proposals and Awards. A firm may elect to submit proposals for essentially equivalent work under other federal program solicitations. However, NASA will not fund duplicate proposals for essentially equivalent work under any Government program. The offeror will 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 during 2000. 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;
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 principal investigator/project manager for each proposal that has been or will be submitted, or from which awards have been received.

Note: All eleven (11) parts must be included. Parts that are not applicable must be included and marked **"Not Applicable."**

3.2.5 Proposed Budget

Summary Budget (Form 9C). The offeror shall complete the Summary Budget, following the instructions provided with the form (Section 9) 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.

Property. NASA will not fund facility acquisition under Phase-I (Section 5.17). Proposed costs for materials may be included. "Materials" means property that may be incorporated or attached to a deliverable end item or that may be consumed or expended in performing the contract. It includes assemblies, components, parts, raw materials, and small tools that may be consumed in normal use. Any purchase of equipment or products under an SBIR contract using NASA funds should be American-made to the extent possible.

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.

3.2.6 Addendum

Prior SBIR Phase-II Awards. The Small Business Administration requires offerors, who have received more than 15 Phase-II awards from all agencies in the prior 5 fiscal years, to report those awards and their progress toward commercialization. The listing of awards shall be included in a separate "Addendum: Phase-II History" that will not be counted against the Phase-I 25-page proposal limit. The Addendum should be concise. Information for each Phase-II contract shall include:

1. Name of awarding agency
2. Date of award and date of completion
3. Funding agreement number and amount
4. Topic or subtopic name
5. Project title
6. Sources, dates and amounts of federal and/or private sector Phase-III follow-on funding agreements
7. Post-Phase-II commercialization activities, including development, marketing, sales, and projections

Prior NASA SBIR Awards. Provide a list of NASA SBIR Phase-I and Phase-II awards received, showing contract numbers, the year of award, Phase-I or Phase-II, the NASA Installations making the award, and project titles.

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 contact Jack Yadvish at NASA Headquarters by email at jyadvish@mail.hq.nasa.gov, or phone at 202-358-1981.

3.3 Phase-II Proposal Requirements

The Phase-I contract will serve as a request for proposal (RFP) for the Phase-II follow-on project. Phase-II proposals are more comprehensive than those required for Phase-I. Submission of a Phase-II proposal is strictly voluntary and NASA assumes no responsibility for any proposal preparation expenses.

Proposal Contents. Proposals shall be prepared in the following order. Failure to include any requested information in the proposal may make it non-responsive to the RFP. The proposal shall not contain any budget data and must consist of all 13 parts numbered and in following order. A proposal omitting any part will be considered non-responsive to this Solicitation and may be rejected during administrative screening.

Part 1: Proposal Cover. (Form provided by awarding Center)

Part 2: Proposal Summary. (Form provided by awarding Center)

Part 3: Table of Contents.

Part 4: Results of the Phase-I Project. Briefly describe how Phase-I 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 R/R&D.

Part 5: Technical Objectives, Approach 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 6: 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 7: 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 SBIR Phase-II contracts as a direct cost (Section 5.17).

If an offeror proposes the use of unique or one-of-a-kind Government facilities, a statement, describing the uniqueness of the facility and its availability to the offeror at specified times, signed by the appropriate Government official must be included with the proposal. Proposals lacking this signed statement may be rejected without evaluation.

> If the proposal does not require the use of Government facilities or equipment, the offeror shall so state in this part of the proposal.

Part 8: Key Personnel. Identify the key 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 9: 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. For Phase-II, a minimum of one-half of the work (contract cost less profit) must be performed by the proposing SBC unless approved in writing by the contracting officer. 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.

Part 10: Commercialization and Phase-III Plans. Describe plans for commercialization (Phase-III) in terms of each of the following areas:

(1) Product or Service Commercial Feasibility: Provide a description of the (a) contemplated commercial product and/or service, the corresponding commercial venture, and the unique competitive advantage of both; and (b) technical obstacles to commercial applications, as well as plans to address them.

(2) Market Feasibility and Competition: Describe: (a) the target market niche including the distinction between U.S. Government and other markets; (b) estimated potential market size in terms of revenues to be realized by the offer from U.S. Government markets and, separately, from other markets; (c) competitive environment in terms of present and likely competing similar and alternative technologies, and corresponding competing domestic and foreign entities; (d) significant developments within the targeted business sector; and (e) offeror’s ability, if any, to protect relevant technology with patents or rights to exclusive access.

(3) Strategic Relevance to the Offeror: Describe the relevance of the targeted commercial venture to the offeror's: (a) current business segments; (b) relative position with respect to its competitors; and (c) strategic planning for the next 5 years.

(4) Key Management, Technical Personnel and Organizational Structure: Describe: (a) the skills and experience of key management and technical personnel relevant to bringing innovative technology to commercial application, (b) current organizational structure, and (c) plans and timeline for obtaining the balance of all necessary key business development expertise and other staffing requirements.

(5) Production and Operations: Describe: (a) business development progress to date regarding the contemplated commercial venture; (b) obstacles, plans, and associated milestones regarding all key business development elements; and (c) sources and components of private physical resources committed to date and plans for obtaining the balance of the necessary physical resources.

(6) Financial Planning: Describe: (a) the amounts and sources of private financial resources expended and committed to date with respect to the technology development project, and with respect to business development of the targeted commercial venture; (b) significant requirements of potential investors, creditors, and insurers of the venture; (c) proforma statement of cash flow with respect to the targeted commercial venture that includes best estimates of at least the following major components and timing thereof: capital investment, revenues, principal and interest payments, depreciation of relevant assets, other operating expenses; and (d) evidence of the offeror's current financial strength (audited or unaudited financial statements may be appended to address this).

Part 11: Capital Commitments Supporting Phase-II and Phase-III. Describe and document capital commitments from non-SBIR sources or from internal funds for pursuit of Phase-II and Phase-III. Offerors for Phase-II contracts are strongly urged to obtain valid non-SBIR funding support commitments for follow-on Phase-III activities and additional support of Phase-II from parties other than the proposing firm. Valid 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 to the proposing entity 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.

Part 12: Related R/R&D. Describe R/R&D related to the proposed work and affirm that the proposed objectives have not already been achieved and that the same development is not presently being pursued elsewhere under contract to the Government.

Part 13: Proposal Pricing. Special instructions for pricing the Phase-II proposal will be presented in the Phase-I contract and may be provided by the contracting officer.

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 9B), 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 will give primary consideration to the scientific and technical merit and feasibility of the proposal and its benefit to NASA. Each proposal will be judged and scored on its own merits using the factors described below:

Factor 1. Scientific/Technical Merit and Feasibility
The proposed R/R&D effort will be evaluated on whether it offers a clearly innovative and feasible technical approach to the 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 principal investigator 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.

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, Insufficient Data). 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 SBIR Source Selection Official has the final authority for choosing the specific proposals for contract negotiation.

Firms selected for negotiations that may lead to an award will be notified by e-mail. The list of selections will be announced in a NASA press release and will also be posted on the NASA SBIR/STTR web site **(http://sbir.nasa.gov)**. Selected firms will receive a formal notification letter that identifies the Contracting Officer at the NASA Center responsible for negotiating the Phase-I contract.

4.2 Phase-II Proposals

4.2.1 Evaluation Process. The Phase-II evaluation process is similar to the Phase-I process. Each proposal will be reviewed by NASA scientists and engineers and by qualified experts outside of NASA as needed. In addition, those proposals with high technical merit will be reviewed for commercial merit. NASA uses a peer review panel to evaluate commercial merit. Panel membership will include non-NASA personnel experts in business development and technology commercialization.

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

Factor 1. Scientific/Technical Merit and Feasibility
The proposed R/R&D effort will be evaluated on its innovativeness, originality, and 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. Consideration will be given to the following:

(1) Commercial potential of the technology: This includes an assessment of the offeror's ability to demonstrate: (a) a specific, well-defined commercial product or service based on the technology to be developed; (b) a realistic target market niche of sufficient size; (c) that the targeted commercial product or service has strong potential for uniquely meeting a well-defined need within the target market niche; and (d) a commitment of significant private financial, physical, and technical personnel resources.

(2) Demonstrated commercial intent of the offeror: This includes an assessment of: (a) the importance of the targeted commercial venture to the offeror's current business and strategic planning; (b) a targeted commercial venture that does not rely on continued U.S. Government markets; and (c) the adequacy of all resource commitments for Phase-III development of the technology to a state of readiness for commercial application.

(3) Capability of the offeror to bring successfully developed technology to commercial application: This includes assessment of the offeror's ability to demonstrate: (a) the offeror's past success in bringing SBIR and other innovative technologies to commercial application; (b) well-thought-out business planning; (c) strong likelihood of the offeror's bringing the remaining necessary private financial, physical, personnel and other resources to bear in a timely way to achieve commercial application of the technology in the not too distant term subsequent to Phase-II; and (d) the strength of the current 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 it receives that are responsive to the Phase-II RFP. 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.

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, any request for a debriefing must be made via e-mail to sbir@reisys.com, within 60 days after the selection announcement. Late requests will not be honored.

4.3.2 Phase-II Debriefings. To request debriefings on Phase-II proposals, offerors must request via e-mail to the Procurement Point of Contact 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.

NASA plans to announce the selection of approximately 290 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 intends that all Phase-I projects selected will be placed under contract by mid-December 2000.

NASA anticipates that approximately 40 percent of the successfully completed Phase-I projects from the SBIR 2000 Solicitation will be selected for Phase-II. Phase-II agreements are fixed-price contracts with performance periods not exceeding 24 months and funding not exceeding $600,000.

5.1.2 Contracting. Fixed-price contracts will be issued for Phase-I. Simplified contract documentation is employed. SBCs selected for negotiation of contract awards can reduce processing time by examining the procurement documents, furnishing the contracting officer with signed representations and certifications, and indicating any contract terms to be negotiated or agreement with the contract terms. NASA will make the 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 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.**

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

An interim progress report is required when the invoice is submitted at project mid-point in accordance with the payment schedule (Section 5.3). This report 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 proposal 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.

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 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 an SBIR 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."

Do not label the entire proposal proprietary. The Proposal Summary (Form 9B) should not contain proprietary information.

5.5 Non-NASA Reviewers

In addition to Government personnel, NASA at its discretion and in accordance with 18-15.413-2 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 9A) and the Proposal Summary (Form 9B). 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 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 Program. The clause provides for rights consistent with the following:

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

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

5.8.3 Non-Disclosure Period. The Government, for a period of 4 years from acceptance of all items to be delivered under an SBIR contract, shall use SBIR 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 an SBIR contract.

5.10 Patents

The contractor may normally elect title to any inventions made in the performance of an SBIR 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. To the extent authorized by 35 U.S.C. 205, the Government will not make public any information disclosing such inventions for a reasonable time to allow the contractor to file a patent application.

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

5.12 Profit or Fee

Both Phase-I and Phase-II SBIR 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 2.1. 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 this Program 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 other actions.

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 work week 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 the SBIR 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 an SBIR 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 contract, the terms of the contract are controlling.

5.16.2 Evidence of Contractor Responsibility. Before award of an SBIR 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.

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

When an SBC cannot furnish its own facilities to perform required tasks, an SBC may propose to acquire the use of commercially available 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 titled to the Government.

An offeror may propose the use of unique or one-of-a-kind NASA facilities if essential for the research. Offerors requiring a NASA facility must clearly document and certify that there is no commercially available facility to perform the R&D. It may be difficult, however, to ensure availability, and non-availability may lead to non-selection. Should an offeror propose the use of unique or one-of-a-kind NASA facilities essential for the R/R&D, an agreement with the responsible installation is required and costs for their use will be determined by the installation. These costs may be chargeable in accordance with the Government property clause of the contract. Total contract costs must not exceed the Phase-I and Phase-II funding limits given in this Solicitation (Section 5.1).

6. Submission of Proposals

6.1 The Submission Process

6.1.1 Submission Requirements. NASA utilizes an electronic process for management of the SBIR program. This management approach requires that a proposing firm have Internet access via the World Wide Web, and an e-mail address.

6.1.2 What Needs to Be Submitted. A proposal submission is comprised of two parts:

1. **Internet Submission.** The entire proposal including Forms 9A, 9B and 9C must be submitted via the Internet. (http://sbir.nasa.gov)
2. **Postal Submission**. Postal submission includes an original signed proposal with all forms plus three copies.

> Firms not able to obtain Internet access must request an exemption by calling 301-286-5661 or 301-937-0888 by Friday, June 30, 2000.

Note: Other forms of submissions such as facsimile or e-mail attachment are not acceptable.

6.2 Internet Submission

6.2.1 Electronic Technical Proposal Preparation. The term "Technical Proposal" refers to the part of the submission as described in Section 3.2.4.

Word Processor. 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 for PC are AmiPro, ClarisWorks for Windows, MS Works, Text, MS Word, WordPerfect, Postscript, and Adobe Acrobat. For Macintosh, the acceptable formats are ClarisWorks, MS Works, MacWrite Pro, Text, MS Word, WordPerfect, Postscript, and Adobe Acrobat. Unix and TeX users please note that due to PDF difficulties with non-standard fonts, please output technical proposal files in DVI format.

Graphics. The offeror is encouraged for reasons of space conservation and simplicity, but not required, to embed graphics within the word processed 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).

Limitations. While only the paper copy will be screened for administrative compliance, the various files comprising the electronic version are required to exactly reflect the paper version.

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 submitted electronic technical proposal, may cause rejection of the proposal.**

6.2.2 Electronic Handbook. An Electronic Handbook for submitting proposals via the internet is hosted on the NASA SBIR/STTR Homepage (http://sbir.nasa.gov). The handbook will electronically guide the firms through the various steps required for submitting an SBIR proposal and issue secure-user identification and passwords for each submission. Communication between NASA and the firm will be via a combination of electronic handbooks and e-mail.

> **Note:** After the offeror has submitted Forms 9A, 9B, and 9C via the Internet, the offeror should use the handbook to print the three forms locally. These forms must be signed as appropriate and included in the postal submission.

6.3 Postal Submission

Postal Submissions are comprised of:

1. One original signed paper copy of the proposal, including paper copies of all original forms (as stated in Section 3.2.2)
2. Three additional paper copies of the entire proposal. Each proposal copy is to be stapled separately.

6.3.1 Physical Packaging Requirements for Paper Copies of Proposal. Do not use bindings or special covers. Staple the pages of each copy of the proposal in the upper left-hand corner only. Secure packaging is mandatory. NASA cannot process proposals damaged in transit. All items for any proposal must be sent in the same envelope. If more than one proposal is being submitted, each proposal must be in its own envelope, but all proposals may be sent in the same package. Do not send duplicate packages of any proposal as "insurance" that at least one will be received.

> A checklist is included in this Solicitation to assist the offeror in submitting a complete proposal. The checklist should not be submitted with the proposal.

6.3.2 Where to Send Proposals. All proposals that are mailed through the U.S. Postal Service first class, registered, or certified mail; proposals sent by express mail or commercial delivery services; or hand-carried proposals **must be** delivered to the following address between 8:00 a.m. and 5:00 p.m. EDT:

NASA SBIR/STTR Program Support Office
REI Systems, Inc
4041 Powder Mill Road
Suite 311
Calverton, MD 20705-3106

The telephone number 301-937-0888 may be used when required for reference by delivery services:

6.3.3 Deadline for Proposal Receipt. All proposal submissions (both internet and postal) must be received no later than 5:00 p.m. EDT on Friday, July 14, 2000 at the NASA SBIR/STTR Program Support Office. Any proposal received after that date and time shall be considered late and handled accordingly.

Note: The server/electronic handbook will not be available for internet submissions after 5:00 p.m. EDT on Friday, July 14, 2000.

6.4 Acknowledgment of Proposal Receipt

NASA will acknowledge receipt of proposals to the SBC Official's e-mail address as provided on the proposal cover sheet. If a proposal acknowledgment is not received within 15 days following the closing date of this Solicitation, the offeror should call NASA SBIR/STTR Program Support Office at 301-937-0888. Information about proposal status will not be available until final selections are announced.

6.5 Withdrawal of Proposals

Proposals may be withdrawn by written notice, signed by the designated SBC Official. Withdrawal notice must include proposal number and title.

7. Scientific and Technical Information Sources

7.1 NASA SBIR/STTR Homepage

Detailed information on NASA's SBIR Program 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 01581-5054
Phone: 508-870-0042
URL: http://www.ctc.org

Southeast:
Southern Technology Applications Center
University of Florida, College of Engineering
1900 SW 34th Street, Suite 206
Gainesville, FL 32608-1260
Phone: 352-294-7822
URL: http://www.state.fl.us/stac

Mid-Continent:
Mid-Continent Technology Transfer Center
Texas Engineering Extension Service
Technology & Economic Development Division
College Station, TX 77843-8000
Phone: 409-845-2913
URL: http://www.mcttc.com/

Mid-Atlantic:
Mid-Atlantic Technology Applications Center
University of Pittsburgh
3400 Forbes Avenue, 5th Floor
Pittsburgh, PA 15260
Phone: 412-383-2500
URL: http://www.mtac.pitt.edu/WWW/

Mid-West:
Great Lakes Industrial Technology Center
Battelle Memorial Institute
25000 Great Northern Corporate Center, Suite 450
Cleveland, OH 44070-5310
Phone: 440-734-0094
URL: http://www.battelle.org/glitec

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 Program, 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. 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 four NASA Strategic Enterprises:

Aero-Space Technology
Human Exploration and Development of Space
Earth Science
Space Science

In addition, synergy among the non-Aero-Space Technology Enterprises is captured in a separate section in the Solicitation called:

Cross Enterprise

8.1 AERO-SPACE TECHNOLOGY

NASA's Aero-Space 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

01 Aviation Safety

NASA is responsible for conducting the research that, upon implementation, will contribute to a five-fold reduction in aviation accidents by 2007, and a ten-fold reduction in aviation accidents by 2017. Accomplishment of these goals require technical advances in the following areas: 1) Increased level of safety for all aircraft flying in an atmospheric icing environment; 2) Prevention and/or mitigation of hazardous conditions during or after an aviation accident; 3) Enhanced flight deck situational awareness for the National Airspace System operators; 4) Automated on-line health management and data analysis; 5) Innovative and commercially viable techniques for non-destructive evaluation and health monitoring of materials and structures.

01.01 Aircraft Icing Systems
Lead Center: GRC
Participating Center(s): none

A major goal of the NASA Aircraft Icing Project 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 inflight 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 (i.e., sensitive electronic systems, digital flight decks, and advanced wing designs). Onboard systems must be aerodynamically non-intrusive and practical. They 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:

- Practical, inflight and/or ground-based, real-time remote sensing of the supercooled water droplet and temperature environment. Technology must be capable of 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 and cloud penetration capability.
- Low cost and practical systems that allow the transfer of remotely sensed (ground-based and/or airborne) icing environment information into the existing aviation information infrastructure. The system will provide the end user (cockpit crews, air traffic controllers, and dispatchers) access to accurate and timely descriptions of the remotely sensed icing environment. These systems must operate such that the existing information infrastructure is not adversely impacted by their presence, absence, or failure. Solutions providing coverage to all aircraft within range of the remote sensing system are desired over those that can only protect aircraft with specific equipage.
- In situ icing environment measurement systems that can provide practical, 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. Possible solutions include multiple aircraft sampling and 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.
- Practical analysis tools for the integrated design and optimization of hot gas ice protection systems. The tool must model the entire heat path from source to protected surface, including the conduction path through the surface and the water loading on the external surface.

01.02 Propulsion Airframe Failure Data 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 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 accidents, but the number of fatalities due to in-flight, post-crash and on-ground fires is large. Recent advances have made significant progress for cabin fire safety (e.g., fire-blocking layers in seat cushions); however, new areas of aircraft fire research have been identified (e.g., fuel tank flammability reduction).

A second emphasis is on crashworthiness. For all transport aircraft accidents, 45 percent of those which 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 the problems that may result from mal functions of aging equipment in the service of commercial transport aircraft, general aviation, and commercial rotorcraft. Because of the needs of increased competition and growth in passenger and cargo traffic, the service lives of dependable aircraft models are being extended. Current inspection and overhaul programs focus almost exclusively on structural integrity and the effects of structural corrosion and fatigue. However, much less attention is given to the potential effects of age on non-structural components, which include electrical wiring; connectors, wiring harnesses, and cables; fuel, hydraulic and pneumatic lines; and electro-mechanical systems such as pumps, sensors, and actuators. Deterioration of aircraft components, particularly wiring and electrical equipment, is also linked to breakdowns and unanticipated ignition sources that can cause fires in aircraft flight.

A final emphasis for this Solicitation 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 emphases in mind, products and technologies are sought to enhance human survivability in the event of an accident, to assure continued airworthiness of the aging aircraft, 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 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.
- Concepts to extend the useful safe life of airframe structures and non-structural systems.
- Advanced non-destructive evaluation (NDE) techniques that can be field demonstrated for aging engines.
- NDE-based material and structural modeling that can be integrated in life models for remaining life assessment of airframe and engine components.
- Concepts to prevent catastrophic failures of engine components, or to ensure fragment containment.
- 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 the above aircraft failure-prevention and mitigation technologies.

- Methods for integration of the above aircraft failure-prevention and mitigation technologies into existing or new aircraft.

01.03 Flight Deck Situation Awareness and Crew Systems Technologies
Lead Center: LaRC
Participating Center(s): none

Information technology has and will continue to provide operational opportunities toward increasing the safe and efficient use of the Airspace System. Significant challenges associated with this evolving technology include maintaining or enhancing the situation awareness of system operators, developing user-centered technologies that facilitate human perception and interpretation and that counteract human information processing limitations and biases, and allowing for geographically and temporally distributed operators to work collaboratively.

NASA seeks highly innovative crew systems technologies that will maintain or enhance situation awareness and aid operator decision-making for improved aerospace safety and efficiency. These technologies and methods may take the form of tools, models, techniques, procedures, substantiated guidelines, prototypes, and devices. In addition, we seek 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 informing, advisements, alerts, and aids for Airspace System 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 and group performance analysis methods and tools.
- Human performance measurement technologies for use in operational environments.
- Collaborative and distributive decision making among Airspace System operators.
- Integrated flight deck information systems and procedures.
- Decision support technologies and methods to assist Airspace System operators that enhance situation awareness and improve aviation safety.
- 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 Airspace System operators especially at critical times.
- Development of human-centered information technology for intuitive guidance queues in advanced concepts
- Guidelines and measurement techniques that allow for successful assessment of the application of human-centered design principles to flight deck display concepts

01.04 Automated On-Line Health Management and Data Analysis
Lead Center: DFRC
Participating Center(s): none

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.

01.05 Non-Destructive Evaluation and Health Monitoring of Materials and Structures
Lead Center: LaRC
Participating Center(s): none

Innovative and commercially viable concepts are being solicited for the development of non-destructive evaluation (NDE) and health-monitoring sensors, instrumentation, and computational models for signal processing and data interpretation to establish quantitative characterization and event determination. Evaluation sciences include ultrasonics, laser ultrasonics, optics and fiber optics, shearography, video optics and metrology, thermography, electromagnetics, acoustic emission, X-ray and X-ray detectors, related management of digital NDE data, and biomimetic sensing approaches for structural health monitoring.

- Technologies may be applied to characterizing material properties; assessing effects of defects in materials and structures; evaluating of mass-loss in materials; in situ monitoring and control of materials processing; detecting cracks, porosity, foreign material, inclusions, corrosion, disbonds; detecting cracks under bolts; and real time and in situ monitoring, reporting, and damage detection for structural durability and life prediction, and characterization of load environment on a variety of structural materials and geometries including thermal protection systems and bonded configurations.
- Uses include identification of loads exceeding design, monitoring loads for fatigue and preventing overloads, suppression of acoustic loads, and early detection of damage. Applications are seen for thermal protection systems, adhesives, sealants, bearings, coatings, glasses, complex composite and hybrid structural systems, alloys, laminates, low density and high temperature materials, monolithics, material blends, and weldments.
- The anticipated 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 aerospace systems. There is additional specific interest in non-contacting, remote, rapid, and less geometry sensitive technologies that reduce acquisition costs or improve system sensitivity, stability, and operational costs.

02 Environmental Compatibility

NASA has very aggressive goals for providing technologies which will ensure the noise and emissions environmental compatibility of future commercial aircraft. In particular, the noise goals are to reduce the perceived noise levels of future aircraft by a factor of two (10 EPNdB) within ten years, and a factor of four (20 EPNdB) within 20 years. The emissions goals are to reduce aircraft emissions by a factor of three within ten years and a factor of five within 20 years. These goals are necessary to meet increasingly stringent local, national, and international noise and emission regulations while enhancing operating safety and productivity and increasing aviation system throughput. Accomplishment of these goals will require revolutionary airframe and propulsion technologies be developed and handed off to the aerospace community in a timely fashion. Particular areas of interest are: Noise prediction and reduction technologies for propulsion source noise, nacelle aeroacoustics, airframe noise, and noise minimal flight procedures for future subsonic and supersonic commercial aircraft. Aircraft interior noise reduction technologies to improve passenger and crew comfort. Emissions reduction technologies for ultra low NOx emissions combustor concepts which also reduce the aerosol and particulates emissions. Innovative airframe and propulsion concepts.

02.01 Airframe Systems Noise Prediction and Reduction
Lead Center: LaRC
Participating Center(s): none

Innovative concepts, techniques, 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.
- Concepts for active and passive control of fan, turbomachinery, and jet noise in engine nacelles.
- Reduction concepts and prediction methods for rotorcraft and advanced propeller aerodynamic noise.
- Reduction concepts and prediction methods for jet noise of subsonic, supersonic, and hypersonic aircraft.
- Simulation and prediction of aeroacoustic noise sources including airframe noise and propulsion-airframe integration.
- Computational and analytical structural acoustics techniques for aircraft and advanced aerospace vehicle interior noise prediction, particularly for use early in the airframe design process.
- Concepts for active and passive interior noise control for aircraft and advanced aerospace vehicle structures.
- Prediction and control of high-frequency aeroacoustic loads on advanced aerospace structures and the resulting dynamic response.

02.02 Propulsion System Emissions and Noise Prediction and Reduction
Lead Center: GRC
Participating Center(s): none

Emissions: Current environmental concerns with subsonic and supersonic aircraft center around global warming and the impact on the earth's climate and, if not addressed, may threaten future market growth. Carbon dioxide (CO2) and oxides of nitrogen (NOx) are the major emittants of concern coming from commercial aircraft engines. CO2 is a greenhouse gas which may impact the warming of the earth's climate. NOx emissions can destroy ozone in the upper atmosphere which protects humans from harmful uv radiation from the sun and NOx can produce ozone in the lower atmosphere. Around airports, it appears as smog and causes breathing and health problems. Current state-of-the-art engines and combustors in most subsonic aircraft are fuel efficient and meet the 1996 ICAO nitrogen oxide (NOx) limits. The Kyoto Agreement is applying pressure for additional CO2 reductions, and Europe and the U.S. Environmental Protection Agency are applying pressure for additional NOx reductions at takeoff and possibly cruise conditions. Stringent CO2 and NOx limits could result in emissions' fees or limited access to some countries. Also, 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.

NASA has set some very aggressive goals for reducing emissions of future aircraft by a factor of three within 10 years and by a factor of five within 20 years. Advanced concepts research for reducing CO2 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 are:

- New concepts for reducing carbon dioxide, oxides of nitrogen (NO, NO2, NOx), unburned hydrocarbons; carbon monoxide, particulate, and aerosols emittants (novel propulsion concepts, injector designs to improve fuel mixing, catalysts, additives, etc.); 1. New fuels for commercial aircraft which minimize carbon dioxide emissions; 2. 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; and 3. 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 2 D and 3 D data; time history measurements; and thin film, fiber optic, and MEMS-based sensors are of interest.

Noise: NASA intends to provide enabling technologies to reduce the perceived noise levels of future aircraft by a factor of two (10 EPNdB) from 1997 technology aircraft by 2007, and a factor of four (20 EPNdB) by 2022. These goals are necessary to meet increasingly stringent local, national and international community noise regulations while enhancing operating safety and productivity and increasing aviation system throughput. Engine noise reduction technologies are required in the areas of propulsion source noise, nacelle aeroacoustics, and engine/airframe integration. These aggressive aircraft noise reduction goals will require revolutionary advances in propulsion technologies. 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 and demonstrated on a relevant source. 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 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 for commercial aircraft concepts. Enabling technologies shall be identified for future research.

03 Space Access and Transportation

Goals include reducing the payload cost to Low Earth Orbit by an order of magnitude, from $10 K to $1 K per pound, within 10 years and from $1 K to $100's per pound by 2020. Of paramount importance is the increase in safety and reliability of our space transportation systems and our goal is to increase flight safety by two orders of magnitude within 10 years and by four orders of magnitude in 20 years. The following are some specific areas that will provide significant advancements. Technologies for hardware concepts, subsystems, and design and analysis tools to support development of advanced launch vehicles while lowering operations cost. Technologies for improvements in vehicle structural margins, propulsion system power densities and/or specific impulse over current earth-to-orbit and space propulsion systems. Methodologies that emphasize justification for selection of matrix material constituents, fibers, interface coatings, fabric architecture, etc. Advanced hypersonic technologies that could impact the design and optimization of future hypersonic vehicles. Airframe technologies in materials and structural concepts, validated, safe structural analysis and design technologies, and improved manufacture of large-scale, advanced structures. Thermal-structural designs for primary structures such as propellant tanks, intertanks, wings, and thrust structures; discrete load carrying systems; along with thermal management/environmental protection that are integrated in these systems. Technologies for materials, processes, and manufacturing that will provide safe, reliable, lightweight, and less expensive launch vehicle and spacecraft components. Concepts for propulsion test operations which 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.

03.01 Advanced Launch Vehicle Systems
Lead Center: MSFC
Participating Center(s): none

Advanced launch vehicle systems will require high mass fraction, reliable system performance, and extended reusability in order to achieve cost goals. This subtopic emphasizes innovative hardware concepts, subsystems, and design and analysis tools to support development of advanced launch vehicles while lowering operations cost. Methodology, design and analysis tools, and hardware developed under this subtopic should address technical issues related to propellant tanks, thermal control subsystems, thermal protection systems, structures, guidance, navigation, and control (GN&C), supporting discipline analysis, and launch vehicle systems integration issues. Specific areas of interest for advanced technologies and innovations include the following:

- Low cost designs, concepts, and manufacturing processes for tanks and vehicle structures; and innovative approaches and techniques to reduce small payload launcher costs.
- Control and health management of vehicle structural systems by using sensors and effectors that have little influence on the structural system parameters with the exception of the structural damping parameters. Continuous estimation of center of mass and inertial properties. Real-time tuning of control algorithms to reflect known changes in vehicle response or sensor performance, and accurate, continuous estimation of fuel remaining on board.
- Advanced concepts and techniques for thermal control of vehicle subsystems and payload thermal accommodation.
- Thermal protection system concepts, instrumentation analysis tools, and testing techniques for reusable vehicles, cryo-tanks, and vehicle base heat shield regions.
- Innovative system level models that support the design, analysis, and integration of vehicle subsystems and propulsions systems into the vehicle (such as the ability to assess operability of the systems and to model the impacts of design changes on vehicle cost, operations, vehicle aerodynamics, and controllability).
- Integrated CAD, solid-model, structural, dynamic, thermal, and fluid-flow analysis methods for multi-disciplinary analysis and optimization of launch vehicles, and vehicle subsystems; and improved vehicle analysis tools in the areas of stress, thermal, structural, and fluid dynamics.
- Automated propellant management systems; and technologies and innovative engineering capabilities to produce propulsion storage, feed, pressurization, fill and drain, vent, and support/restraint systems that are robust, lighter, or require less volume.
- Optimal fault detection and redundancy management strategies; onboard autonomous mission planning/abort mode determination; execution software and advanced navigation hardware/software architectures; and adaptive GN&C utilizing data from sensors such as GPS.
- Advance guidance concepts that will reduce operational costs and increase reliability by autonomously reshaping trajectories in the presence of abort/failure situations to satisfy vehicle and control constraints and to achieve a safe abort.
- Advance 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 for retuning and analysis.

- Analysis and testing techniques for prediction and measurement of damage and stress including life prediction, 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 materials and subsystems. 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 technologies for integrated structural systems such as integrated thermal and structural cryogenic tanks, efficient and effective repair techniques, technologies for modal, acoustic and static testing of large-scale aerospace structural systems, experimental-empirical methods for composite material thermal characterization and response prediction.

03.02 Revolutionary Space Propulsion Technologies
Lead Center: MSFC
Participating Center(s): none

This subtopic focuses on innovative, advanced propulsion technologies, devices and systems that could lead to dramatic reductions in launch costs, rapid and affordable in-space transportation, and ambitious exploration of the solar system and beyond. Technologies that offer significant improvements in vehicle structural margins, propulsion system power densities and/or specific impulse over current earth-to-orbit and space propulsion systems are sought. Concepts that can be applied to high-payoff commercial 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:

- Advanced airbreathing/rocket combined cycle engines. Technologies may include high-performance concepts based on non-chemical energy sources, deeply cooled turbojets, and liquid air cycle engines.
- Advanced propellants and high-energy density materials. Technologies may include 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 Magneto Hydro-Dynamic (MHD) interactions for thrust generation, drag reduction and power generation.
- High-power electric propulsion systems. Technologies may include high-power density energy sources, advanced energy conversion techniques, and pulsed inductive and electromagnetic plasma thrusters.
- Fission propulsion. Technologies may include solid-core nuclear thermal rocket fuels, components and systems, gas-core thermal rockets, external pulsed plasma propulsion, 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.
- Solar thermal propulsion. Technologies may include solar concentrators, lightweight concentrator support structures, engine/thrusters for solar energy conversion, and controls and pointing systems.
- Sails. Technologies may include solar, magnetic, laser, microwave and plasma sail systems, lightweight, high-strength, high-temperature materials, and high-power, space-based lasers.
- Electrodynamic and momentum transfer tethers. Technologies may include materials or coatings for improved performance and lifetime, designs and analysis for tether behavior and dynamics, and testing and characterization techniques.
- 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.
- "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.

03.03 Lightweight Engine Components
Lead Center: MSFC
Participating Center(s): none

Next generation space propulsion systems must address the significant challenge of achieving lower life-cycle cost while increasing safety & performance relative to current propulsion systems. Innovative processing methodologies and use of lightweight engine components offer the potential for increases in propulsion safety and for cost reduction. NASA, through this subtopic, is seeking research proposals that:

- Justify selection of matrix material constituents, fibers, interface coatings, fabric architecture, etc.
- Control processing parameters to ensure successful scale-up and reproducibility.
- Verify processes with microscopic analysis (e.g., microprobe, SEM, XRD, BET, etc.) and macroscopic analysis (e.g., tensile strength, interlaminar shear strength, thermal and physical properties, etc.).
- Verify specific end-use application by testing for permeability, thermal shock, etc. and
- Evaluate components and/or coupon material nondestructively (NDE).

Composites are desired composed of fibers selected by end users such as high strength SiC fibers, carbon fibers, and ultrahigh temperature type fibers, component health monitoring fibers, and a hybrid tow or architecture composed of the fibers mentioned. Advanced fiber interface coatings yielding optimal composite life and composite performance with respect to cost and time for fabrication are desired which are resistant to hot steam & hydrogen environments (eg. platinum & other refractory metals & metal alloys, silicon tetra or hexaboride, zirconium silicide, boron carbide, multi-layers, etc.) Matrices selected by end users such as silicon, zirconium, and hafnium based matrices. Also matrices or doped matrices composed of, or formed in situ during operation, hafnium silicate & zirconium silicate type matrices are desired. Matrices that resist environmental erosion and reactive gas diffusion are desired.

Proposals are sought which address the Advanced Space Transportation Program goals by quantifiably describing the technology advancement payoff beyond the state-of-the-art. For those efforts which fabricate components, plans are sought which describe how the component will handle the projected or potential system requirements (i.e., how blisk handle hoop and interlaminar shear loads, how cooled or gas path parts are manifolded to metal connections, how unique components are joined and function, level to which thrust chambers & ducting are impermeable with time, etc.). Flexible, detailed test matrices correlated to processing variables are also of interest in the proposal and reports. Also, please note any manufacturing scale-up necessary for the target components and list the deliverables. Deliverables that are sought 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).

When components are delivered to NASA for potential testing & analyses, possible means to manifold (for cooling and gas ducting) and attachment plans are sought. Specific areas of technology development include, but are not limited to, the following:

- Development of lightweight turbomachinery components [e.g., integrally bladed disks (blisks), rotors, stators, housings, seals, etc.] having capability to operate in hot (> 1000 C) hydrogen rich steam and oxygen rich environments.
- Development of fabrication techniques capable of producing uniform densities in CMC blisks for thicknesses ranging from 1 to 3 inches, and diameters up to 18 inches.
- Innovative technologies providing lower cost, lightweight combustion components (e.g., cooled and uncooled thrust chambers and nozzles, injector faceplates, minimal erosion throats, etc.) for LOX/H2 and LOX/RP environments.
- Ultrahigh temperature (greater than 2000 degrees Celsius) propulsion and plasma confinement development for solar thermal absorbers and nuclear thermal applications.
- CMC components or components lined with CMCs which can contain pressure.

- Continuous nanofiber or microfiber preform such that the fibers are connected to each other in the fashion of a foam and having high nearly isotropic CMC tensile strength properties suitable for propulsion applications.
- Fabrication of a simple CMC or ceramic lined turbopump housing.
- Fabrication of a simple CMC or ceramic, impermeable, reliable turbopump housing.
- Development of CMCs with preforms containing fibers aligned in principal stress trajectories, hybrid (fiber type & size) preforms, process & component operation health monitoring preforms, etc. Characterization of CMC components with unique > 2D preforms.
- Development of functionally gradient materials for preceding applications.
- Low cost (with metrics), rapid, scalable, repeatable CMC fabrication processes development for preceding applications.
- Joining of ceramic composites to CMCs and ceramics for thrust chambers, uncooled & cooled nozzle components, blisks, injectors, housings, & end user specified components accounting for ply direction and surface condition.

All monolithic ceramic development must be justified for use on manned or unmanned flight vehicles. A commitment must be obtained from end users that state the risks and results of impact damage to the component which are acceptable for the monolithic ceramic components.

03.04 Hypersonic Vehicle Design and Systems Technology
Lead Center: LaRC
Participating Center(s): none

Innovative system-oriented research is sought to support, develop, and/or enable advanced hypersonic technologies that could impact the design and optimization of future hypersonic vehicles. The focus is on hypersonic airbreathing vehicles with emphasis on hypersonic cruise airplanes and single- or two-stage-to-orbit vehicles. Design/analysis software/algorithms and graphical user interfaces to the software to address hypersonic vehicle design and performance prediction needs can include the following:

- Conceptual and preliminary design.
- Total multidisciplinary configuration design and optimization.
- Three-dimensional methods for external and internal vehicle/propulsion flowpath analyses (includes CFD and closed form methods or a combination thereof).
- Vehicle sizing and scaling.
- Subsystems design/database including sizing, integration, and networking routines with or without power balance capabilities.
- Methods for design/analysis of cooled leading edges including heat load predictions.
- Inverse design methods.
- Trajectory design, analysis, and optimization.
- Aerodynamic/aerothermodynamic performance prediction methods.

Advanced hardware and systems with the potential to reduce structural weight fraction and/or increase vehicle performance are sought and can include:

- Heat exchangers, reactors, and secondary coolant designs for endothermic fuel systems.
- Propulsion cycles applicable from Mach 0 to 25 and accompanying design and integration techniques.
- Heat-rejection radiators, compact, high-performance convective heat exchangers, and cooling panel design.
- Lightweight, durable coating or insulation systems that can significantly reduce the aerothermal heat load to external/internal surfaces with those improvements.
- MHD propulsion/flowpath.
- Systems for reduction of drag at hypersonic speeds.
- Plasma augmented propulsion.
- Systems for reduction of aeroheating at hypersonic speeds.
- Innovative flight controls.
- Specialized hypersonic fuel systems.

03.05 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.

03.06 Launch Vehicle Manufacturing Technologies
Lead Center: MSFC
Participating Center(s): none

NASA seeks new and innovative technologies for materials, processes, and manufacturing that will provide safe, reliable, lightweight, and less expensive launch vehicle and spacecraft components. Advanced materials and fabrication processes will enable next generation advanced space transportation systems. Projects should focus on technologies leading to decreased cost, and reducing the weight of systems and components while increasing reliability and service life above current capabilities. Only processes that are environmentally friendly and worker-health-oriented, will be considered. Proposals in the following areas of interest are sought:

- Innovative materials and manufacturing technologies that utilize advanced polymer matrix composite materials. Areas of interest include, but are not limited to:
  - Large scale manufacturing
  - Non-autoclave curing; especially automated fabrication techniques using e-beam, and thermoplastics
  - Technologies for providing damage tolerant and repairable structures
  - Development of materials and manufacturing processes compatible with Fuels/Oxidizers
- Developments in "Intelligent Synthesis Environment" and collaborative engineering tools for manufacturing. Emphasis is placed on:
  - "The Manufacturing Element" of Life Cycle Product Development including 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)
- Rapid-prototyping technologies leading to improved structural integrity materials for use in end-item component processing.
- Innovations in aerogel insulation which effectively address: the strength limitations of most aerogels; the environmental and safety issues associated with aerogel manufacture; efficient processes for application of aerogel to space hardware.
- Biomimetic processes with high potential for increased structural properties and decreased weight.
- Fabrication and joining of advanced metallic and metal matrix composite (MMC) materials for increased strength and reduced weight. Areas of interest include, but are not limited to:
  - Particulate, fiber or hybrid composites, high or low temperature application, gaseous/liquid oxygen or hydrogen compatibility application
  - Isotropic property for ultra high strength and lightweight metals, alloys and nanophase materials to achieve more than 120 ksi tensile strength at room temperature, and 60 ksi at elevated temperature above 500 F
  - Low cost and net shape fabricating methods for metal matrix composites and advanced metallic materials
- Innovative technologies for bonding and joining of similar and dissimilar 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.

03.07 Space Propulsion Systems Test Operations
Lead Center: SSC
Participating Center(s): none

Proposals are solicited for innovative 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

- New innovative non-intrusive sensors for measuring flow rate, temperature, pressure, rocket engine plume constituents, effluent gas detection, hydrogen leak detection, and hydrogen fires.
- On-line particulate and quality sampling for facility propellant (liquid oxygen and hydrogen) and support gas systems (helium, hydrogen, oxygen, nitrogen, and missile-grade air).

Improvement in Ground-Test Operation, Safety, Cost-Effectiveness, and Reliability

- Smart system components (control valves, regulators, and relief valves) which provide real-time closed-loop control, component configuration, automated operation, and component health.
- Cryogenic propellant transfer system operation technologies which include automated propellant transfer, automated propellant-line (liquid hydrogen) purge systems, and automated and/or manual propellant-line quick-disconnect systems.
- Long-life, liquid-oxygen-compatible seal technology.
- Cryogenic storage tank lifetime monitor systems for temperature cycles, stress, acoustics, pressure and shock.

Application of System Science to Ground-Test Operations in a Resource Constrained Environment

- Digital simulation techniques to support decision making processes to address reliability, availability, and return on investment and training of environment for test conductors.
- Techniques to improve high-speed data acquisition and high-speed video systems for test area data and video transmissions.
- Techniques to reduce required sample size to maintain acceptable levels of confidence in cost data.
- Risk management techniques.

04 Small Aircraft Transportation System

Numerous factors combine to create opportunities a small aircraft transportation system for business and personal travel in the 21st century. These include rapid growth in air travel (increasing pressure on National Airspace System (NAS) capacity and safety and for affordable NAS operations for the Government and users), declining numbers of communities served by scheduled air carriers, increasingly stringent international environmental standards, an aging fleet of small aircraft, and aggressive foreign competition. NASA seeks innovative technologies supporting advances in flight systems, airspace and ground systems infrastructure, integrated design and manufacturing and aircraft configuration design concepts as well as general aviation propulsion technologies.

04.01 Small Aircraft Transportation System Technologies
Lead Center: LaRC
Participating Center(s): none

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 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 by half. Advanced concepts for roadable aircraft are also desired. This category must include a sound business plan 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, 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

- 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.

04.02 Small Aircraft Transportation System Propulsion Technologies
Lead Center: GRC
Participating Center(s): none

NASA seeks proposals that offer small aircraft dramatic improvements in acquisition and life-cycle costs, performance, safety and reliability, environmental compatibility (noise, emissions and fuel), ease of operation and passenger comfort through innovative propulsion concepts and/or integration of innovative propulsion technologies. In all cases, the offeror must demonstrate acquisition and life-cycle costs that are at least comparable to current propulsion system costs. Anticipated benefits must be defined using appropriate theoretical and experimental data. An understanding of the basis of the technology innovation and its application to aircraft engines must be demonstrated. Offerors must address commercialization potential. Paths to FAA certification must be described. Proposals are sought in the following areas:

Propulsion Technologies. NASA seeks propulsion technologies for small aircraft that will result in substantial improvements over those targeted in the NASA General Aviation Propulsion program. Any improvements in areas such as performance, safety, and environmental compatibility must be accomplished with affordability as a prime consideration. Substantially reduced costs, at least 75 percent less than current systems, are highly preferred. Advanced technologies which could lead to advantageous alternate propulsion systems and fuels (e.g., electric propulsion, hydrogen fuel, etc.) are also sought. Offeror must provide strong rationale for the viability and affordability of the propulsion concept which would use the proposed technology, and show substantial benefits over conventional propulsion systems. It is recognized that unconventional propulsion systems will likely be long term developments, however, it is highly preferred that the specified technology development addressed by the offeror have an application which could be commercialized in the nearer term.

Propulsion System Control and Health Monitoring Technology. NASA seeks proposals for low cost electronic engine control and health monitoring system technologies which substantially reduce pilot workload, fuel consumption, and engine emissions, and increase safety, reliability, and time between overhaul (TBO). Engine diagnostics should focus on pilot notification of engine status and operability, post-flight diagnostic methods, trend analysis, maintenance aides, and automatic fault accommodation. Much of this technology already exists, but it is too costly and/or too costly to certify for light aircraft. In some cases, cost reductions by orders of magnitude must be achieved. Development of methods for using commercially available high volume hardware and achieving low cost software production and validation is encouraged.

05 Aero-Space Vehicle Design Tools

The Aero-Space Technology Enterprise is engaged in developing the tools, techniques, and technologies to revolutionize the design and development processes of the aerospace industry with the goal to reduce the aerospace vehicle development cycle time by one-half. Aerospace vehicle systems design of the future will more fully integrate the various aerospace disciplines and require a greater understanding of not only the critical physics of the various disciplines, but also how the physics of the various disciplines play together. Thus, an important element in the next generation design of aerospace vehicle systems will be the control of these physics to enhance safety, affordability, productivity, and environmental compatibility. The concept of design spans the evaluation of requirements;

consideration of manufacturing, operations support, and other non-traditional domains; effective utilization of ground and flight test results, up to the point of actual manufacture. Information technology, advanced physics-based analytical tools, methods to control the process of design, innovative test instrumentation, and flow control and simulation are key areas in this effort.

05.01 Modeling and Control of Complex Flows Over Aerospace Vehicles and Propulsion Systems
Lead Center: LaRC
Participating Center(s): none

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 subsonic, transonic, and supersonic aircraft, and 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, boundary layer transition and turbulence; 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 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.
- Control and/or mitigation of separation, and vortical flows, including drag-due-to-lift, and shock 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, improved boundary condition procedures, efficient grid-algorithm interfacing, and applications of automation techniques.
- 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 of 100 kHz.

05.02 Modeling and Simulation of Aerospace Vehicles in a Flight Test Environment
Lead Center: DFRC
Participating Center(s): none

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, multi-disciplinary, 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.

06 Advanced Concepts and Experimental Flight Research

The NASA Aero-Space Technology Enterprise is engaged in developing the tools, techniques, and technologies to revolutionize the Aerospace design and development process. This topic seeks advanced vehicle concepts that accelerate the exploration of high-risk, breakthrough technologies in order to enable revolutionary departures from traditional approaches to air vehicle design (Revolutionary Aerospace Vehicle Systems Concepts), propulsion (Revolutionary Technologies and Components for Turbine Based Combined Cycles), and flight test (Flight Sensors, Sensor Arrays, and Airborne Instruments for Flight Research).

06.01 Revolutionary Aerospace Vehicle Systems Concepts
Lead Center: LaRC
Participating Center(s): none

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 technologies 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 technologies applicable to these. 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 aircraft designs. Innovative system-oriented research to support, develop, and/or enable advanced airframe technologies and concepts that could impact the design and optimization of any future class of aircraft.

Efficient, design-oriented application software embodying the mathematical and algorithmic aspects of both multidisciplinary design optimization (MDO) and systems analysis methods for aerospace vehicles.

Adaptation of newly emerging technologies, such as biomimetics and carbon nanotubes to aerospace vehicle concepts.

06.02 Revolutionary Technologies and Components for Turbine Based Combined Cycles
Lead Center: GRC
Participating Center(s): none

A turbine based combined cycle (TBCC) propulsion system consists of low-speed turbine engine propulsion and high-speed propulsion, probably RAM/SCRAM, to achieve missions of high-speed aircraft, access to space, global cruise, and high-speed transports. NASA seeks highly innovative approaches in all technologies and components pertinent to TBCC which will enable high thrust-to-weight turbine engine operation over the flight spectrum up to Mach 5. The emphasis in this subtopic is on revolutionary changes to the existing state-of-the-art. Specific technical areas include the following:

- Advanced cooling concepts that provide reduced 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 fuel distribution, piloting, flame holding and active and passive combustion controls in order to extend the operability of the combustion components to a wider range of operating conditions which would be experienced in a TBCC engine.
- 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 to enhance the performance and reduce the cost and weight; and 3) innovative life prediction techniques for ceramic/composite turbomachinery components.
- New concepts to combine turbine propulsion with other propulsion concepts to achieve acceptable thrust and fuel consumption over the entire flight spectrum of a TBCC. Proposals for these concepts should address analytic assessments of feasibility, cost/benefit tradeoff studies, and engine life cycle analyses.

06.03 Flight Sensors, Sensor Arrays, and Airborne Instruments for Flight Research
Lead Center: DFRC
Participating Center(s): none

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) 0 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.

07 Aviation System Through-Put

A major NASA goal in global civil aviation is to triple the aviation system throughput in all weather conditions while maintaining safety. An additional goal is to significantly reduce the cost of air travel. These increases in the capacity and productivity of the National Airspace System (NAS) can be achieved through development of revolutionary ground-based and airborne operations systems, and vehicle concepts.

07.01 Advanced Concepts in Air and Space Traffic Management
Lead Center: ARC
Participating Center(s): none

Air-Traffic Management (ATM) combines the traditional separation assurance performed by Air-Traffic Control (ATC) and the flight-path management functions concerned with improving system capacity and capability. The challenge for the next generation ATM system is to accommodate growth in air traffic while reducing the aircraft accident rate by a factor of five within 10 years, and by a factor of ten within 20 years. This can only be achieved by the introduction of technical innovations in communication, navigation, and surveillance (CNS) and by the development of decision support tools for controllers, pilots and airline operations. It also requires a new look at the way airspace is managed and automation of some crew functions, thereby intensifying the need for a careful integration of machine and human performance. 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 (en route, terminal and surface).
- Integration of DST across different airspace. Simulation and modeling tools to assess benefits of new concepts. Technologies and concepts leading to greater airborne operational independence.
- Methods of integrating air and ground roles and responsibilities.
- Distributed decision making and its impact on the stability of the airspace.
- System recovery and safety in the event of failure of sensors and decision support tools.
- Weather modeling and improved trajectory estimation.
- New concepts in air space management and impact of Commercial Space Transportation on ATM.
- Role of data exchange and data link in co-operative decision making.
- Modeling of National Airspace System.
- Human factors and workload concepts relating to safe control/integration of aircraft and other ground vehicles systems.
- Concepts and innovative methods to integrate simultaneous movement of the ground vehicles and the aircraft fleet.

07.02 Rotorcraft/STOVL Aerodynamics and Dynamics
Lead Center: ARC
Participating Center(s): none

Many aspects of rotorcraft/STOVL (Short Take-Off and Vertical Landing) aerodynamics and dynamics are not thoroughly understood or adequately predictable enough to enable efficient and accurate design processes for economically viable civil aviation aircraft with vertical lift/STOVL capability. NASA requires innovative methods, approaches, and technologies that describe phenomena involved in rotorcraft/STOVL aerodynamics, dynamics, acoustics and autonomous control; provide greater knowledge of the detailed characteristics of these phenomena; and permit well-verified designs. Innovative developments with applications to tilt rotors, single main rotor and tandem helicopters, coaxial helicopters, hover-capable unmanned aerial vehicles and rotors with on-blade control are needed to refine next generation rotorcraft and STOVL aircraft that will meet civilian global aviation requirements for safer, quieter, more efficient, lower direct operating cost aircraft. These requirements directly impact the enabling technology goals identified by NASA to support the agency's mission in rotorcraft.

Examples of problems currently of importance include: efficient rotor design tools which reduce design cycle time; improved vehicle performance with reduction in ownership and operation costs; advanced active control strategies/methodologies for aeromechanics control and enhanced vehicle capability; innovative solutions for reducing airframe vibration, rotor vibratory loads, and radiated noise; and improving rotorcraft safety. New analysis methodologies addressing the unique aspects of civilian rotorcraft aircraft through CFD/CSM/CAA for individual and integrated vehicle systems are also sought.

8.2 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/

08 Explore the Space Frontier

Earth orbit, the Moon, and near-Earth space, Mars and the asteroids, eventually the moons of the giant planets of the outer Solar System, and someday more distant worlds-these are collectively the endless, ever-expanding frontier of the night sky under which the human species evolved and toward which the human spirit is inevitably drawn. There are certain ideas which many believe to be inherent in the human psyche and integral to American culture: ambition for progress, curiosity about the unknown, the need to pose profound questions and to answer them, the concern of new frontiers that, once achieved, promise a better quality of life for all peoples. Space is such a frontier. Earth orbit, the Moon, and near-Earth space, Mars and the asteroids, eventually the moons of the giant planets of the outer Solar System, and someday more distant worlds-these are collectively the endless, ever-expanding frontier of the night sky under which the human species evolved and toward which the human spirit is inevitably drawn. It is therefore a fundamental goal of NASA to expand the frontier of space progressively through human exploration missions, utilization of space for scientific research, and commercial development.

08.01 In Situ Resources Utilization of Planetary Materials for Human Space Missions
Lead Center: JSC
Participating Center(s): KSC

Significant benefits for future human missions to the Moon, 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 at the planet instead of bringing it all the way from Earth", In Situ Resource Utilization (ISRU) can result in reduction of mass requirements for the exploration mission, reduction in mission risk and cost, and expanded human presence on the planetary surface. It can also enable industrial participation in planetary exploration and commercial development of space. Even though NASA currently does not have approved plans for human exploration missions beyond Low Earth Orbit, studies and mission design efforts, and technology and system development activities are being pursued to develop technologies and mission concepts that can significantly reduce the mass, cost, and risk, or enable robotic and human exploration initiatives early in this century. 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, enable or enhance new mission concepts, be truly innovative, and use methods not already in the literature.

Proposals may be submitted for ISRU concepts at various destinations, including the Moon, Mars, asteroids, etc. However, the focus of this year's subtopic is upon lunar and potential commercial space ISRU applications, and proposals that are responsive to this focus will receive higher priority. Technologies that are applicable to multiple locations or applications will also have appropriately higher weighting. 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 materials to a processing reactor. Such systems should be lightweight, efficient, and capable of operating with minimal human supervision and maintenance.
- Methods for extracting, collecting, and processing (if required) mission enabling or enhancing consumables (propellants, oxygen, etc.), or commercially viable resources and/or products from lunar regolith that are power efficient and require a minimum of Earth-supplied reagents. Alternatives and improvements to previously-studied methods, such as reactors that expose lunar regolith to hydrogen or methane gas at elevated temperature, and extraction and collection of possible water/ice are of interest. However, emphasis should be placed on innovative designs that minimize power requirements, and proposals for water/ice extraction should recognize the uncertainty and potential variability of both the location and abundance of such water.
- Methods for processing surface materials into useful equipment (e.g., solar panels, radio antennas, replacement parts, etc.) which require no further manufacturing or assembly.
- Methods and systems for extracting, processing, and manufacturing in situ materials that can be used for construction of habitable structures or other needed products and infrastructure on the Moon or Mars that enable long-term settlement.

- Methods for extraction, collection and processing (if required) of mission enhancing consumables or commercially viable resources that may be present on the surface or subsurface of asteroids, comets, or other planetary moons of commercial or scientific interest. Proposals in this area should recognize the uncertainty and potential variability of both the location and abundance of such resources.
- Innovative processes and alternative approaches for extracting and producing propellants and/or other mission enhancing consumables and products from atmospheric, surface, and subsurface resources on Mars which have low power requirements and minimize the amount of equipment that must be brought from Earth. Systems should be capable of operating autonomously, independent from continual Earth-based control, and should recognize the uncertainty and potential variability of both the location and abundance of such resources.

08.02 Robotics
Lead Center: JSC
Participating Center(s): KSC

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.

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.

09 Expand Scientific Knowledge

As we have gained control over crucial variables, such as gravitational acceleration, a new window has opened on the world around us. Throughout the history of scientific inquiry on Earth, gravity has been an inescapable and confounding influence. Every living organism we know has evolved under gravity's constant pull; every physical process we have studied, we have studied in the presence of gravity. Access to the environments of space and of the planets has led us to raise new and profound questions affecting our fundamental theoretical understanding of nature including living systems. As we have gained control over crucial variables, such as gravitational acceleration, a new window has opened on the world around us. It is the goal of HEDS to take advantage of the opportunities afforded by space to expand our fundamental knowledge of physical and biological processes - first using relatively simple model systems and then increasingly complex ones. This approach will enable rigorous contributions to both scientific knowledge in general, as well as longer-term advances in technology of benefit to both NASA and commercial applications.

09.01 Exploiting Gravitational Effects for Combustion, Fluids, Synthesis, and Vibration Technology
Lead Center: GRC
Participating Center(s): none

NASA seeks innovative proposals for products to improve the operation and safety of orbiting spacecraft based on chemical and physical processes that exploit the microgravity and partial gravity environment. Also sought are products for application to NASA missions involving Mars and the Moon and for ground-based application and commercialization based on principles, understandings, or testing in simplified, non-convective microgravity and partial gravity fields.

For some demonstrations to support product development, the NASA Glenn Research Center can provide access and assistance to outside investigators in its unique facilities, including the Space Experiment Laboratory, the 2.2-second and 5.2-second drop towers, and parabolic-trajectory (20 seconds of low gravity) aircraft (See Section 5.14). Specific areas of interest are:

- Products based on combustion or related chemical reactions in gaseous, liquid, solid, or mixed phases for application to spacecraft operational needs or to derived ground systems, aided by principles, models, or demonstrations validated in the simplified environment of microgravity and partial gravity.
- Products based on physical contact or transport in fluid, dispersed, or mixed phases for application to spacecraft operational needs or to derived ground systems, aided by principles, models, or demonstrations validated in the simplified environment of microgravity and partial gravity.
- Small-scale intermetallic, ceramic, or similar products produced through combustion synthesis in solid, filter-flow, thermite, or other reactions, with product uniformity, composition, or yield controlled or improved by exposure to the non-convective microgravity and partial gravity environment.
- Products to measure, isolate, or control acceleration, vibration, or jitter for application to spacecraft operational needs or to space experiment payloads or to derived ground systems.
- Sensors, instrumentation, and diagnostics systems for application to non-disturbing measurement of chemical, thermal, or flow parameters in microgravity and partial gravity or to derived ground systems, based on principles, models, or demonstrations validated in microgravity or partial gravity.
- Products to promote or improve fire safety through prevention, detection, suppression, or post-fire restoration for application to spacecraft or to derived ground systems, aided by principles, models, or demonstrations validated in microgravity or partial gravity.
- Fluid dynamic phenomena associated with materials processing, protein crystal growth and separation processes in microgravity and partial gravity as well as in the Earth-bound environment.
- Technology that explains, enables or improves combustion and fluid processes in partial gravity environments to promote application of these processes to NASA's missions involving Mars and/or the Moon.

09.02 Understanding and Utilizing Gravitational Effects on Molecular Biology and for Medical Applications
Lead Center: JSC
Participating Center(s): none

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 implantable 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, oglionuceotides, 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 (-80oC) and biological sample preservation methods.

09.03 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 Gravitational Biology and Ecology 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 specific concern and emphasis include:

- Measuring the atmospheric and radiation environment and optimizing the lighting and nutrient delivery systems for plants.
- Innovative approaches to 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 studies which range from organism development, including gametogenesis through fertilization, embryonic development and maturation, through ecological system stability. Studies may include 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 (O2, CO2, CO, NO2, etc.), and solute concentration (e.g., Na+, K+, Ca2+, Mg2+, SO4 2-, Cl-, PO4 3-, 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. Interests applicable to plant, microorganism, and animal study applications include:

- Expert data management systems.
- Capabilities for specimen storage, manipulation and dissection.
- Video-image analysis for biospecimen (cell, animal, plant) health and maintenance.
- Sensors for primary environmental parameters and microbial organisms.
- Biotelemetry monitors and biological monitors carried on remotely controlled spacecraft.

09.04 Understanding and Utilizing Gravitational Effects on Biotechnology and Materials Science
Lead Center: MSFC
Participating Center(s): none

NASA has interest in experiments that characterize and utilize the influence of microgravity on biotechnology processes and materials science. Areas of interest include protein crystal growth and structural analysis techniques, separation science and technology, advanced electronic and photonic materials research, metals and alloys technology, and glass and ceramic materials technology. Other areas relate to microgravity processing approaches such as containerless processing and advanced thermal processing techniques. Innovations are sought in the following research areas and in their enabling technologies:

Biotechnology
- Advancement of high-yield protein or recombinant drug expression systems that function in cultures grown under simulated microgravity.
- Automatic drug separation and purification from plants and cell cultures grown under confined conditions anticipated for prolonged residence in microgravity or off-Earth habitats.
- Experiments and theoretical research in separation techniques and protein crystal growth for a greater understanding of such processes in the reduced-gravity environment of space.
- Mathematical modeling, new methods, materials, and techniques to exploit the potential of microgravity for the improvement and understanding of biochemical separation processes.
- Instrumentation to determine the influence of crystallization parameters on the size and quality as well as growth rates of protein crystals that lead to commercial and medical applications.

Materials Science

- Technology and instrumentation leading to the formation, interaction and synthesis of particulate materials on Earth and in planetary environments and their application to the establishment of extraterrestrial outposts.
- Materials and studies leading to applications in radiation shielding during human extraterrestrial exploration of space.
- Polymers, composites, and other materials that incorporate sensory, effector, and self-repair technologies.
- Electronic and photonic materials leading to solid-state detectors with improved properties, and controlled crystal growth for scientific and commercial applications.
- Metallic alloys with improved grain structures by directional solidification and processing involving supercooling and undercooling states.
- Simulation capabilities that will elucidate the interaction of transport properties during liquid state processing and can lead to desired microstructures and properties. Experimental design methodologies combining advanced process models, optimization techniques, and control.
- Advanced modeling techniques that can simulate the slow translation of a sample container relative to a host furnace for gradient processing, rapid translation for quench, and the quench. Methods for simplifying this type of modeling process.
- Methods for integrating the furnace with the sample containment system to allow fast, cheap microgravity experiments.
- Experimental sample containment, instrumentation, or processing approaches that enhance scientific return or minimize impact to experiment samples. Two examples are 1) containerless processing to control impurities and nucleation sites or allow processing of reactive melts, and 2) provide rapid cooling of the sample to enhance microstructural analysis.
- Microgravity furnace instrumentation technologies to better understand sample health and experiment status while minimizing the instrumentation's effect on the sample.
- Thermal insulation or heating approaches that enhance safety and use resources more efficiently.
- Microgravity furnace technology for minimizing power, enhancing thermal axial gradients, and improving quench performance, while maintaining flat solidification interfaces, and minimizing disturbances to the sample.

10 Enable Humans to Live and Work Permanently in Space

Human presence will be an inextricable and critical factor in successfully opening the space frontier and expanding knowledge through research in space. Advances in technology notwithstanding, the human element continues to be the major factor in the success or failure of most terrestrial enterprises. In many cases, the human element is a quintessential component in the public's continuing interest in, and support for the space program. Human presence will be an inextricable and critical factor in successfully opening the space frontier and expanding knowledge through research in space. As our activities in space grow, so too must human involvement. In this way we open the door to an array of benefits, tangible and intangible, for the people of the United States and the world. It is therefore a goal of NASA to enable and establish permanent and productive human presence in space, in order to advance America's aspirations in space and increase the opportunities afforded by space through new technologies and new ways of doing business.

10.01 Spacecraft Life Support Infrastructure
Lead Center: JSC
Participating Center(s): ARC, JPL, KSC, MSFC

Advanced life support systems are essential for the success of future human planetary exploration. Striving for self-sufficiency and autonomous operation, future life support systems will integrate physicochemical and biological processes. These hybrid systems, which include plant growth systems for the production of food and oxygen and utilization of recovered wastes, represent an additional closure of regenerative life support systems to further reduce mass 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 desired in all areas of regenerative physicochemical and biological processes for the basic life-support functions of air revitalization, water reclamation, waste management, plant food production, and sensors and controls. Also innovative, cost-effective concepts are desired to assess, predict, control and enhance the effect of microgravity and partial-gravity on the operation and performance of physicochemical and biological life support technologies. In addition to these space exploration related applications, innovative regenerative life support approaches that could have terrestrial application are encouraged. Phase-I research should lead to Phase-II's that strive for experimental development that could be integrated into a functional life support system. 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.

- 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.
- Separation of nitrogen and oxygen from carbon dioxide to reduce concentrations of nitrogen and oxygen to less than 0.2 percent by volume.
- Removal of trace contaminant gases from cabin air with advanced regenerable sorbent materials, improved oxidation techniques or other methods.

Water Reclamation. Efficient, direct treatment of waste water (e.g., urine, wash water, and condensates) without requiring expendables to produce potable and hygiene water including stabilization of waste water and purge gases prior to storage, processing, or overboard-venting. In particular, processes are required that reduce impurities in composite waste streams from greater than 1000 ppm total organic carbon (TOC) content to less than 0.25 ppm TOC and inorganic salts from greater than 1000 mg/l total dissolved solids (TDS) to less than 50 mg/l TDS.

- Physicochemical methods for primary treatment of wastewater to reduce TOC concentration from 1000 ppm to less than 50 ppm and TDS from 1000 mg/l to less than 100 mg/l.
- Methods of processed water post-treatment to reduce TOC from 100 ppm to less than 0.25 ppm, to reduce TDS from 150 mg/l to less than 50 mg/l, and to reduce microorganisms from > 10 million colony forming units (CFU) per ml to one CFU per ml.
- Methods to optimize two-phase fluid movement, measurement and phase separation of gases and liquids in a microgravity environment.
- Development of nitrifying bioreactors capable of at least 75 percent nitrification of a 1000 ppm ammonium feedstream.
- Methods to enhance oxygenation of water in a microgravity environment, specifically to levels above 25 ppm dissolved oxygen.
- Methods of cold sterilization, including filtration, ultraviolet radiation and in situ-generated hydrogen peroxide.
- Non-expendable methods to control urine solids formation (e.g., calcium phosphate), compatible with a bioprocessing system (i.e., no acid).
- Methods to minimize or limit biofilm formation on fluid handling components (such as electromechanical flowmeters, regulators, checkvalves, etc).
- Methods to enhance biofilm formation on polymeric and/or ceramic substrates in metal housings.

Waste Management. Biological and physicochemical technologies for recovering resources (e.g., carbon dioxide, water, nitrogen, hydrogen, ethylene, etc.) from wastes (trash, plant biomass, human fecal wastes, etc.). Existing technology examples follow for which significant improvements may be proposed, but new technology approaches are encouraged.

- Waste stabilization and pretreatment, including but not limited to microbial control techniques and waste fluidization.
- Waste processing techniques such as, but not limited to, incineration, aerobic biodigestion, anaerobic biodigestion, wet oxidation, supercritical oxidation, steam reforming, electrochemical oxidation and catalytic oxidation. Any effective waste treatment technology can be considered.
- Product and by-product post-treatment technologies that eliminate undesirable by-products such as nitric oxide and sulfur dioxide and stabilize the product for storage.

Plant Growth and Food Production. Technologies for the controlled environment production of crop plants to produce food and to contribute to the reclamation of water, purification of air, and recovery of resources.

- Crop Lighting: 1) sources for plant lighting such as, but not limited to, high-efficiency lamps or solar collectors; 2) transmission and distribution systems for plant lighting including, but not limited to, luminaires, light pipes and fiber optics; and 3) 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, including 1) technologies for production of crops using hydroponics or solid substrates; 2) water and nutrient management systems; 3) sanitation methods to prevent excessive build-up of microorganisms within nutrient delivery systems; 4) regenerable media for seed germination plant support; 5) 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 of propagation, seeding, and plant biomass processing. Plant biomass processing includes harvesting, separation of inedibles from edibles, cleaning and storage of edibles (seed, vegetable, and tubers) and removal of inedibles for resource recovery processing.
- Facility or system sanitation methods to prevent excessive build-up of microorganisms within nutrient delivery systems.
- Health measurement of plant growth systems from parameters such as rate of photosynthesis, transpiration, respiration, 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.

Sensors. Significant improvements in accuracy, operational reliability, real-time multiple measurement functions, in-line operation, self-calibration, reduction of expendables, and low energy consumption for monitoring and control of the life support processes. Species of interest include nutrient composition of plant growth hydroponic delivery systems, 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.

10.02 Space Crew Accommodations and Performance Enhancements
Lead Center: JSC
Participating Center(s): none

The goal of this subtopic is improving crew and ground operations performance and productivity in a system context, documenting the cost-effectiveness of the improvements; and developing innovative concepts in crew accommodations, equipment, and computer-based support which will enable complex, future human space missions including missions of 5 years without resupply.

As NASA develops new operational capabilities to support multiple manned missions, and long duration and long distance missions, dramatic improvements will be needed in crew and ground operations performance and productivity. The crew will be increasingly autonomous from the ground, with significant control and maintenance responsibilities. However, the crew will not have the time or expertise to function primarily as operators in an onboard control center or as maintenance personnel. Science activities and operations will produce large volumes of data that will influence decisions about subsequent science activities and operations. Responsibility for updating operations software and associated data and knowledge bases will shift from software specialists to engineers, operations personnel and crew. Communications constraints and increased autonomy will limit ground support. Budgetary constraints and mission complexity will drive innovations in system design, crew accommodations and equipment to make ground support, mission preparation and training more productive. Specific areas of interest for innovations in space crew accommodations and performance enhancements include:

Human Factors
Methods to better predict and analyze crew performance and environmental variables will facilitate effective mission planning and task/function allocation. Better equipment for crew support will enable enhanced performance. Specific areas of interest for innovations in human factors areas include:

- Advanced methods for collecting and analyzing human performance with minimal human operator involvement. For example, methods for automatically identifying categories of performance from videotaped records, such as time spent at a given task, time spent in translation, and time spent in interaction with other crew members.
- New technology in the area of passive human posture, position tracking, and kinematics in 3D capable of accuracy better than 5 mm, with sample rates greater than 50 Hz for the whole body, all the major limbs, and head.
- Technologies or tools to evaluate, measure or enhance habitability including spacecraft interior layout, illumination and material reflectivity, and lightweight acoustic control methods. An area of special interest would be in techniques for reconfiguring spacecraft habitable areas including stowage, galley, sleep compartments, waste management systems, etc. for optimal use in both micro-g during transit to a planetary surface, and in partial-g on the planetary surface.
- New technology for illumination modeling, evaluation, and design with particular attention to real-time displays of shadowing, glare, bloom, and energy distribution.

Food and Food Preparation Systems

- Extended duration missions require food with 3 to 5 years of shelf life. This shelf life extension may be accomplished through packaging and preservation technologies which minimize waste, and improve acceptability and food safety.
- Long shelf life palatable dairy products are needed.
- Food packaging waste is a problem for all missions and methods for reducing food waste are desired. Food waste on Shuttle is currently returned to Earth for disposal. Edible/biodegradable packaging is desirable.
- Advanced food preparation equipment and processes for heating, chilling, rehydration, ease of handling in micro-gravity, and food service onboard space vehicles are also needed, including advanced ovens such as advanced microwave systems, advanced convection systems, induction systems, and combined systems. Current capabilities include a forced air convection oven for Shuttle and a microwave/forced air convection oven is being developed for the International Space Station.
- Processing and preparation of chamber-grown wheat, rice, soybeans, sweet potatoes and potatoes into edible foods in partial gravity (1/6 - 1/3 g) is a high priority for planetary based missions. Methods for converting these crops to edible ingredients and/or foods in a closed environment, while optimizing crew time, volume, power, water usage, and generated waste are needed. Products of interest include oil, sugar, and meat and dairy analogs.
- Advanced methods of flavor enhancement including condiments.

Crew Equipment

- Personal hygiene systems in a zero-gravity environment. Examples: total body cleaning, hand washing; hair grooming, cleansing agents compatible with closed-loop life support systems.
- Personal crew equipment: flame and soil resistant clothing, portable lighting, safety and emergency equipment, and body and equipment restraints.
- Housekeeping for zero-gravity including: habitat cleaning, high efficiency trash compaction and containment systems, apparel cleaning, particulate reduction and control, and cleansing agents compatible with closed-loop life support systems.
- Tools, techniques, and software for an in-flight maintenance system to maintain a complex system, including expert diagnostics, in-flight manufacturing tools/techniques.

Crew Training and Space and Ground Operations

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

- 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 countermeasures.
- 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 reuse 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.

10.03 On-Board Human Health Maintenance, and Countermeasures
Lead Center: JSC
Participating Center(s): ARC, DFRC, 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 and on the psychology of the crew. A variety of environmental monitoring and biomedical activities to protect crew health and to counter the effects of space on human physiology is required. Countermeasures must be developed to oppose the deleterious changes that occur in space or upon return to Earth. Health care and medical intervention also must be provided over extended duration missions. As launch costs are extremely sensitive to mass and volume, sensors and instruments must be small and light with an emphasis on multi-functional aspects. 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, non-invasive sensors, and easy-to-read information displays are all-important considerations.

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

Human Health Monitoring and Countermeasures

- Methods and equipment to maintain and assess levels of aerobic and anaerobic physical capability.
- Methods to monitor physical activity and loads placed on different segments of the human body.
- Exercise equipment able to load the musculoskeletal and cardiovascular systems and monitor, record, and provide feedback about performance.
- Approaches for sustaining, maximizing, assessing, and modeling individual as well as team performance.
- Countermeasures against deleterious changes in body systems in flight or upon returning to the ground. Changes include space adaptation syndrome effects such as space motion sickness, in-flight loss of muscle and bone mass, post-flight orthostatic intolerance, and post-flight reduction in neuromuscular coordination.
- In Vitro methods for evaluating the effectiveness of pharmacological countermeasures against the cellular effects of space radiation.
- 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.
- Approaches to achieve health care and intervention within the operational constraints of space flight, including pharmaceuticals having extended shelf-life, diagnostic methods and procedures, medical monitoring, dental care and surgery, and blood replacement technology.
- In-flight procedures and techniques for assessing the human metabolism of proteins, carbohydrates, lipids, vitamins, and minerals.
- In-flight specimen collection and analysis to evaluate physiological and metabolic and pharmacological responses of astronauts. Non-invasive methods to measure crew performance and related factors.
- Novel software methods for documentation, storage, retrieval, analysis, and diagnosis of crew health.
- Microgravity refrigeration systems for the storage of biological samples and incorporating refrigerants acceptable for use in a spacecraft environment. Development of virtual training tools to enhance adaptability of sensory-motor functions.

Non-Invasive Instrumentation

- Instrumentation to be used for in-flight and ground-based studies for reliable and accurate non-invasive monitoring of human physiological functions such as the cardiovascular, musculoskeletal, neurological, gastrointestinal, pulmonary, immuno-hematological, and hematological systems.
- Instruments to provide a) quantitative data to establish the effectiveness of an exercise regimen in ground-based research and b) measure of bone strain in the hip, heel, and lumbar spine during exercise.
- Smart sensors capable of sensor data processing and sensor reconfiguration.
- Ultrasonic doppler systems for blood flow analysis.
- Virtual medical instrumentation.
- Automated biomedical analysis.
- Analysers for measurement of blood, urine, and respiratory gas volumes in microgravity.
- Non-invasive, biosensors for real-time monitoring blood chemistry, gases, calcium ions, electrolytes, cellular components, proteins, lipids, and hormones.
- Real time, in-vitro, urine chemistry sensors for automated urine chemistry analysis in a smart toilet.

Telemedicine
Telemedicine, the integration of telecommunications, computer, and medical technologies, permits NASA medical doctors and researchers on Earth to monitor the health and physiology of astronauts in space. Innovative technologies are being sought to support the current flight programs (Space Shuttle and the International Space Station), and future Space exploration programs. Telemedicine air/ground communications are supported through available spacecraft communication channels for voice, video, and data. Innovations in the following areas of telemedicine technology are being sought.

- Biomedical monitoring and sensing involves the acquisition, processing, communication, and display of electrical, physical, or chemical aspects of a human's health or physiologic state. This mode of telemedicine may be used for real time monitoring or for store-and-forward applications.
- Autonomous systems for support of medical care and training, where the experience of experts on the ground is programmed into a computer system to provide that expertise to flight personnel in space.

The following telemedicine enhancing technologies are of particular interest:

- Small, portable, medical diagnostic equipment (digital X-ray and ultrasound imaging systems) capable of being deployed and used in space, with provision for downlinking the data to physicians on the ground. Small, low power, wireless communication systems, for bidirectional data/ command communication between instrumented astronauts and spacecraft subsystems.
- Advanced human/computer interface systems for improved immersion in virtual and augmented realities in support of medical operations.
- Expert systems to support medical diagnosis and treatment.
- Virtual reality medical training system to support in-flight training on medical diagnosis and procedures.
- Augmented reality supervisory system to support medical treatment and minor surgery.
- Improved data mining technology for on-orbit access to medical and training databases.
- Reliable means for remote assessment of the emotional state and operational efficiency of crew members during long duration space flight.

10.04 Spacecraft Environmental Monitoring for Crew Health
Lead Center: JSC
Participating Center(s): JPL

Long-term manned space missions require continuous environmental monitoring to protect crew health. Research disciplines include cell biology, clinical chemistry, endocrinology, immunology, hematology, microbiology, muscle physiology, pharmacology, nutrition, radiation biology, toxicology, and air and water quality. Quantitative assessments require innovative, space flight-compatible approaches for environmental health monitoring and clinical laboratory operations. Special instruments are needed to assess the overall acceptability of the environment for human habitation. In addition, methods are needed for determining thresh holds for unacceptable atmospheric contamination levels and for assessing associated risks. Specific areas of interest include:

- In-flight monitoring of the chemical, microbial, and physical quality of the spacecraft environment, including recycled water, atmosphere, food, and surfaces. Of particular interest are the detection, quantitative measurement, and removal of organic contaminants and the assessments of potential health effects for low level contamination.
- Real-time and quantitative broad spectrum or target compound-specific analyzers for trace contaminants in spacecraft atmospheres and/or recycled water. These instruments must be compact, feature low power consumption, low maintenance, highly automated (requiring minimal crew intervention) and must be functional for long periods of time.
- There is a current need for new sensors to quantify levels of hydrogen cyanide in the spacecraft atmosphere.
- Maintenance of microbial quality of the atmosphere, water and surfaces during space flight and means of assessing their effectiveness, including new, clinical microbiology methods for rapid identification of pathogens, methods for measuring bio-films and novel systems for sterilization.

- In-flight monitoring of non-ionizing, neutron and charged particle radiation for determining interior and exterior environment of manned spacecraft, organ doses and the cytogenetic and carcinogenetic effects of protons and heavy ions, especially at low doses; measurement of effectiveness of radio-protectants and development of new biological and chemical radio-protectants against acute and late cellular effects of particulate and high energy cosmic radiation at cellular and organism level; development of biomarkers and amplified assays for measuring radiosensitivity and genetic damages by charged particles in human cells; development of computer biophysical models for organ dose calculation and for extrapolation of radiation data from cell to organism and from animal to human.
- Miniaturized optical sensors (infrared, ultraviolet, or visible light), electrochemical sensors, and biological sensors for measuring chemical contaminants in the atmosphere or water systems. These sensors are used for providing outputs for caution and warning, support of control functions, or safety precautionary measures.
- Selected methods for biomedical testing, sampling, and some inflight analysis are needed to understand the effect of the spacecraft environment on human physiology.

10.05 Extravehicular Activity Productivity
Lead Center: JSC
Participating Center(s): none

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 low ambient pressure, including the gaseous environment of Mars and the hard vacuum environments of the Moon and low Earth orbit.

EVA Mobility
- Space suit gloves, produced with size-reproducible manufacturing processes, that provide highly dexterous hand, fingers, and thumb mobility and tactile sensitivity, and that incorporate active thermal control capability for removing and/or adding heat, depending upon external ambient thermal conditions and hand-grasp surface temperature.
- Space suit soft joints that provide dual-axis capability and low torque in rotational components and that also minimize stowage volume, and that are lightweight, low cost, and large range.
- Space suit shoulder that can accommodate large range of suit pressures from 3.5 to 8.3 psi, and is low torque, lightweight, and low cost.
- Space suit low profile waist-bearing that maximizes torso 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 crewmember cooling, heat rejection, and removal of expired water vapor and carbon dioxide.
- Fuel cell technology that can provide power to a space suit.

- Convection and freezable radiators that will be low cost and weight for thermal control.
- Space water membrane evaporators for a space suit.
- 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.
- CO2 and humidity control devices which, while minimizing expendables, function in a CO2 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
- Information displays and input and output interfaces for use by the EVA-suited individual, including displays for obtaining status information of and/or controlling systems performance or work-task related equipment. Preference is to avoid visual displays since the visual input channel of the crewmember is potentially near saturation.
- CO2, bio-med, and core temperature sensors with reduced size, lightweight, increased reliability, and packaging flexibility.
- IR camera that displays temperature of environment for safe handling of objects and are integratable into a spacesuit.
- Visual camera that provides excellent environment awareness for crewmember and public and are integratable into a spacesuit that is light weight and low power.
- Microphone on glove that detects flows and proper operation of equipment by glove sound sensors.
- Mini-mass spectrometer that detects N2, CO2, NH4, O2, 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.
- Recharge and checkout systems that lower EVA overhead time for crew.
- Work tools that assist the EVA crewmember during movement 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.
- Surface mobility devices for EVA crewmembers.

10.06 Thermal Control Systems for Human Space Missions
Lead Center: JSC
Participating Center(s): none

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:

- Fault tolerant fluid to fluid heat exchangers that cannot fail in a way which permits leakage between fluid loops.
- Heat pumps to acquire waste heat at near 273 K and reject the heat above 300 K.
- Internal heat pumps to provide cabin dehumidification on-orbit with a fluid heat sink of 288 to 298 K.
- Lightweight, flexible radiators which can be stowed compactly for transport and deployed for use.
- Micro-meteoroid tolerant and freeze/thaw tolerant radiators.
- 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 transport loops and associated controls which require low power for operations. Thermal energy storage systems.
- Controllable water evaporator heat rejection devices for use in vacuum environments.
- Microgravity compatible refrigerator/freezer technologies and/or system designs for food or scientific samples storage. Also, refrigerator/freezer technologies and/or system designs for long-duration planetary (partial gravity) usage.
- 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 design and analyses, which are amenable to concurrent engineering processes.

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.

10.07 Spaceport and In-Space Cryogenic Fluids, Handling, and Storage Technologies
Lead Center: KSC
Participating Center(s): 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 extra-terrestrial applications (lunar & mars environments). These focus areas include technologies that will increase the performance, operational efficiencies, safety, and reliability and provide for autonomous cryogenic operations in earth, space and extra-terrestrial environments.

Spaceport Cryogenic Fluids, Handling and Storage Technologies

Advanced technologies are being solicited for spaceport cryogenic systems for conditioning, storage, densification (sub-cooling) of cryogenic propellants and transfer & control to improve operational efficiencies, safety & reliability, and enable autonomous loading and off-loading operations as part of the Spaceport Technologies Initiative. Specific areas of interest include the following:

- Cryogenic pumping systems that minimize thermal losses and can be utilized in liquid oxygen and liquid hydrogen and other cryogenic systems. These systems should possess high reliability and demonstrate ease of maintainability. These systems could be hermetically sealed from ambient surroundings and reduce or eliminate cool down requirements prior to operation and provide minimum loss in standby mode. These devices should provide for defrost free maintenance, plug-in type design and have a minimum of moving parts for increased reliability.

- New technology valves for cryogenic applications, including LOX, LH2, and LCH4 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 compliant cryogenic quick disconnects that can be reliably mated, demated, and remated under high misalignment (25-30 degrees for connectors 1-inch and larger) and dusty/windy conditions. Smaller connectors (1/4-inch to 1-inch) that require a low connecting force (for Mars applications) are critical. Reconnect issues that must be resolved include thermal (potential icing), sealing (surface damage due to environmental contamination), and cleanliness (potentially imposed by wind, etc.).

- Cryogenic couplings utilizing robust sealing technology that are compatible with cryogenic temperatures and liquid oxygen.

- New and innovative technologies to provide for propellant densification (LH2 & LOX). These technologies should provide for increased efficiencies and reduced costs associated in producing densified (sub-cooled) propellants.

- Propellant conditioning systems to load and maintain densified propellants on the spacecraft. System should provide accurate measurement of propellants on board (0.5 percent of total propellant mass) and be able to maintain the densified condition on the spacecraft for up to six hours to accommodate crew ingress and long launch windows.

- Recovery and storage system for gaseous hydrogen as vented from propellant storage and during vehicle loading and drainback operations. Gaseous helium recovery (from hydrogen stream) is also desired. System must have bypass capability to preclude potential launch impact in the event of a subsystem anomaly.

- Propellant servicing mechanisms including umbilical alignment, latching, and release mechanisms which provide reliable and verifiable single and multiple mating, and enable autonomous loading operations. Integrated alignment and connection methods are desirable. Innovative latching technologies such as shape memory alloy applications and technologies that allow for maximum preload with minimal application loading are also desirable.

- Reliable, low cost liquefaction methods are needed to allow for a centralized production site and the transport and re-liquefaction at the launch site via long distance pipelines and extraterrestrial environments.

- Flowmeters and densitometers for measurement of densified, multi-phase cryogen at flowrates from 1.4 to 5.6 liter per second.

- Energy efficient, cost effective distribution systems for transfer of cryogens over long distances (up to several miles in distance).

Low Gravity/In-Space Environment Cryogenic Fluids, Handling and Storage Technologies

Innovative component technology and/or novel system concept proposals are being solicited to improve the performance, operating efficiency, safety and reliability of cryogenic fluid management in low-gravity/in-space environments (10-6 g to 10-2 g) - including liquefaction, transfer/handling, and storage. Cryogenic fluids may be utilized in a wide range of in-space applications, including high-energy propulsion, space energy storage/generation, life support, and other areas. Also, in-space cryogenic propellant depots may be of particular interest for a variety of mission scenarios. However, these could require in-space integration of separately launched depot elements (including cryogen couplings). Moreover, low-pressure/sub-critical cryogenic fluids, stored for extended periods in space are susceptible to fluid loss through environmental heating, resulting in higher costs, lower performance, and limitations on the application of high-energy propellants for various future missions. Technologies that provide for efficient long-term storage (including reduced heat conduction, active cooling, etc.), increased safety and reliability, and measurement, integration of depots from multiple, discrete elements, control and transfer of cryogenic fluids/propellants in low gravity in-space environments are of prime interest. Specific areas of interest include:

- Innovative instrumentation for monitoring a cryogen in low-gravity including mass quantity gauging, liquid vapor sensing and free surface imaging.

- Advanced tank materials and structural concepts - including lightweight, low thermal conductivity tank strut and support concepts.

- Lightweight, insulating thermal protection schemes.

- Low thermal conductivity cryogenic tank penetrations, i.e., instrumentation feed-throughs, fluid lines, and vent lines.

- Innovative concepts for automated cryogenic connects/disconnects and couplings - including connections/transfers from propellant depots to vehicles in a low-gravity environment.

- Robust tank/insulation/fluid management concepts for long-life operations involving multiple ambient/vacuum pressure cycles.

- Innovative devices/approaches for vapor free acquisition of cryogenic liquids in low gravity (including magnetic fluid management concepts).

- Small to moderate capacity, low power, lightweight cryogenic fluid transfer pumps for low-gravity applications.

- Tank pressure control (e.g., thermodynamic vent), and/or integrated tank boil-off control and liquefaction technologies.

Partial Gravity/In-Situ Cryogenic Fluids

Handling and Storage Technologies that enable the autonomous control of cryogenic systems, high thermal efficiencies and lightweight, autonomous liquefaction of cryogens for Martian (high CO_2 atmosphere) and lunar environment are areas of focus. Specific areas of interest include:

- Propellant transfer systems that minimize the potential for cryogenic leaks, as well as minimizing heat leak into the systems. Pipe connections, flexhoses, pumps, valves, components and instrumentation ports are potential leak sources in a cryogenic system. Minimizing these potential areas with non-intrusive instrumentation, redundant seals or self-healing seals is greatly desired. Connectors and seals must reliably maintain a less than 10^{-7} standard cubic centimeters per second leak rate.

- Autonomous cryogenic disconnects and couplings.

- Lightweight thermal protection schemes.

- Tank pressure control (e.g., thermodynamic vent) and/or integrated tank boiloff control and liquefaction technologies.

- Lightweight mechanical fittings and flexhoses with low heat leak properties.

- Low heat leak, lightweight, electromechanical shut-off valves for LO_2 and LCH_4 applications in size ranges from 1 to 1.5 inches.

- High capacity liquefaction systems for oxygen.

- Cryocooler systems with high cooling capacity (greater than 25 watts).

- Very low heat leak oxygen dewars.

- Efficient LH_2 storage systems for transporting LH_2 to Mars and storage on the Martian surface.

10.08 Terrestrial and Planetary Spaceport Instrumentation and Range Technologies
Lead Center: KSC
Participating Center(s): none

This subtopic focuses on the development of sensors, transducers, instrumentation systems, meteorological and range technologies uniquely suited to and used at earth and planetary spaceports for processing, launch, tracking, controlling, and landing of space vehicles and payloads. This subtopic also focuses on sensors, transducers and instrumentation systems uniquely suited for instrumentation test beds to be characterized as payloads on Space Shuttle or other future space vehicle flights as well as space and ground based range systems. These test beds will be used to develop Integrated Vehicle Health Management System technologies with potential applications on future space systems. Specifically, this solicitation subtopic includes:

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 18 G vibration over a range of 5-2500 Hz for 15 minutes, 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.

Portable Hydrazine Vapor Sensors. Development is needed for portable direct-reading sensors, which can rapidly and accurately measure hydrazine and monomethyl hydrazine vapors over a range of 1 to 1000 parts per billion (ppb). The sensor should be easily carried and operated by one environmental health technician, and thus the mass of the sensor should not exceed one kilogram and the maximum volume 3500 cubic centimeters. The instrument should be capable of accurately measuring the target vapors with a maximum error from all sources of plus or minus two parts per billion or ten percent of reading, whichever error is greater. The instrument should respond to a positive or negative change of concentration in less than 60 seconds to achieve 90 percent of the accurate final reading when exposed to concentrations of 10 to 1000 ppb hydrazine or monomethyl hydrazine vapor in normal air. The sensor should not give a false hydrazines indication greater than 5 ppb in response to other chemicals such as nitrogen dioxide, isopropyl alcohol, ammonia, and carbon dioxide at of their respective allowable concentration time weighted averages (TWA) as defined by the American Conference of Governmental Industrial Hygienists (ACGIH). The sensor should be capable of operating in 0-50 degree C air having a relative humidity range of 10 to 90 percent. The sensor should require 15 minutes or less warm-up time to reach full performance level, operate without requiring either calibration or maintenance for 3 months, and be capable of continual operation up to 16 hours. Current portable hydrazine sensor technologies require more than 10 minutes to achieve 90 percent of final reading when exposed to 10 ppb monomethyl hydrazine vapor and require calibration approximately every 30 days.

In Situ Test Bed Micro Sensors. The development of Mars In Situ Propellant Production (ISPP) systems requires lightweight, low power micro-sensors for use on space flight test beds to detect H_2, CO, CO_2, O_2, CH_4, Argon, and N_2. Applications include Mars ground fuel production systems and hydrocarbon based rocket engines. For all sensors, the following specifications apply, including electronics, to give an output in engineering units or a high level electrical output. Volume, < 20 cc; Weight, < 20 grams; Power, < 0.3 watts; Range, 0 - 100 percent (v/v);

Accuracy, +/- 0.5 percent; Response Time, < 10 seconds for a 90 percent response to a step change. The devices should survive vibration to 20g RMS (5 - 2500 Hz) and shock to 40g for 11ms. The operating temperature ranges should be: H_2, 0 to 500 degrees C; CO, 0 to 1000 degrees C; CO_2, -80 to 1000 degrees C; O_2 -80 to 1000 degrees C; CH_4, -80 to 500 degrees C; Argon, -80 to 400 degrees C; N_2, -80 to 400 degrees C. Also required is electromagnetic compatibility per MIL-STD-461 C. All specifications should be met for an unattended operating period of at least 3 years. Integration of several sensors into a single package is highly desirable. Useful application groupings would be for (H_2, CO_2, CO, CH_4, and O_2) and (CO_2, Argon, and N_2). Current state of the art can meet size and weight requirements for combustible gases, but does not separate the individual gases in mixtures, as several of them are combustible (H_2, CH_4 and CO), and often require higher levels of power for heated detector elements, such as oxygen sensors. Infrared-based systems do not meet size, weight and power restrictions, and can not measure several of the gases requested. Mass spectrometers can measure all of these gases, but the size, weight and power requirements are excessive, especially with the vacuum pumps included.

10.09 Process/Industrial Engineering Technologies
Lead Center: KSC
Participating Center(s): ARC

Spacecraft launch and payload processing systems have many unique aspects which require development of innovative process 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 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 Mars missions) are also projected to have lengthy operational phases. Payload processing activities are also emphasizing 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 proposals should address the generic challenges of delivering safer, better, faster, and cheaper products/services. Proposals should also identify potential applications for enhancing the operational phases of new NASA programs and aviation depot maintenance processes. Advanced process/industrial engineering technologies should support NASA's goal of achieving safe, reliable, and low cost space access. 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; management information systems; and benchmarking. Specific interests for the 2000 solicitation include, but are not limited to, those listed below:

- Advanced task/methods analysis and procedure design techniques for complex, relatively long-duration, and infrequent test and checkout activities.
- Development of computer-based training for writing human-centered procedures. Development of evaluation and testing 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.
- Advanced technologies to enable easy, affordable development of graphical tools to train new engineers on Space Shuttle subsystems.
- Tools to measure and improve human-computer interaction with consoles and portable data collection devices.
- Web-based scheduling technologies to improve range, vehicle, and payload processing systems by supporting reduced cycle time, reduced resource requirements, more robust schedules, timely feedback of process/task completion, enhanced applicability to other domains and to new vehicles, and more explicit knowledge representation.
- Advanced operations research and human factors engineering tools for optimizing utilization of scarce resources and minimizing the potential for human error during aircraft/reusable spacecraft (Shuttle and X-vehicles) maintenance activities.

- Advanced statistical quality control techniques for ensuring high quality, affordable manufacturing and maintenance of unique spacecraft hardware. Automated statistical quality control techniques that can be applied to data generated by space vehicle health monitoring systems.
- Advanced operations process modeling, simulation, verification and validation technologies for cost-effective evaluation of the impacts of proposed changes to operational processes and procedures. Tools for rapidly assessing cost, schedule, and technical risks of proposed Shuttle hardware/software upgrades and process changes.
- Tools to identify the parameters needed to quantify logistics mass and volume required to support a human Mars, lunar, or asteroid mission. Parameters include, but are not limited to, spares, tools, test equipment, maintenance consumables, and crew food and water. Tools should identify the typical system, subsystem, and line replaceable unit failure rates, mass, and volume characteristics to be used as input parameters for estimating logistics requirements until mission specific hardware data is available. Develop a model that utilizes these parameters to estimate logistics mass and volume requirements for a specific mission and then optimizes the spares mix based on cost, mass, volume, or system availability once the detailed mission specific hardware data set is available.
- Develop concepts for autonomous fabrication of parts from raw materials. Study availability of raw materials at the landing site of current or future programs and availability of materials from depleted systems or carried along in the complement of mission stores. Define a candidate list of parts that could be manufactured from available materials en-route or at the landing site. Utilize commonality of hardware to facilitate interchangeability of parts and limit the number of unique parts. Decide which types of raw materials to carry along on a mission to complement the raw materials at the destination. Study types of devices and systems needed for manufacturing. Develop techniques for stowage, transportation, and utilization of space-borne manufacturing equipment.

10.10 Flight/Ground System Autonomous Operations
Lead Center: JSC
Participating Center(s): GSFC

Development of spacecraft with ground systems that support a high degree of onboard autonomy, possessing autonomous navigation and control, self-monitoring systems, intelligent agents, and smart instruments will enhance the efficiency of upcoming NASA flights. The challenges include selective migration of control center operations functions to the spacecraft, new onboard software architecture and operating system concepts to integrate these functions, and new software design methodologies. Overcoming these challenges will enable the planning, design, development, and operation of challenging observational or exploration missions with reduced human involvement. NASA seeks innovations that demonstrate the following characteristics: spacecraft and instruments appearing as nodes on a network; interoperable ground and flight operating systems; spacecraft interfaces that appear the same to ground support systems; ground system operations requiring minimal hands-on effort; centralized anomaly resolution; and direct delivery of science data to users. Areas of interests include:

- Autonomous guidance, navigation, and control.
- Planning, scheduling, and resource management.
- Onboard data management.
- Fault detection and recovery.
- Onboard software architectures and operating systems.
- Design, testing, and validation tools or techniques for autonomous systems.
- Direct access or on-demand access to and control of instruments and their returned data by the investigators.
- Distributed intelligent agents for automation of spacecraft and ground operations functions.
- Autonomous instrument operations.
- Advanced applications of expert system, model-based, and agent-based technologies in mission-operations system design and operations monitoring.
- Internet-based and Java-based approaches to mission operations.
- Advanced data and information visualization techniques for mission operations.

- Techniques for electronic documentation, electronic process control, massive distributed databases, intelligent archiving and retrieval, data analysis and visualization and other advanced information management technologies.
- End-to-end goal-oriented planning, commanding, and reporting.

Innovations should use commercial standards for development, off-the-shelf hardware and software when possible, and have a high degree of commercialization potential.

11 Enable the Commercial Development of Space

Commerce is essential to human society; free market transactions are the foundation of the dramatic progress humankind has made during the past several centuries. Wherever humans go and wherever they live, there too is commerce. Moreover, the free market is the most effective mechanism for delivering tangible benefits from space broadly to the American people. If humanity is to explore and develop space, to better exploit the space environment for profound scientific discoveries, and to someday settle the space frontier, it will only be through the continuing expansion of the private sector-of individuals and of industry-into space. As we open the space frontier, we must therefore seek to expand the free market into space. It is a goal of NASA to enable the commercial development of space.

11.01 Commercial Microgravity Research
Lead Center: MSFC
Participating Center(s): none

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.

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.

12 Share the Experience and Benefits of Discovery

All Americans should have the opportunity to share in the experience and the benefits of space exploration and development. During the past four decades, ambitious human space flight missions have inspired generations of young people to undertake careers in science, mathematics and engineering. Benefiting both themselves and society. 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.

12.01 Telescience and Outreach for Space Exploration
Lead Center: MSFC
Participating Center(s): none

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 investigations 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.

8.3 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

13 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.

13.01 Advanced Instrument Technology for Transitional Boundaries of Land and Water
Lead Center: SSC
Participating Center(s): none

The Earth's transitional boundaries of land and water, the shorelines or coasts, comprise elements of the ecosystems marked by frequent changes and widely fluctuating environmental areas. Technology is needed to better identify and delineate important environmental phenomena and to characterize both the change and impacts effecting human existence. Example areas of study include the complexities and dynamics of boundaries extending several kilometers seaward or inland of the shoreline. Some of the measurements required for conducting this research involve atmospheric measurements and in situ & in vivo measurements of biological, geological, chemical and physical processes including the following:

- Both surface and subsurface water variables (e.g., chemical composition, nutrient content, biological/organic content, inherent and apparent optical properties, temperature, salinity, suspended materials) and their changes with depth.
- Vegetation changes occurring on small spatial scales or for which the spectral response is influenced by changing water level.
- Natural hazards (e.g., hurricanes, sea level rise) and man-induced pressures on land cover and land use change in near shore areas (e.g., particulate loading, nutrient loading).
- Subsurface soil and sediment properties and their changes with depth in environments covered by vegetation or water.
- Atmospheric variables necessary to correct remotely sensed data. Parameters required for data corrections include aerosol absorption, ozone absorption, oxygen and water vapor absorption, atmospheric path length, Rayleigh scattering, aerosol size distribution and Mie scattering.

It can be seen by current research that new innovative technologies and approaches are required to improve instruments, analysis tools and concepts for conducting coastal zone research. Specific technological areas of focus include the following:

- Airborne and ground based multispectral and hyperspectral-imaging systems providing improved spectral resolution (e.g., less than 10 nm bandwidths, and less than 1nm resolution). Spatial resolution (e.g., less than 30 cm ground sampling distance) with higher sensitivities (e.g., .05 NedL) and signal to noise ratios (e.g., greater than 1000:1) necessary for water observations but with the dynamic range (e.g., albedo of .01 to .5) to include terrestrial observations as well.
- Ancillary data collection for imaging systems which including the integration of the Global Positioning System coordinates system, platform attitude, altitude, radiometric and atmospheric data characteristics.
- Improved data processing and analysis systems for image data mosaics, geometric correction, atmospheric correction, radiometric correction, formatting for ease of analysis.

- Instruments for measuring apparent and inherent optical properties of rivers, lakes and oceans.
- Improved instruments for enhancing the collection of water samples and in situ measurements with equipment deployed from small and large research vessels (e.g., profiling instruments).
- Instruments for measuring bio-optical fluorescence of particles in water.
- Data acquisition systems that integrate multiple sensors integrated data analysis software, networking of multi-sensor arrays, autonomous acquisition and transmission.
- Improvements in ground penetrating radar to improve portability expand frequency ranges, receiver sensitivities, software analysis tools, and integration of ground penetrating radar data with other sensor systems.
- Instruments and tools for in situ and in vivo analysis of terrestrial and aquatic plant bioactivity (e.g., evapotranspiration, optical properties, fluorescence, chlorophyll content, and nutrient uptake).
- Instruments for collecting and analyzing bottom sediments in water for particle size distribution, nutrients, metals and radio-nucleides.

13.02 In Situ Terrestrial Sensors
Lead Center: GSFC
Participating Center(s): ARC

Proposals are sought for the development of in situ measurement systems that will enhance the scientific utility of the Earth Science Enterprise program and that will broaden the uses of its systems to include products of interest to commercial and governmental entities around the world. Systems that measure oceanic, land and atmospheric parameters either directly or near-remotely are desired. Typical uses include remote sensing algorithm development and surface calibration and validation of sensors in space. These measurements are critical to NASA and have commercial applications in the areas of environmental monitoring and industrial process control. Topics of interest include:

- Autonomous GPS-located ocean platforms to measure and transmit to remote terminals upper ocean and lower atmosphere properties including temperature, salinity, momentum, light, humidity, precipitation, and biology. Similar sensor packages for use onboard ships while under way.
- Autonomous low cost systems to measure surface and lower atmospheric parameters including soil moisture, precipitation, temperature, wind speed and humidity.
- Systems for in situ measurements of cloud radiative properties including extinction, absorption, scattering phase function and phase function asymmetry.
- Small, lightweight instruments suitable for balloon, kite, or small remotely piloted aircraft for in situ measurement of cloud parameters including liquid and ice hydrometers and atmospheric trace gases.
- High sensitivity measurements of atmospheric trace-gas mixing ratios using robust instrumentation for unattended operation in harsh environments.
- Systems and devices for measurement of atmospheric aerosol chemical, microphysical, and radiative properties. Autonomy desired for ground-station network applications and deployment aboard aircraft.
- 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 the flight path of remotely piloted vehicles.
- Low cost, stable (< 1 percent over several months) portable radiometric sources for field characterization of spectral radiometers.
- Innovative approaches for the gathering, storing, and forwarding of in situ measurements using common carrier infrastructures.
- Lightning location techniques to locate VLF sferic sources (5 to 15 kHz) within 100 km at ranges of 2000 km or more.
- Systems for in situ measurements of atmospheric electrical parameters including electric and magnetic fields, conductivity, and optical emissions.
- Wide-band microwave radiometer 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).
- Autonomous GPS-located air borne sensors that remotely sense atmospheric wind profiles in the troposphere and lower stratosphere with high spatial resolution and accuracy.

- Mass spectrometer time-of-flight system with: 1) a total weight of less than 1 kg, 2) a large dynamic range of at least 1E8, 3) a mass range of 1 to 2000 amu with unit resolution throughout the entire range, and 4) innovative ionization techniques that will improve the sensitivity by an order of magnitude over current mass spectrometer ion sources.
- Miniaturized valve that is: 1) latching, 2) bakeable to 300 C, 3) case leak and seat leak rate less than 1E-10 atm.cc/sec, 4) less than 5 grams and less than 20 mm long x 13 mm diameter.
- Advanced aerosol instrumentation to provide quantitative chemical composition, fast response time, robust calibration methodologies, and reliable inlet geometries for particle sampling.
- Self-diagnosis techniques that provide a continuous measure of data quality and instrument health. Real-time adjustments in sensor operation to compensate for instrument degradation or changes in sensed properties.
- Measurement of seismic, electromagnetic, magnetic and gravity fields and properties for the prediction and mitigation of natural hazards (e.g., earthquakes, landslides, volcanic eruptions, tsunamis).

13.03 Special Event Imaging and Other Earth Observing Instruments
Lead Center: MSFC
Participating Center(s): none

Proposals are sought for the development of innovative technology for the observation of short-lived phenomena in the Earth's atmosphere, oceans, and land. These innovations will make important contributions to the Earth Science Enterprise (ESE) science and application themes. Areas of interest include, but are not limited to, phenomena such as severe weather, thunderstorms, lightning, volcanoes, wildfires, flash floods, and ocean blooms. These innovations are intended to increase our understanding of the effects of short term forcing on the interacting physical, chemical and biological processes that effect the environment in which we live. In addition, it is anticipated that proposed innovations should directly contribute to the ESE goal of predicting and mitigating natural hazards.

Atmospheric measurements of interest include meteorological parameters that play important roles in short lived phenomena including clouds, precipitation, lightning, cloud ice, water vapor, aerosols, winds, temperature and chemical constituents and effluents.

Surface measurements include temperatures of ocean and land, ocean productivity and color, terrain mapping and changes, vegetation index and biological productivity.

Sought after technological advances include techniques that lead to improved temporal, spatial and spectral response to the above-described geophysical phenomena. These advances may be at the component, subsystem, and complete system level and should address reduced size, weight or power, improved reliability and lower cost in addition to the requirements for improved performance. These innovations should expand the capabilities of airborne systems (manned and unmanned) and the next generation spaceborne systems. Innovative approaches are an important element of competitive proposals under this solicitation. Specific sensor needs include:

- Storm/cloud sensing technology used to obtain a proxy to the instantaneous internal convective strength of storms and its relationship to latent heat release and transport.
- Lightning sensing technology to measure total flash distribution, frequency and intensity, and provide flash type discrimination (e.g., intracloud versus cloud-to-ground lightning).
- Technology to aid in the mitigation of wildfires, either by early detection or through the measurement of phenomena that contribute to or initiate fires.
- Agile optical sensors with high temporal, spectral and spatial resolution capabilities.
- Active and passive microwave instrumentation to provide rapid interrogation of targets of opportunity.
- Onboard data processing capabilities to process large volumes of data in need real-time. Requirements include event detection and discrimination, background suppression, data compression, atmospheric correction and geolocation and geometric correction.

Component requirements include:

- Large CCD arrays (e.g., 4000 x 4000 pixels) with high frame rate capability (e.g., 1000 frames per second) and large well depth (e.g., > 1.5 million electrons).
- Stable, large area (e.g., 15 cm dia.), narrow-band (e.g., 1 nanometer) interference filters.
- Wavelength programmable filters.
- Broad-band microwave transmitters and receivers.
- Fast (e.g., F/1), compact optics.

13.04 Active Microwave
Lead Center: JPL
Participating Center(s): none

Radar has proven to be an ideal instrument 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 resources - power, mass, size, and data rate - required by the radar instrument, often making radar not cost competitive with other remote sensing instruments. Order-of-magnitude advancement in key radar 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 radar 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 L-band (1.25 GHz), C-band (5.30 GHz), and X-band (9.6 GHz). The required bandwidth varies from 20 MHz to 300 MHz to achieve the desired 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 (< 100 MHz) with a very high percentage bandwidth (100 percent). Ocean altimeters typically operate at C-band (5.3 GHz) and Ku-band (12 GHz). The atmospheric radars operate at very high frequencies (35 GHz and 94 GHz) with only modest bandwidth requirements on the order of a few MHz.

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 and beam-formation networks.
- 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 or signal up/down conversion within the module.
- Advanced radar system architectures including flexible, broadband signal generation, direct digital conversion radar systems, and autonomous radar control concepts.

- 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 (flexible) electronics; high-efficiency power converters; high-speed analog-to-digital converters; low-sidelobe chirp waveform generator and optical chirp generator.
- Digital beamforming and on-board processing technology.
- SAR data processing algorithms and data reduction techniques.
- SAR data applications and post-processing techniques.

Radar Ice-Sounder
- Synthetic aperture processing technique to increase resolution.
- Lightweight broad-band (100 percent or more) low frequency (< 100 MHz), high gain (> 10 dB) deployable antennas.
- Highly efficient, broadband, low frequency (< 100 MHz) transmitter.
- Low-power, highly integrated radar components.
- Ionospheric correction, data processing algorithms and data reduction techniques.
- Data applications and post-processing techniques.

Atmospheric Radar
- Low sidelobe, electronically steerable millimeter wave phased-array antennas and feed networks.
- Low sidelobe, shared aperture, multi-frequency millimeter wave antennas.
- Large, lightweight, low sidelobe, millimeter wave antenna reflectors and reflectarrays.
- Lightweight deployable antenna structures and deployment mechanisms.
- High power Ka-band and W-band transmitters (10 Kwatt).
- 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.
- Advanced data processing techniques for real-time rain cell tracking, and rapid 3-D rain mapping.

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
- Calibration techniques, data processing algorithms and data reduction techniques.
- Data applications and post-processing techniques.

Polarimetric Ocean/Land Scatterometer
- Shared aperture, multi-frequency antennas.
- Large, lightweight, electronically steerable, dual polarization, reflectarrays.
- Lightweight deployable antenna structures and deployment mechanisms.
- High efficiency, high power, phase stable 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.

13.05 Passive Microwave
Lead Center: GSFC
Participating Center(s): none

Proposals are sought for the development of innovative technology for measuring the Earth's atmosphere and surface using passive microwave techniques. The innovations are intended 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, such as temperature, aerosols, clouds, water vapor, precipitation and chemical constituents such as ozone, nitrogen dioxide, nitric oxide, and carbon monoxide.

Surface measurements of interest include multispectral imaging, temperatures of water, land and ice, and snow coverage. Technology innovations may include components, subsystems, and complete systems and should address reduced size, weight or power, improved reliability and lower cost.

The innovations should expand the capabilities of airborne systems (manned and unmanned) and the next generation spaceborne systems. Innovative approaches are an important element of competitive proposals under this solicitation. Specific needs include:

- Examples of instruments include imaging radiometers, receivers on a chip, and flux radiometers for microwave wavelengths (1 – 500 GHz). Innovative measurement concepts or advances leading to smaller, lower power, and lower cost instruments will be considered.
- Onboard data processing capabilities to perform the following in near real-time: 1) Reconfigurable computing of image and sounder data to enhance research flexibility and enable high compression ratios, 2) atmospheric correction, and 3) 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 if a source with sufficient strength is radiating within or near the reception band of the radiometer. Electronic subsystems that can be incorporated into microwave radiometers to detect and suppress RFI will insure higher data quality.
- New technology calibration reference sources for microwave radiometers that provide greatly improved reference measurement accuracy. High emissivity (near block-body) surfaces are being used as on-board calibration targets for microwave radiometers, either airborne or spaceborne. NASA is seeking new designs using noise-diode or other electronic devices as additional reference sources for on-board calibration. NASA is also seeking ways to significantly reduce the weight of aluminum core target designs. Innovative designs using noise-diode or other electronic devices as additional reference sources for on-board calibration are desired. Of particular interest are variable correlated noise sources for calibrating correlation-type receivers used in aperture synthesis and polarimetric radiometers.
- New approaches are sought for microwave radiometer system calibration that provide end to end calibration including corrections for temperature changes and other potential sources of instrumental measurement drift and error.
- NASA is developing satellite systems that will use L-band microwave emission from the surface to measure soil moisture to a depth of ~ 10 cm. A ground based network of sensors capable of measuring areas at least 100,000 km2 with spatial resolution of 20 km 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.
- Focal plane array modules for large-aperture passive microwave imaging applications.
- High power (> 5 mW) signal sources and low noise (< 2500 K) heterodyne receivers for operation in the range between 500 GHz and 3 THz.
- Computer aided design software for 3 dimensional layout and performance evaluation of quasi-optical components and systems.
- Multi-GHz. Low power, 4-bit undersampling analog-to-digital converters and associated digital signal processing logic circuits.

13.06 Active Optical
Lead Center: LaRC
Participating Center(s): GSFC, MSFC

Innovative developments are needed in lidar technology for the remote measurement of atmospheric aerosols, clouds, molecular species (ozone, water vapor, carbon monoxide, carbon dioxide, methane, and nitrous oxide), meteorological parameters (density, pressure, temperature, and wind profiles), planetary surface topography, vegetation, and sub-surface ocean layers; for ground-based lidar systems and laser ranging systems that measure atmospheric backscatter, vegetation structure and composition, and pulse time-of-flight to laser transponders or reflectors on satellites. Specifically, technologies for expanding the measurement capabilities of current airborne lidar systems and for the next generation of spaceborne and Unmanned Aeronautical Vehicle (UAV) lidar systems are sought. Technology innovations may include lidar components, subsystems, and complete systems and may address reduced weight or power or increased energy efficiency, reliability, or autonomous operation.

Atmospheric Constituent Measurements

- Solid-state laser technology for tunable and/or fixed frequency, high-energy (> 500 mJ at more than 10 Hz) pulsed lasers for spaceborne applications. This includes solid-state laser materials compatible with diode pumping and high efficiency (> 2.5 percent wallplug) and new or improved optical materials for high efficiency frequency conversion. Of prime interest are long-lifetime, low weight and volume materials and technologies applicable to highly efficient, conductively cooled lasers operating in the 0.28-0.36, 0.47-0.54, 0.7-1.1, and 1.5-2.8 micron regions; also interested in the 3.2-4.7 micron region. Also needed are single-mode, line-narrowed, compact sources for injection seeding in the 0.28-0.36, 0.7-1.1 and 1.5-2.1 micron regions and high reliability, high efficiency, high brightness, conductively cooled diode arrays operating in wavelength regions for pumping solid-state lasers.
- Lidar receiver technology for large (> 3m^2), lightweight collection apertures having multiple-wavelength operation from UV to near IR is needed. Inherent spectral selection/dispersion and high peak transmission (50-80 percent), electromagnetically tuned, narrow bandwidth (10-100 picometers) filtering is desirable. Small- and large-angle scanning (up to 3 degrees and 30-60 degrees off nadir, respectively) of 0.5 meter and 1.0 meter lidar systems is needed for space. Low mass and few to no moving parts.
- Signal detection and processing subsystems with quick recovery (less than 3 microseconds) from saturation and high-speed, high-quantum efficiency (30-80 percent) detectors with low-noise and good linearity are needed for lidar operation over large dynamic ranges.
- For UAV applications, compact, high repetition rate, narrow linewidth laser transmitter systems are needed that produce energies from micro- to milliJoules per pulse. Laser energies of more than 100 mJ at 30-1000 Hz in the UV and more than 200 mJ at 10-20 Hz in the 355, 936, 944, and 1064 nm region are needed.
- High CW power (> 500 mW-1 W) single spatial mode laser diodes, based on simplistic structures such as the Fabry-Perot cavity, for core-pumping of fiber lasers. Wavelength regions mainly include 800-810 nm, but also of interest are 780-785 nm, and 980 nm.
- Single-element and array detectors, combined with preamplifier circuitry in a single integrated circuit, for lidar detection at 355nm, 532nm, and 1064nm having several gigahertz bandwidth, high quantum efficiencies, good linearity, and minimum cooling requirements.
- Optical phased array scanning concepts for programmable beam pointing with high transmission (> 90 percent) and angular deflection capability > 20 degrees. Aperture diameters from 2 cm to 1 m are of interest and preservation of beam quality is a primary requirement.
- Large aperture, ultra light, scanning lidar receivers with high efficiency, narrow field-of-view, and narrowband filtering.
- Scanning lidar transceivers that use aperture sharing and are capable of producing multiple look angles, each with a small field-of-view.

Coherent Wind Measurements in the 1.5-2.5 Micrometer Wavelength Range

- Low mass, compact optics for deflecting a circularly polarized laser beam for a conical scan. Diameters of 5 cm to 1 m with an immediate need of up to 50 cm. Preservation of laser beam quality is required.
- Low mass, 1-m class beam expanding telescope technology with low fabrication cost and long-lived performance in space environment.
- Technology for autonomous operation and alignment maintenance of coherent lidar systems; such as a low-mass, low-power, low-voltage optical element capable of correcting piston, defocus, astigmatism, coma, and spherical aberrations.
- Integrated opto-electronic receiver combining photodetectors, local oscillator laser, beam conditioning and combining, and signal processing components.

- Fast (few tens of microseconds) lag-angle compensation optics technology for precise, reliable steering of the optical axis of a space-based Doppler lidar.
- Single-element and array detectors having high bandwidth, high quantum efficiencies in the 1.5-2.5 micron wavelength band. Bandwidths up to 6 GHz are desired.
- Pulsed, eye safe laser technology having technical path leading to simultaneous characteristics of > 2J energy, > 12 Hz PRF, < 500 W laser power requirement when pulsing, < 2 microsecond duration, < 1 m/s equivalent pulse spectrum, < 1.3 M^2 beam quality, intermittent operation with periods of 1-10 minutes and duty cycle around 20 percent and minimum "off" power draw and minimum time to restabilize, and which shows potential for 7-year lifetime in space environment.
- Diode-laser arrays operating near 0.79 micrometers having pulse lengths > 1.0 ms, energy densities > 1.3 J/cm^2, duty cycle > 0.20 and narrow beam divergence.
- High efficiency methods for concentrating the emissions from nominal 1.0 cm square arrays to 4.0 mm diameter spot sizes.
- Tunable single-mode semiconductor lasers or other compact, single frequency sources for use as injection seeders and/or local oscillators, with linewidths 0.1-0.2 MHz operating in the 1.8-2.2 micron and 3.0-3.5 micron regions.

Surface Topography and Oceanic Measurements

- Compact, conductively-cooled near-infrared laser transmitters with less than 1 nsec pulses, single spatial mode, several millijoule performance at multi-kilohertz pulse rates.
- Oceanic LIDAR systems or components in the 480-685 nm wavelength region for remote sensing of sub-surface ocean layers and fluorescence.
- Quadrant Geiger-mode avalanche, photo diodes or comparable microchannel plate photomultipliers with a quantum efficiency approaching 40 percent @ 532 nm, less than or equal to 400 psec risetime, and submicrosecond gating at 2 kHz rates.
- Silicon avalanche photo diodes, photodiode arrays, and photon counting detectors with quantum efficiency greater than 35 percent at 1064 nm wavelength; and high efficiency, high speed, & low noise detectors for the 1500 to 2200 nm wavelength region.
- Signal detection and processing subsystems with quick recovery (less than 30 microsec) from saturation and high-speed, high-quantum efficiency (30-80 percent) detectors with low-noise and good linearity are needed for lidar operation over large dynamic ranges.

Direct Detection and Other Measurements

- Laser techniques and component technology for measurement of the wind field and wind shear using direct-detection methods, with high accuracy and high range resolution. Eye safety is a consideration.
- High spectral resolution filters with high throughput, out of band spectral blocking, frequency tunable, and frequency stabilization for direct-detection measurements of winds at 355 nm (1 GHz bandwidth) and 1064 nm (100 MHz bandwidth).
- Compact, power efficient, frequency reference with better than 1 part in 10^14 stability and accuracy; that is suitable for interplanetary missions.
- Adaptive photon-counting correlation range receivers capable of extracting satellite range data with high time resolution (better than 20 psec) during daylight operations.
- High detectivity, spectrally diverse receivers including narrowband notch filters, high transmission narrow bandpass optical filters, & multi-channel array detection.

13.07 Passive Optical
Lead Center: ARC
Participating Center(s): JPL

Proposals are sought for the development of innovative technology for measuring the atmosphere and Earth surface using passive optical techniques. The innovations are intended 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, such as temperature, amounts of aerosols, clouds, water vapor, carbon dioxide and methane; and, chemical constituents such as ozone, nitrogen dioxide, nitric oxide, carbon monoxide, and hydrocarbons. Surface measurements of interest include vegetation index, multispectral imaging, bi-directional reflectance, biological productivity, surface terrain mapping, temperatures of water, land and ice, ocean productivity and ocean color. Technology innovations may include components, subsystems, and complete systems and should address reduced size, weight or power, improved reliability and lower cost. The wavelengths of interest include IR, visible and ultraviolet bands. The innovations should expand the capabilities of airborne systems (manned and unmanned) and the next generation spaceborne systems. Innovative approaches are an important element of competitive proposals under this solicitation. Specific needs include:

System Architectures

- Innovative instrument architectures that provide flexibility in system configuration to address specific measurement requirements. For example, sampling flexibility in either the spectral or spatial domain of an imaging spectrometer focal plane array will provide the ability to trade between spectral and spatial resolution in the context of a specific scientific problem as constrained by limited downlink bandwidth.
- Innovative instrument architectures that expand scientific knowledge and provide significant reductions in the end-to-end implementation. This includes designs and component technologies relating to improved sensors for observations Earth's surface and atmosphere. Examples of instruments include multispectral imaging radiometers and flux radiometers for wavelengths from the UV to microwave. Innovative measurement concepts or advances leading to smaller and lower cost instruments will be considered. Technical approaches should include application of uncooled infrared detectors, non-mechanical choppers, calibration methods and tuned filters.
- High throughput compact systems (f/1-f/2).
- Wide field of view spectrometer systems (e.g., with expandable architectures) with no moving parts.
- Systems with inherent environmental stability.

Component Technologies

- Optical technologies that will enable high spatial resolution (< 10 meter) measurements along track for spacecraft sensors in low earth orbit. Combinations of high light collection efficiency and instrument throughput, and fast, low noise detector readout are required to provide adequate signal power (SNR > 500) to address multi- and hyper-spectral measurement requirements.
- Wedge filters suitable for space application and 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.
- 4 K x 4 K 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.
- Optical imager technologies that will enable lightweight, low cost large aperture optical systems optics for a variety of land, ocean, and atmospheric observations through the elimination of conventional telescopes and focal planes in space based imagers. For example, phased arrays or multispectral imagers based on holographic and/or diffractive optics. Instruments should have performance specifications comparable to or better than current imagers such as MODIS aboard NASA's Terra satellite.
- Fast, 1-meter diameter lightweight telescope for space application with minimal distortion in the 0.3- 3-micron wavelength range.
- Ultra-stable remote sensor calibration techniques for long term trend determination in space instruments.
- Development of innovative techniques and component technologies for measuring polarization of light scattered from the atmosphere.
- Advanced gratings on flat or curved surfaces that maximize efficiency and minimize scatter and ghosts.
- Linear variable filters with extended range, seamlessly stitched filter strips.
- Broadband antireflection methods that can be applied to the photodetector array, in the visible and infrared.
- Novel or improved high-resolution dispersive elements.
- Environmentally robust, electronically variable filters with extended spectral range.

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. Very low mass, power and high speed and flexibility are desired.
- Compact, lightweight optical designs that utilize a minimum number of optical surfaces.
- Non-classical designs utilizing guided wave optics.
- Self-aligning systems or methods of assembly.

14 Platform Technologies for Earth Science Measurements

NASA is fostering innovations that support implementation of the Earth Science (ES) program, an integrated international enterprise 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 Earth Science Instruments. That is, they provide the infrastructure for an instrument or suite of instruments. Traditionally, the term platform would be synonymous with spacecraft, and it certainly does include spacecraft. However, platform is intended to be much broader in application than spacecraft and is intended to include nontraditional 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.

14.01 Power Management and Distribution
Lead Center: GRC
Participating Center(s): GSFC

Future Earth Science missions will be characterized by extended duration missions, operation in various orbits, constellations of spacecraft, and real-time networking of space, airborne, and in situ platforms. This subtopic seeks technologies that will significantly reduce development and operations costs, increase mission capabilities and enable revolutionary concepts such as virtual spacecraft constellations, or unconventional platforms such as long-duration UAVs and piloted vehicles, balloons, buoys, or even utilization of the Moon as an observation platform.

Areas of special interest in power management and distribution (PMAD) include autonomous operations, advanced power-conditioning devices that help reduce size and mass, microelectronic devices, and improved wiring system designs. In addition, technologies of interest include very high efficiency, flexible and light-weight photovoltaics, advanced batteries (such as Nickel Metal Hydride), lightweight/high efficiency regenerative fuel cells, and multi-purpose flywheel systems that combine the functions of attitude control and energy storage. Advanced materials, surfaces, and components for space power systems that are durable under different space environment conditions are also of interest.

Innovative concepts utilizing advanced technology are needed to manage and distribute power in lighter, smaller, cheaper, more durable, and high performance spacecraft and unconventional platforms, and to improve reliability and reduce overall costs (including development and operations). Advances for power management and distribution (PMAD) systems are sought in the following areas:

- Management, control and monitoring of power systems, adjustable speed drives, or autonomous operation of space power systems.

- Advanced power-conditioning devices for housekeeping and control of a wide range of regulated voltages on Earth Science payloads to reduce size and mass utilizing hybrid, multi-chip, and other techniques.
- Improved wiring system designs, new fault detection techniques, and advanced circuit protection to improve safety, reliability, and performance of aerospace systems.

Innovative concepts for systems and components are solicited in the areas of photovoltaics and lightweight, high-efficiency regenerative fuel cell systems.

NASA missions also require systems having high energy density and cycle life. This includes advanced batteries, regenerative fuel cells for energy storage, and competing alternatives with high-power-density such as lightweight flywheels. Power levels of interest range from tens of milliwatts to several kilowatts. Specific areas of interest are:

- Large applications of photovoltaic technology with targeted cell efficiencies over 30 percent, array performance up to 1000 watts per kilogram and 400 watts per square meter and lifetimes of 15 to 20 years.
- Nickel-hydrogen and nickel metal hydride battery technology capable of more than 30,000 cycles, at least 100 watt-hours per kilogram, and 10-year life in LEO at greater than 40 percent DOD, and 20 year life in GEO at greater than 70 percent DOD for spacecraft and space systems.
- Demonstrations of multi-purpose flywheel systems that combine attitude control and energy storage functions.
- Materials, surfaces, and components that are durable for atomic oxygen.

14.02 Advanced Communication Technologies for Near-Earth Missions
Lead Center: GRC
Participating Center(s): JPL

To realize the Earth Science Enterprise vision of Sensor-Web, a host of in-space and terrestrial communication link technologies 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 a 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 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 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.

Specifically, the required products are described below, but are not limited to the following:

- High rate data communication microwave or optical system technologies for supporting multi-Gigabit/sec data rates from spacecraft to ground networks.
- 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 interspacecraft communications for spacecraft constellations are needed.
- Inter satellite communication link technologies to transfer sensor data from LEO or MEO orbiting spacecraft to GEO spacecraft;
- Communication link technologies to transfer data from an Earth observing balloon or airplane, where the collection and transmission of data is by Internet protocols.
- In the component area, innovative approaches are required 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.

- Low loss MEMS based RF switches are needed that would enable the development of reconfigurable antennas and filters for in flight control of the radiating frequency bandwidth and power.
- RF component and sub system technologies are required that increase the level of integration above the current state of the art to enable "system on a chip" type communication systems. Low cost, Ka band flat plate array antennas; 2 watt Ka-band MMIC power amplifiers and low noise block down-converters are desired for small earth terminals applications. Low cost, precision tracking Ka-band earth terminals for high data rate (OC-3 to OC-12) 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 transcievers and closed loop acquisition/tracking algorithms for low-orbit space platforms and communication satellites are desired.
- Power and bandwidth efficient modems, combined modulation and coding schemes, multiple access and other digital transmission techniques for application in Earth science enterprise communication links, space- or ground-based are sought.
- Novel approaches are needed to reduce size, mass, power and cost of spacecraft digital components to enable multi-Gigabit/sec throughputs.
- Another technology that would enable the next generation of satellites is the development of analog to digital and digital to analog (A/D and D/A) converters operating at 10-20 Gbps. High speed, internet protocol (IP) based digital transceivers and network processing and interface modules for controlling onboard LAN's, including routing, encoding, encrypting of data to allow services on demand to address the need for autonomous spacecraft operations are sought.
- For optical communications, highly efficient laser transmitters, modulation and demodulation schemes for near-earth (up to 10 Gbps diode and MOPA) sources (including WDM schemes) with greater than 1 W of average power are sought.

14.03 Command and Data Handling
Lead Center: GSFC
Participating Center(s): none

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:

- 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 back plane are necessary to achieve higher science data throughput.
- Volatile data storage - large capacity Solid State Recorders (SSRs) that 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 SSRs 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. 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 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 this future need.
- 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.

14.04 Guidance, Navigation and Control
Lead Center: GSFC
Participating Center(s): none

The future Earth science architecture will include collaborating assets performing coordinated scientific observations. These assets will include spacecraft but could also include balloons, aircraft (both piloted and unpiloted), and surface assets. Advanced GN&C technology is required for each of these platforms that address low power, low mass, low maintenance, and reliabilty issues. A vigorous effort is needed to develop guidance, navigation and control methodologies, algorithms, sensors and actuator technologies to enable revolutionary Earth science. Exploiting new vantage points, developing new sensing strategies, and implementing system-wide techniques which promote agility, adaptability, evolvability, scalability, and affordability are characteristic of the technological challenges faced and representative of the significant leap beyond the current state of the art required. Specific areas of research include:

- Advanced sensors, actuators, and components with new or enhanced capabilities and performance, as well as reduced cost, mass, power, volume, and reduced complexity for all spacecraft GN&C system elements. Additional emphasis is placed on improved stability, accuracy, and lower noise angles.
- Concepts for autonomous guidance of space transportation systems during atmospheric flight phases.
- Control theory, filtering techniques, processing advances, software architectures, and improved environmental models for attitude and trajectory determination and prediction. Filtering techniques and expert systems applications for near real-time trajectory determination and control. Methods for in-flight attitude sensor alignment and transfer function calibration.
- Rigid and flexible body control methods that are robust to parametric uncertainty and modeling error.
- Innovative testbed development capabilities and computer aided engineering and design tools with parallel algorithms for analysis and development of GN&C systems.
- Autonomous performance of ground system functions including attitude and trajectory determination, monitoring of spacecraft functions and environmental conditions, assessing ground system and spacecraft health status, ground system fault detection, orbital event and attitude dependent prediction support utilizing advanced techniques such as fuzzy logic and neural networks. Assessing spacecraft health status and optimizing performance through in-flight identification, fault detection stabilization, and re-configurable control.
- Low power and mass propulsive attitude control actuators and related subsystem components. Actuators to 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 GPS receiver hardware and algorithms that use GPS code and carrier signals to provide spacecraft navigation, attitude, and time:
  - Combined navigation and attitude space receivers. Advanced antenna designs.
  - Navigation techniques that may employ WAAS corrections.
  - Navigation, attitude, and control for spacecraft proximity operations.
  - 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.
- Advanced GNC solutions for balloon-borne stratospheric science payloads, including sub-arcsecond pointing control, sub-arcsecond attitude knowledge determination and trajectory guidance.

14.05 Structures and Materials
Lead Center: LaRC
Participating Center(s): none

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 structures 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.
- Multifunctional structures with flexible electronics.
- Thermally stable materials and components and integrated thermal/structural concepts for high efficiency passive thermal management.
- Low cost, high power-to-weight efficiency deployable/inflatable solar arrays.
- 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 structures concepts.
- UAV material systems which enable multiple year continuous mission operations.

15 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, but not limited to, data acquisition, data transmission, data processing, data management & storage, data distribution, data/metadata/document search, browse and assess, data subsetting, generic analysis, and generic 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.

15.01 Data Transmission from Onboard Sensors to Users
Lead Center: GRC
Participating Center(s): none

Earth science missions are transitioning to higher data production by onboard sensors while also developing smaller sized payloads. Innovations are sought that offer significant reductions in cost and enhanced performance of system technology while improving system reliability and the efficiency of transmission of these data from the sensors to the users. Products are sought in the following areas:

- Advanced data compression techniques and buffer management strategies for both on-board and transmitted data that will lead to an order of magnitude improvement in data compression. The data compression techniques must be applicable to a wide variety of data, such as radar, infrared and optical sensors, and should be lossless so that all data that is desired to be transmitted can be analyzed. Hardware needed to support these techniques will also be needed.
- Innovative modulation techniques that provide high capacity bandwidth efficiency with low power requirements while still maintaining highly reliable communications for LEO and GEO platforms.

- Network architectures are sought that optimize transmission between multiple spacecraft to ground, and that allow spacecraft to be addressed as nodes on the internet by researchers. Technology is needed to allow transparent and seamless interoperability of the mission data with commercial terrestrial networks using common commercial protocols such as TCP/IP and ATM. Technologies are sought that lead to space-qualified codec, local area network, routing and switching hardware and software.
- Often times, verification of techniques and software can be performed using lower risk terrestrial-based test beds. Test beds that are proposed along with the above technology development are also viewed as acceptable areas.

15.02 Knowledge Discovery Data Fusion
Lead Center: JPL
Participating Center(s): none

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.

15.03 Geospatial Data Analysis Processing and Visualization Technologies
Lead Center: SSC
Participating Center(s): ARC

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:

- Visualization of multi-variate 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.
- Innovative approaches 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.
- Design and implementation of a virtual reality CAVE for scientific data visualization that is at least 1/20 the cost of current CAVE implementations.
- 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.
- Tools for enabling distributed scientific collaboration.
- Data merge and fusion software for efficient production and real-time delivery of commercial digital products to teams and remote users.
- Innovative techniques to automate quality assurance processes for science data products.
- Innovative techniques for validation of imaging systems (i.e., thermal and LIDAR imaging systems).
- Software to develop commercial products from digital topography and vegetation canopy data obtained from airborne and space-based active optical sensors.
- Software to automate the rapid processing and distribution of sub-setting and presenting RS data over a network
- Unique, innovative data reduction and rapid analysis methodologies and algorithms, particularly for hyperspectral data sets.
- 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.

15.04 High Performance Computing and Networking
Lead Center: GSFC
Participating Center(s): none

This subtopic focuses on innovations in efficient and effective techniques for processing large volumes of data into useful information. Collaboration between Earth scientists and computer scientists required for these proposals to demonstrate useful results. Areas of interest include:

- High performance processing.
- Computing: Distributed computing, Reconfigurable computing, Parallel/cluster computing, Embedded computing, Optical computing.
- 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 comp uting".
- 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).

15.05 Data Presentation Management
Lead Center: GSFC
Participating Center(s): none

This subtopic focuses on innovative approaches to locating, summarizing and presenting Earth science data in a highly distributed and networked environment. Collaboration between Earth scientists and computer scientists required for the proposals to demonstrate useful results. Specific examples of topics of interest are:

- Techniques for capturing and managing client profile information.
- Tools to facilitate product quality assurance and metadata updates.
- 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.
- Software approaches to capture/automate workflow management.
- Object relational technologies specific for Earth sciences.
- Automatic documentation of data production prioritization and scheduling.
- Enterprise process methods including simulation, monitoring, reporting, coordination and analysis.
- Meta-data discovery.
- Automated and analytical verification.
- Automatic metric collection and analysis.
- Scalable data management.
- Smart Objects Dumb Archives (SODA).
- Storage, archival and retrieval standards.
- Technologies supporting management, storage, search and retrieval of very large, distributed, geo-spatial earth science data volumes.

15.06 Automation and Planning
Lead Center: ARC
Participating Center(s): GSFC

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. 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.

8.4 SPACE SCIENCE

NASA's Space Science Enterprise seeks to discover the mysteries of the universe, explore the solar system, find planets around other stars, and search for life beyond Earth. From Origins to Destiny, the Enterprise seeks to chart the evolution of the Universe, its galaxies, stars, planets, and life. Its mission includes four science themes: Sun-Earth Connection - SEC (Space Physics); Solar System Exploration - SSE (Planetary Science); Structure and Evolution of the Universe – SEU (Astrophysics); and Astronomical Search for Origins and Planetary Systems. Each of these themes has a committee made up of both NASA and non-NASA scientists. Among their activities is the creation of a scientific roadmap for the next 20 years -- a plan for future space missions that will probe the mysteries of the universe.

http://spacescience.nasa.gov/

16 Sun Earth Connection

The goal of the Sun-Earth Connection (SEC) theme in the Office of Space Science 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) going to new vantage points within the Solar System, and even out into the interstellar medium, to make critical measurements; 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.

16.01 Solar Remote Sensing
Lead Center: GSFC
Participating Center(s): MSFC

Research proposals are sought that address one of the following aspects of solar remote sensing: optics (mirrors), detectors, spectrographs, transmission gratings, or magnetographs (polarimetry).

Optics – Mirrors. Light gathering mirrors are the primary step in any remote sensing. Large (meter class), lightweight optics are needed for science goals outlined in the NASA Sun Earth Connection (SEC) roadmap. Surface quality (figure and mid-frequency errors) must achieve diffraction limited quality. Microroughness must be reduced to improve image contrast (scattered light). Reflectivity is desired in the spectral range from X-rays through the visible.

Research on optical coatings and transmission filters is needed. Improved transmission filters for EUV (Robust, improved transmission, solar/FUV blind) would greatly enhance our current capability.

Detectors. After the primary optical mirror, the most critical item in remote sensing is the detector. Current detectors generally are CCDs or some other Cartesian devise that have the capability of measuring the number of photons falling on arrays of (2x103) x (2x103) to (4x103) x (4x103) pixels. The integration times and readout times of these devises are typically on the order of 5 seconds. Devices capable of time resolution of 1 second or less.

An idealized device would have the same characteristics, but would also be able to resolve the energy of the photons. The energy range should be from hard X-rays through the visible and be able to distinguish velocities to 1 km/s or better. A further enhancement would be the ability to measure the angle and degree of polarization to determine magnetic fields to better than 5 gauss. This would allow for the elimination of spectrographs and thus greatly reduce the size and weight of current instruments. It would also greatly enhance the time resolution of spectroscopic measurements.

Spectrographs. In view of the difficulty in obtaining energy resolving detectors it is necessary that spectrograph technology be further advanced. Low scatter, variable line spaced gratings are needed to support moderate resolution EUV solar diagnostic spectroscopy with reasonable efficiency, good control of aberrations, and high contrast. Blazed ion etched holographic gratings are one possible approach.

Active gratings (e.g., gratings replicated onto a deformable spherical or toroidal substrate) may be useful as the wavelength(s) at which aberrations are corrected may be tuned by changes to the surface figure without effect on the efficiency properties (which are determined by groove profiles at the submicron level). Grating metrology techniques that validate designs, high efficiency, and low scatter of gratings are needed.

Techniques are needed which result in very high line densities (e.g., > 6000/mm) for higher dispersion EUV and FUV solar spectroscopy.

Transmission Gratings. Nanometer-period transmission gratings (TG) are a key enabling technology for several types of space physics and astrophysics instrumentation. Space usage of TG falls into two categories: 1) X-ray/EUV spectroscopy and 2) UV filtering.

TG will be used on the IMAGE and TWINS missions to provide UV blocking in the MENA neutral-atom imaging experiment. Medium-energy neutral atoms (200 eV to 100 keV range) are emitted by important components of magnetospheres and are rich with information about the parent plasma population. Neutral atoms are typically accompanied by very large UV fluxes that are difficult to block in the medium-energy range without severely attenuating and scattering the atoms. Metal TG fabricated with deep and narrow slots are extremely good blockers of Lyman alpha UV radiation (the dominant contamination). Slots narrower than 50 nm are required. Competing UV filter technologies require much larger and heavier instrumentation to achieve equivalent sensitivity. Best current-generation UV filters have UV/particle discrimination exceeding one million, but achieve geometric transmissions of less than 5 percent. This is unacceptable for future missions with stringent size and mass limits, since it requires a large instrument to detect the low-flux particles. Increases in the geometric transmission of 5-10X are desired using extensions of current technology, enabling technology for MENA imaging on future micro-satellites.

Magnetograph – Polarimetry. The HRSOT mission is designed to do polarimetery to measure magnetic fields above the Sun's photosphere. To accomplish this we would need a telescope of 2 m for resolution, but 4 m for signal to noise on the magnetograph. The various pieces needed in this development would be:

- A tunable, high spectral resolution, multi-etalon Fabry-Perot filters for use in the FUV (wavelengths between 3000 A and Lyman alpha). The goal is to develop filters with transmissions of 50 percent and FWHM of 10 milli-Angstroms. Two major efforts are envisaged, first in the development of materials in boules of the right size and purity to fabricate FUV etalons, and second in the development of high finesse mounts for the etalons that will withstand the rigors of launch. Material selection should pay attention to their radiation hardness.
- Narrow band (Delta lamda =0.5 A) blocking filters for the FUV with peak transmissions of greater than 35 percent are required to isolate particular spectral lines within the broad waveband coverage of the coatings. The blocking filters need to be customized for specific emission lines. e.g., CIV at 1550 A.
- High sensitivity, large area, low voltage array detectors for use in the FUV (better than 2 k x 2 k CCDs with QE's of 35 percent or better at 1200 A.)
- Coating technology required to deposit FUV broad band, high reflectance coatings on a variety of optical elements. Requirements are for a Delta lamda=1000 A and reflectivity's of ~98 percent.
- High sensitivity polarimeters for the analysis of linear polarization below 10-4.

16.02 Particles and Field Instruments
Lead Center: GSFC
Participating Center(s): none

Research designed to improve our knowledge and understanding of the Sun-Planetary Connections requires accurate measurement of the composition, flow, and thermodynamic state of space plasmas and their interactions with atmospheres. Low energy charged particle analyzers and DC to RF electromagnetic field sensors provide direct in situ measurements. This instrumentation is often severely constrained by spacecraft resources. Therefore, miniaturization, low power consumption and autonomy are common technological challenges across this entire category of sensors. Specific technologies are sought in the following categories:

Plasma 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 electrical 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.

16.03 Remote Sensing for Planetary Magnetosphere/Aeronomy and Outer Heliosphere Missions
Lead Center: GSFC
Participating Center(s): none

The Sun-Earth-Connections theme studies the Sun, its photon and particle emissions, and the subsequent responses of the Earth and planets. This involves remote sensing of the upper atmospheres of the Earth and planets, their magnetospheres and interfaces with the solar wind, the heliosphere and the Sun. Traditional remote sensing of photon emissions (Radar to gamma-rays) is now aided by remote sensing of ion populations via neutral atom cameras. Technologies are sought in the two categories below:

Photon Remote Sensing (radar to infra-red through X-ray and gamma-ray wavelengths)

- Advanced lightweight, diffraction-limited mirrors.
- Advanced optical spectrograph components.
- Advanced detectors for visible through X-ray.
- Improved techniques for spectrometric imaging of IR emissions from planetary atmospheres and ionospheres, such as large array (8 Mpixel) 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.
- Techniques for the high-efficiency and robust imaging of energetic neutral atoms covering any part of the energy spectrum from 1 eV to 100 keV.

16.04 Spacecraft Technology for Nanosats
Lead Center: GSFC
Participating Center(s): JPL

Research development must be geared toward enabling and enhancing technologies needed for a 100-spacecraft constellation of scientific nanosats studying the Earth's magnetosphere. All proposed technology must ultimately be suitable for use on SEC nanosats, roughly envisioned to have mass of ~10 kg, total electrical power < 10 W, and cylindrical dimensions of ~ 30 cm in diameter and ~10 cm high. Specific technologies needed are:

- Nanosat avionics that are ultra-low power (< 1 W), low mass (< 250 g), and radiation-tolerant; advanced packaging to meet nanosat volume and mass.

- Guidance, navigation, and control sensors and actuators such as sun/earth sensors and star trackers suitable for nanosats spinning at 20 rpm, satellite positioning, and automated ground systems.
- Low-mass, high energy storage batteries suitable for 10-kg, 10-W nanosats with eclipse periods of several hours.
- Low-mass, low cost multifunctional structures that incorporate elements such as power, thermal, electrical and attitude control systems.
- Advances in manufacturing to enable low cost production of up to 100 scientific nanosats, improved efficiencies to reduce spacecraft cost, labor, and schedule time.
- Passive and active thermal control technologies suitable for nanosat size and power limits yet capable of handling eclipse periods of several hours.
- Cost-effective measures to ensure and verify spacecraft compatibility with SEC science instruments such electrically conductive surfaces (solar arrays & thermal control surfaces), active devices that help reduce spacecraft potential, and radiation tolerance & shielding.
- Communications with the earth will be at X-band, and advances in antennas or high-efficiency solid-state amplifiers will enable an EIRP of at least -3dBW.
- Systems that lead to greater constellation autonomy (and reduced operational expenses); systems that increase the science return possible given bandwidth, ground station constraints; management, analysis, and visualization tools for SEC constellation data (e.g., magnetometer, plasma analyzer, energetic particle detection).
- Low-mass, high reliability mechanisms for deployment of nanosats and booms.
- Low-mass, low-power propulsion technologies for both delta-V and attitude control of spinning nanosats, such as mini solid rocket motors and cold-gas microthrusters.

16.05 Solar Sails
Lead Center: JPL
Participating Center(s): LaRC

The objective of this topic is to stimulate breakthroughs in technologies associated with solar sails. Solar sails are envisioned as a low cost, efficient transport system for future deep space missions. They are baselined for several strategic missions in the Sun-Earth Connection (SEC) Space Science theme, including Solar Polar Imager and Interstellar Probe, a solar 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, solar sail technology.

Areas in which innovations are sought include lowering the cost of sail development and application, enhancing sail delivery performance, and reducing the risks associated with sail development and application. Innovations are sought in but not limited to the following areas:

- Packaging and deployment.
- Materials.
- Structure/systems.
- Fabrication.
- System control (attitude, etc.).
- Maneuver/navigation.
- Operations.
- Durability/survivability.
- Sail impact on science.

Three parameters have been used for sail definition in mission applications that imply levels of technology capability: sail size, sail survivability for close solar approaches, and areal density (ratio of mass of the sail to area of the sail). Keeping in mind that overall system metrics are cost, benefit, and risk, technologies geared toward following wide range of sail sizes, solar closest approach distances, and areal densities are of interest:

Sail sizes from the very small (meter-sized; e.g., for use with tiny payloads or use as auxiliary propulsion) to the medium (50-100 m size, for achieving high-inclination solar orbits) and ultimately to the very large (hundreds of meters; e.g., for use in leaving solar system at high speed).

- Closest solar approaches from 1 AU down to 0.1 AU.
- Areal densities from 0.1 to 10 g/m**2.

17 Structure and Evolution of the Universe

The goal of the Office of Space Science'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: A) Identify dark matter and learn how it shapes galaxies and systems of galaxies, B) Explore where and when chemicals elements were made, C) Understand the cycles in which matter, energy and magnetic fields are exchanged between stars and the gas between stars, D) Discover how gas flows in disks and how cosmic jets formed, E) Identify the sources of gamma-ray bursts and high energy cosmic rays and F) Measure how strong gravity operates near black holes and how it affects the early universe. The technologies needed to achieve these goals fall into the following categories: 1) Detectors and sensors, 2) Optical systems and lightweight systems, 3) Long lived Cryo-coolers, Thermal control and Cryogenic Support Systems, 4) Precision station keeping and metrology, 5) Gravitational, Submm, UV and X-ray Interferometry Technologies, 6) Ultra Long Duration Balloon Technologies.

17.01 Detectors and Sensors for Astrophysics
Lead Center: GSFC
Participating Center(s): JPL

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

Gravity Waves. 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.).

Space VLBI. Very Long Baseline Interferometry (VLBI) systems with one element in space (called Space VLBI) need development of space-borne low-power low-noise amplifiers (down to 20 K at 43 GHz and 86 GHz) with wide bandwidths (up to 2 GHz), to serve as primary receiving instruments. Also needed are light-weight, deployable (up to 50-meters diameter), space-borne radio telescopes with high efficiency at millimeter-wave observing bands (up to 86 GHz), to serve as primary observing instruments.

High Energy. The next generation of astrophysics observatories for the 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 three energy regions, many of the parameters where improvements are needed are present in all three 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. The SEU program seeks innovative technologies to enhance the scope, efficiency and resolution of instrument systems at all energies/wavelengths.

- 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 percent dead time at 10 ns response time), high segmentation with low dead area (< 20 percent nominal, < 5 percent 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.
- Advanced X-ray calorimetry improvements in several areas are needed, including: superconducting electronics for cryogenic X-ray detectors such as SQUID-based amplifiers and multiplexers for low impedance cryogenic sensors and super-conducting single electron transistors and multiplexers for high impedance cryogenic sensors, micromachining techniques that enhance the fabrication, energy resolution, or count rate capability of closely-packed arrays X-ray calorimeters operating in the energy range from 0.1 keV to 10 keV, and surface micromachining techniques for improving integration of X-ray calorimeters with read-out electronics in large scale arrays.
- Improvements in readout electronics, including low power ASICs and the associated high density interconnects and component arrays to interface them to detector arrays.
- Improvements in material growth techniques for solid state hard X-ray detectors.
- Large format detectors for use with "lobster eye" X-ray optics. Could be arrays of CCDs, silicon strip detectors, or gas micro-strip or micro-gap detectors, optimized for low energy X-ray operation in relatively low-rate environments.
- Superconducting tunnel junction devices and transition edge sensors for the UV and X-ray regions. For the UV, these offer a promising path to having "three-dimensional" arrays (spatial plus energy). Improvements in energy resolution, pixel count, count rate capability, and long wavelength rejection are of particular interest. We seek techniques for fabrication of close packed arrays, with any requisite thermal isolation, and sensitive (SQUID or single electron transistor), fast, readout schemes and/or multiplexers.
- Arrays of CZT detectors of thickness 5 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.
- Micro-well structures on amorphous thin film transistor arrays for two-dimensional pixel readout with fine pitch (few hundred microns) for large X-ray and gamma-ray area arrays (meters scale).

17.02 Astrophysical Observing Systems
Lead Center: GSFC
Participating Center(s): JPL, LaRC, MSFC

The NASA Space Science Enterprise is studying future missions to explore the Structure and Evolution of the Universe, 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. These observatories will peer farther and view objects more fainter than current Earth-based or space-based observatories and therefore will have increased resolution and light-gathering ability by greatly increasing the aperture size. It also will be necessary to operate some of these telescopes at cryogenic temperatures and at a substantial distance from the Earth. Apertures for normal incidence 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.

The observatories required for many future SEU missions will also be operated at cryogenic temperatures (30 K) and at a substantial distance from the Earth. Therefore, 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 potential significant benefits possible from employing systems that can adaptively correct for image degrading sources from inside and outside the spacecraft. This subtopic also 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, and ultra-smooth (2-3 angstrom 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/m2, 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.

17.03 Gravitational, Submillimeter, UV and X-Ray Interferometry
Lead Center: JPL
Participating Center(s): none

Interferometry figures prominently in NASA's plans for 21st century Space Science. The Structure and Evolution of the Universe roadmap includes multiple projects which use interferometry for the detection and imaging of astrophysical sources. Both monolithic and free formation-flying interferometer systems are contemplated. The objective in all cases is to use the extraordinary resolution offered by interferometry to explore the structure of our universe as seen across the electromagnetic spectrum and as represented by gravitational waves generated by the dynamics of dense matter regions. This topic is looking for high-payoff, innovative concepts that will help to achieve the interferometry goals, including reduction of cost and schedule.

Gravitational-Wave Interferometry. Innovative technologies for supporting the measurement of low-frequency (0.1 - 0.001 mHz) gravitational waves, by measurement of the change of distance between freely falling proof masses which are caused by gravitational waves. Examples of needed technologies are:

Inertial Sensors. Provide free-falling proof mass with external housing; noise forces on proof mass must produce accelerations less than 3x10-15 m/s/s/sqrt (Hz) (corresponding to displacement noise < 1 picometers rms over 100 seconds); position of proof mass with respect to housing must be measured with accuracy < 1 nanometer rms over 100 seconds.

Stablized Lasers. Greater than 1 watt single mode power with very narrow linewidth (typically a few kiloherz), which can be externally stabilized to better than 1 Hz rms at 100 second time scales.

Laser Phase-Tracking System. Measure beat-frequency between two laser signals with frequency difference up to 10 MHz with accuracy better than one-millionth of a cycle over 1-1000 seconds.

X-ray Interferometry. Technologies to support acquisition and tracking of X-ray fringes from separate collecting optics, which may be on different spacecraft. Examples of needed technologies include.

Precision Optics. Produce X-ray flats (~1 cm x 1 m) with surface accuracy better than 1/200 of a (633 nm) wavelength, to allow for high X-ray fringe visibility.

Laser Metrology. Laser metrology gauge systems and components are needed to provide high-finesse baseline range sensing. Precision requirements vary with application, ranging from 50 picometers for a 10 meter baseline to 10's of nm for a 1 km baseline, and a few picometers for a thousand kilometer baseline. Full aperture metrology gauge schemes appear to be essential.

Vibration Isolation and Suppression. Concepts, components, subsystems, algorithms, and software to isolate, attenuate and suppress vibrational motions of the structure and key components when subjected to excitation over a broad frequency range. The amplitude of the vibrations to be suppressed is in the 1-10 nanometer range, with frequencies ranging up to 100 Hz.

Submillimeter Interferometry. Technologies to support acquisition and tracking of sub-millimeter and far-infrared fringes from separate collecting optics, which may be on different spacecraft. Examples of needed technologies include.

Beam-Splitter/Combiner. Optical elements(s) to split and combine signals in the 40-200 micron band.

Dual-Star Feed. Optics to concentrate light from different parts of sky onto at least two discrete detectors.

Correlators. Low-power low-mass devices to cross-multiply signals from heterodyne detectors.

17.04 Thermal Control and Cryogenic Systems
Lead Center: GSFC
Participating Center(s): ARC, JPL, JSC, MSFC

Future spacecraft and instruments for NASA's Space and Earth Science Enterprises will require increasingly sophisticated thermal control technology to meet the demands of tight control and minimal mass. Heat load centers may be more numerous and more widely dispersed, flux levels may increase, cryogenic instrument applications will be more common, and very tight temperature control will be required. Some applications may require significantly increased power levels while others may require extremely low heat loss for extended periods. The advent of very small spacecraft will also drive the need for new technologies, particularly since such small spacecraft will have low thermal capacitance. This situation, combined with the need for tighter temperature control, will present a challenging situation when such spacecraft/instruments undergo transients. The use of "off-the-shelf" commercial spacecraft buses for science instruments will also present challenges. In general, low cost, low weight, and high reliability are prime technology drivers. Specific areas for which innovative proposals are sought include:

- Advanced thermal control coatings such as variable emissive surfaces that are controllable.
- Cryogenic (4 K to 80 K) heat transport devices which incorporate a diode function.
- Advanced thermoelectric coolers capable of providing 100s of milliwatts of cooling at 150 K and below.
- Phase change devices for thermal storage.
- Advanced analytical techniques for thermal modeling, focusing on techniques that can be easily integrated with emerging mechanical and optical analytical tools.
- Highly reliable Loop Heat Pipes and CPLs which allow multiple heat load sources and multiple sinks.

Many future space missions will have operational lifetimes of 5 to 15 years and will require similar lifetimes for cryogenic cooling systems. Both the lifetime and the reliability of the cryogenic systems are critical performance concerns. Mechanical coolers, thermoelectric coolers, radiative 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 3-8 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 cooling technologies, particularly at very low temperatures.
- MEMS and miniature solid-state cooler systems.
- Hybrid cooling systems that make optimal use of radiative coolers.

17.05 Terrestrial and Extraterrestrial Balloons and Aerobots
Lead Center: GSFC
Participating Center(s): JPL

Innovations in materials, structures, and systems concepts have enabled buoyant vehicles to play an expanding role in NASA's Space and Earth Science Enterprises. A new generation of large, stratospheric balloons based on advanced balloon envelope technologies will be able to deliver payloads of several thousand kilograms to above 99.9 percent 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. Miniature balloons capable of long duration flight also are emerging as an important tool in planetary exploration, terrestrial climate investigations, and weather prediction. Such balloons also have potential significance for commercial communications. NASA is seeking innovative and cost effective solutions in support of terrestrial and extraterrestrial 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 180 K and 300 K, resistance to fracture, low helium permeability, and good handling and folding characteristics.
- Membranes for extraterrestrial 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 are 70-90 K (Titan), 140-300 K (Mars) and 250-750 k (Venus).

Support systems

- Trajectory control techniques for maneuvering terrestrial and extraterrestrial 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.

18 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. The technologies and discoveries needed to achieve these goals fall into the categories of very large space observatory systems, precision spacecraft constellations, advanced astronomical instrumentation, and new techniques for laboratory astrobiology.

18.01 Large Telescope Systems
Lead Center: MSFC
Participating Center(s): GSFC, JPL, LaRC

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 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/m2 is typical for conventional telescopes, and NGST is striving to achieve between 10 and 15 kg/m2. However, for ASO missions and other future telescope programs, areal densities of ˜1 kg/m2 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 1-10 kg/m^2 areal densities) and/or far-term objectives (i.e., 20-40 m apertures and < 1 kg/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.

18.02 Precision Constellations for Interferometry
Lead Center: JPL
Participating Center(s): GSFC

(Note: All proposals addressing formation flying and control, other than interferometry related applications for the NASA's Origins Program theme, should be submitted to the Cross-Enterprise "Formation Control", Subtopic 22.02.)

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.

18.03 Astronomical Instrumentation
Lead Center: JPL
Participating Center(s): ARC, GSFC

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 infrared to 100 um. These measurement techniques include imaging, photometry, spectroscopy and polarimetry. In addition, Origins missions based on optical interferometry are being developed. These systems require efficient optical beam combiners and techniques for extremely high contrast detection of faint planets near bright stars. Of particular interest are:

Advanced Detectors (Vis, IR, FIR). These efforts should propose breakthrough capabilities in spectral coverage, large array size with uniform high quantum efficiency, low dark current, 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.

Optical and Opto-mechanical Instrument Components. Given the need for miniature and multiple capability instruments, there is a growing need for breakthrough concepts in instrument optics, which reduce the volume requirements while adding capabilities (spectral, or otherwise) to the instrument.

High Contrast Sensing Techniques (achromatic starlight nulling). There is a need for nulling/blocking of a 20 percent optical bandwidth star image intensity within 1 arcsecond (5 microradians) of a dim planetary object. The required nulling ratio is greater than 1 million at a wavelength of 10 microns. Current state-of-the-art is 10,000 at visible wavelengths.

18.04 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 us to search for extant or extinct life elsewhere in the solar system, to obtain an organic history of planetary bodies, to discover and exp lore water sources elsewhere in the solar system and to distinguish microorganisms and biologically important molecular structures within complex chemical mixtures. 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:

Mobility/Sampling/Subsurface Water Detection Systems

- Innovative techniques that meet these needs are required, e.g., 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.

Analytical Tools

- 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.
- 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.
- 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.
- Algorithms for processing and analyzing recovered data.

Instrumentation and information technologies to support the study of evolution of ecological processes and CESR are:

- Miniature to microscopic, high resolution, field worthy, smart sensors or instrumentation for the accurate and unattended monitoring of environmental parameters that include, but are not limited to, solar radiation (190-800 nm at < 1 nm resolution), ions and gases of the various oxidation states of carbon and nitrogen (at the nanomolar level for ions in solution and at the femtomolar or better level for gases), in a variety of habitats (e.g., marine, freshwater, acid/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 pCO2 (change in CO2 over the eons) and solar UV radiation on carbon sequestration and N2O 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.
- Microscope Digital Array Scanning Interferometer (DASI) or its equivalent 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.

19 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: 1) How do planets form? 2) Why are planets different from one another? 3) Where did the makings of life come from? 4) Did life arise elsewhere in the Solar System? 5) 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.

19.01 Lightweight Materials for Planetary Aerocapture and Balloons
Lead Center: JPL
Participating Center(s): none

The desire to launch deep space mission payloads on lower cost, 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, struts, antenna, 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, for example) at Venus and Titan if we wish to dramatically reduce the cost of in situ science. 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. Materials and processes, and their associated mission use constraints, must have the potential to meet all important requirements or they will not be considered.

- Ballute materials for aerocapture missions with high temperature capability (> 400 C), high emissivity e > 0.8, low mass-areal density < 10 gm/m2, 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/m2. 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 lifetime; 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/m2 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; and shape memory thin films/low density polymeric materials for deployable structures.

19.02 Instruments for Conducting In Situ Scientific Measurements
Lead Center: JPL
Participating Center(s): ARC

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, and for exobiology. Achieving Solar System exploration goals will require innovative components and miniaturized instruments for in situ analysis that offer significant improvement over the state of the art in terms of size, mass, power, cost, performance, and robustness. 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 a 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 are of interest - geological, chemical, biological, physical, and environmental. Particular emphasis is needed on astrobiology related measurements, seeking to understand the origin and evolution of life and pre-biotic processes.

New in situ analysis techniques for exobiology flight experiments are desired to identify and quantify biogenically important elements (C, H, N, O, P, and S) and their compounds (e.g., CH4, NOx, H2O) within extraterrestrial atmospheres, soils, ices, sedimentary rocks, and minerals.

Examples of in situ measurement technologies include but are not limited to:

- Chemical sensing instrumentation for the surface and subsurface chemical and isotopic analysis of soils, rocks, and ices, such as Raman spectrometers, laser-induced breakdown spectrometers, 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 biogenically important elements and compounds for the identification and characterization of biomarkers of extinct or extant life, such as ultraviolet-Raman, infrared reflectance and transmittance spectrometers to identify and measure the C, O, and N isotopes in CO2 and NOX with a precision of 0.1 percent or better, fluorescence microscopy, total organic carbon analyzers, 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 as electron microscopy techniques and atomic force microscopy.
- Instrumentation for the chemical and isotopic analysis of planetary atmospheres.
- 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.
- 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.

19.03 Sample Access, Handling, and In Situ Investigation Systems
Lead Center: JPL
Participating Center(s): none

Future scientific exploration of planets and small bodies will require improvements in the tools for accessing surface and sub-surface materials for sample collection, sample handling, and in situ investigation. These tools will be required to operate in extreme environments including high temperature, high-pressure environments as well as low temperature, near vacuum environments. Novel devices and approaches are needed in the areas of manipulation and positioning of instruments; penetration of surface materials that have a wide range of properties; acquisition and storage of pre-determined amounts of material; protection of samples from handling and environmental damage; and placement of samples into analysis systems. Example technology concepts include, but are not limited to, the following:

- Surface sample handling systems including, for example, miniature sample acquisition mechanisms with integrated feedback sensing, low-power miniature rock crushing and transport systems, impact technologies for rock fragmentation, and sample confinement and containment techniques for sample return missions.

- Sub-surface sample access systems including, for example, low reaction force coring and drilling devices, low power rock ablation devices, and anchoring techniques for microgravity bodies.
- Sample access and collection within aqueous environments including, for example, mini-pump and transport systems, sample acquisition within sub-surface ice environments, and passive entrapment devices for liquid collection.

19.04 Technologies for the Reduction of Biological Contamination on Flight Hardware
Lead Center: JPL
Participating Center(s): none

As space flight missions venture into planetary atmospheres and onto surfaces, NASA is committed to implementation of its planetary protection policy and regulations. There is a need to support projects in all mission phases from design to close-out. 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 area of cleaning, cleaning validation, maintenance of biologically clean work areas, encapsulation and containerization, and archival preservation of organic and inorganic samples. Examples of such technologies include but are not limited to:

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

8.5 CROSS ENTERPRISE

In addition to the above research subtopics specific to each Enterprise, this section captures critical technologies that may support multiple Strategic Enterprises. Cross Enterprise topics reflect the current agency management structure for these Cross Enterprise technologies.

20 Advanced Power and Onboard Propulsion

The Advanced Power and On-Board Propulsion (APOBP) Cross Enterprise seeks to provide dramatic reductions in the mass, volume, and cost for spacecraft power generation, power management, energy storage, thermal management, and propulsion systems through breakthroughs in several space power and on-board propulsion technologies. These technology breakthroughs will enable deep space science missions with greatly reduced trip times, increased capability and longer planetary encounters; enable human exploration with short trip times and self-sustaining systems; greatly enhance more ambitious and lower cost earth science missions; and enable revolutionary concepts such as virtual spacecraft operating as diverse constellations. Technologies are sought that will extend the capability, to travel farther faster, and enable longer planetary encounters; improve power generation (solar and nuclear) and energy storage (various battery technologies and flywheel energy storage; improve on-board propulsion, including chemical, ion, and ACS propulsion systems, with an emphasis on Micro-Newton thrusters.

20.01 Energy Conversion and Storage and Power Control
Lead Center: GRC
Participating Center(s): none

Innovative concepts utilizing advanced technology are solicited in the areas of energy conversion, storage, power electronics, and power control. Power levels of interest range from tens of milliwatts to many kilowatts. NASA programs require energy systems with high energy density, cycle life, and reliability and reduce overall costs (including operations). Advances are sought in the following areas:

Static and Dynamic Energy Conversion

- Photovoltaic technology: (cell efficiencies > 30 percent, array up to 1000 W/kg and 400 W/m2), rigid arrays, thin film arrays, concentrators, radiation resistance, low temperature/low intensity, high temperature/ high intensity operation.
- Thermal-to-electric conversion: Radioisotope Heater Units (RHUs) or General Purpose Heat Source (GPHS) to electricity (tens of milliwatts to hundreds of watts with efficiencies > 20 percent), and advances in AMTEC, thermophotovoltaics, thermoelectrics, Stirling, small lightweight heat reaction systems, and microfabricated power systems.

Energy Storage

- Primary batteries: > 600 Wh/kg, > 1200 Wh/l, operation-100 C with > 30 percent specific energy.
- Secondary battery (lander): > 500 Wh/kg, > 1000 Wh/l, > 150 Wh/kg at –100 C, operation 65 C.
- Secondary battery (LEO): > 200 Wh/kg, > 30,000 cycles @ 40 percent.
- Li/Li-polymer battery: > 200 Wh/kg, low/wide-temperature operation.
- Distributed micro to milliwatt power sources integrated with microelectronics operation –100 C to +100 C, long cycle life.
- Conformable batteries to fit in under-utilitied areas of spacecraft.
- Regenerative fuel cell system with > 50 percent round trip efficiency, > 500 Wh/kg, > 1000 Wh/l, and > 20,000 hours of life.
- Proton Exchange Membrane (PEM) URFC Electrodes: > 40 percent round trip efficiency.
- Fuel Cell, Electrolyzer, URFC PEM Membranes < 10 mA/cm2 cross diffusion at 80 C, 400 psi, improve electrical efficiency through operation at 120 C, improve conductivity to > 0.1/ohm-cm).
- Fuel Cell, Elecrolyzer, URFC Stacks: reduce weight > 1500 cm2 active area/kg of stack weight at > 400 psi, improve efficiency and power density > 0.59 V/cell at > 4.2 A/cm2.
- High specific energy density flywheels or ultracapacitors.
- Flywheel energy storage or components (50-1000 Wh, 50-1500 W) improved specific energy, efficiency, cycle life, and/or cost. Dual function power/attitude control systems using flywheel elements for power storage and attitude control over a wide power range: development and demonstration of control laws.

Power Electronics and Control

- 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.
- Advanced electronic materials, devices and circuits including transformers, transistors, integrated circuits, capacitors, ultra capacitors, electro-optical devices, micro electro-mechanical systems (MEMS), sensors, low loss magnetic cores, motor drives, electrical actuation.
- Thermal control integral to electrical devices capability of > 100 W/cm2 heat flux.
- Advanced electronic packaging 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.
- Advanced control technologies including fault detection, isolation, and system reconfiguration, including "smart components," built-in test, health management, and power-line or wireless communication.
- Modular, integrated control building blocks which drastically reduce system size, mass, and recurring costs using advanced power packaging and flexible, reusable architectures based on monolithic, mixed mode application-specific integrated circuits, and/or field programmable gate arrays.

20.02 In-Space Propulsion
Lead Center: GRC
Participating Center(s): GSFC, JPL, JSC

In-space propulsion is a critical technology area for Space Science, Earth Science, and HEDS missions. In-space propulsion functions include orbit insertion, orbit maintenance, constellation maintenance, precision positioning, in-space maneuvering, de-orbit, vehicle reaction control, planetary injection, and planetary descent/ascent. The mass and volume of spacecraft are usually dominated by the propulsion system, limiting mission capabilities. Innovations are needed in chemical and electric in-space propulsion technologies to reduce the mass, volume, and cost of propulsion systems, while increasing their capability, reliability, and lifetime.

Innovations are sought in electrostatic (ion and Hall) and electromagnetic (pulsed plasma thrusters) technologies for unmanned Earth-space and planetary transportation applications. Technologies are sought that increase efficiency, increase lifetime, reduce mass, and reduce system complexity.

High-power (> 100 kW) electric propulsion technologies are needed for HEDS and space solar power applications. Innovations in power processing are also sought.

High-performance (specific impulse > 250 sec) monopropellant technologies are sought for small satellite orbit insertion and on-orbit maneuvers. Of particular interest are ignition technologies, both catalytic and non-catalytic, for high-temperature monopropellants. High-performance bipropellant technologies (specific impulse > 350 sec) are of high interest for planetary propulsion applications.

Propulsion technologies applicable to spacecraft less than 40 kg are of high interest to Space Science and Earth Science missions. These propulsion technologies should emphasize system simplicity, low power requirements, minimal mass, and leverage the unique nature of microscale devices.

For all of the electric, chemical, and micro propulsion systems described, there is a need for propellant management components that reduce total propulsion system mass and volume by a factor of two or better, while maintaining or improving reliability of existing components.

Technologies are sought that will significantly increase capabilities and reduce costs for Earth science platforms, as well as enabling new missions with revolutionary concepts. Propulsion functions for Earth science missions include orbit insertion, orbit maintenance, constellation maintenance, precision positioning, and de-orbit. Of particular interest are propulsion technologies for nano-spacecraft (< 20 kg) that emphasize system simplicity, low power requirements, and minimal mass. These include propulsion technologies that provide high-precision (impulse bit

< 100 mN-s) station keeping and attitude control; high-performance, high-density, low-freezing point monopropellant technologies; and high-efficiency electric propulsion technologies for small, power-limited spacecraft.
Deep space missions have certain unique propulsion requirements, compared to those for earth-orbital missions, such as very high specific impulse, longer service life and higher reliability requirements, stricter mass and volume constraints, very fine pointing and positioning demands, and capability to operate in more extreme thermal and radiation environments. Innovative approaches to meeting these requirements are sought. Particular technologies of interest include: lightweight 5-20 lbf-class bipropellant rocket engines, lightweight propulsion system components, low freezing point propellants, thrusters with a combination of very low impulse bits and high thrust-to-power ratios, and high reliability micropropulsion (particularly MEMS) technologies.

Innovations in small chemical propulsion are needed for spacecraft systems used for in-space transfer, in-space maneuvering, and ascent/descent missions. Other mission applications include reaction control systems for reusable launch vehicles. Systems that use non-toxic bipropellants are of primary interest, but advances in conventional hypergolic propellants are also sought (specific impulse > 325 s). Figures of merit also include reduced cost, longer life, improved maintainability, and higher reliability. System/component technologies of interest include: materials compatible with high-temperature, oxidizing and reactive environments; components for fluid isolation, pressure/mass flow regulation, relief quick disconnect, and flow control; techniques for metering, injection, and ignition of fluids in combustion devices; and gaseous storage and pressurization systems.

21 Breakthrough Sensors and Instrument Component Technology

The Breakthrough Sensors & Instrument Component Technology (BSICT) thrust develops advanced detectors, sources, and components that enable a wide array of sensing capabilities for NASA. Sensors and instruments are the primary payloads for NASA's unmanned missions, and are key elements for human missions. Cameras that image the universe, radar systems that probe the earth and seas, sensors that monitor the environment inside crewed spacecraft are examples of the reach of sensor technology. Through the use of advanced micro- and nano-technologies, the BSICT thrust is creating detection capabilities that offer orders of magnitude improvement in sensitivity, coverage, and speed while also greatly reducing mass, power, and cost. NASA seeks new observation capabilities for astrophysics, space physics, planetary and Earth science remote sensing and in situ sampling. The objective is increased sensitivity while achieving significant reductions in mass and overall mission costs. Applications range from new sensing techniques using distributed spacecraft to bio-sensors for astrobiology missions. Accordingly, this topic seeks the development of new detector technologies based on fundamentally new measurement principles and techniques, new materials, and new architectures. Expanded use of different spectral regions including high energy is also under consideration for future missions.

21.01 Nano/Quantum Devices
Lead Center: JPL
Participating Center(s): none

This subtopic seeks new or revolutionary developments in nano/quantum device technology for NASA applications. 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.

Nano/quantum device technologies in the following areas are solicited:

- 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.

21.02 Integrated Photonic and Micro-Optic Devices
Lead Center: MSFC
Participating Center(s): none

New and innovative approaches to the design, fabrication, and application of optical devices are needed to fully exploit the ability of photonics to provide size, weight, and cost reduction in optical systems, instruments, and components. Areas of interest include:

- Microlithography, micromachining, and microfabrication approaches to the development of micro-optic devices, with special emphasis on applications using direct write electron beam-lithography or photolithography fabrication techniques.
- Active optical elements such as liquid crystal spatial light modulators, electro-optic modulators, acousto-optic modulators, piezo-electric modulators, and other modulation techniques.
- Techniques for the fabrication of large aperture (> 10 cm) phase gratings possessing micron-sized surface features.
- Software design tools for use in developing computer-generated holograms, phase gratings, diffractive optics, and sub-wavelength structures.
- Generalized design software for scalar and/or vector-based assessment and analysis of wavefront propagation through diffractive and sub-wavelength structures.
- Methods of dual-mode integration between electronic circuits and optical circuits.
- Non-linear optics for use in integrated optical circuits, systems, detectors, and devices.
- Optical circuits with integrated sources, waveguides, directional couplers, modulators, and detectors.
- Design and fabrication of diffractive and integrated optic devices for broadband applications.
- Micro-optic fabrication techniques for the production of high aspect ratio (> 3:1), sub-micron surface structures.
- Wavelength division multiplexing techniques for handling high bandwidth optical signals using integrated optical circuits.
- Large area (> 2 cm squared) blazed diffractive optical elements and gratings deposited on curved surfaces with optical power for use in miniaturizing optical systems.

21.03 Advanced Photon Detectors
Lead Center: GSFC
Participating Center(s): none

In support of ongoing and future scientific missions, NASA is constantly pursuing advances in detector technologies and technologies closely related which advance detector performance. NASA missions require a wide range of focal plane detectors which operate from room temperature (300 K) to less than 0.1 K. The focal plane may have as few as a single detecting element to over 10 million elements (a large format CCD, for example). Detector electronics can be as simple as a single JFET source follower or as complex as a custom multi-million cell readout integrated circuit. The ultimate goal is to deliver the absolute highest quality science data possible with minimal cost. To achieve this goal, NASA is looking for improvements in a wide range of detector technologies spanning the electromagnetic spectrum from gamma rays to the very far infrared. This may include new detector materials or novel approaches to conventional materials. Specific sensor technologies that are of particular interest are:

- Large format UV, visible and IR detector arrays including: Solar blind UV detectors such as GaN, front and backside illuminated CCD's in excess of 50 mega pixels with improved quantum efficiency and read noise, silicon strip detectors, active pixel, polarization sensitive detector arrays.
- Very large format arrays of InGaAs, InSb, HgCdTe, extrinsic silicon, GaAs QWIPS.

- Monolithic multicolor detector arrays (such as detector arrays having different spectral response at different material depths or other methods of energy resolution on chip.)
- Advanced IR and visible detectors including: IR detector arrays operating at warmer temperatures, uncooled IR detectors arrays, radiation hard visible and IR detectors.
- Develop photon counting detectors for far infrared and sub-millimeter radiation using super conducting and quantum dot technology with NEP < 10-20 W/vHz along with fast readout schemes and/or multiplexers to read our arrays as large as 1000 pixels.
- Low and high temperature Super conducting detectors (tunnel junction and transition edge, for example) and readout electronics.

To further improve the detector system performance NASA is also seeking advances in supporting technologies. Some examples of these technology areas are:

- New and innovative detector/readout electronics hybridization for very large format focal planes.
- New and improved electronics for cryogenic temperatures (LN2 and LHe) such as CMOS and GaAs readouts, ASICs, low noise FETs, SQUIDS.
- Extremely small area very high value (greater than 100 mega ohms) low noise, low capacitance resistors for detector loads.
- New and novel blackbody sources for on-board real time detector calibration.
- Detector thermal isolation improvements to reduce head loads to or from the focal plane.

22 Distributed Spacecraft

Virtual platforms and distributed spacecraft control technologies will revolutionize the manner in which Earth and Space Science missions are conceptualized, planned, designed, and implemented. This Cross Enterprise includes concepts, approaches, and strategies that enable higher levels of interaction between vehicles, cooperation between vehicles, and the ability to function with a common system wide capability. Distributed networks of individual vehicles will replace large complex observatories. They will operate under virtual infrastructures capable of responding to changing needs and conditions and evolving over time to introduce new capability and technology. Extensive co-observing campaigns, coordinated multi-point observing programs, significant improvements in space-based interferometry, and entirely new approaches to conducting Earth and Space Science will be achievable while reducing the complexities, costs, and schedule requirements associated with traditional mission concepts. This topic focuses on the guidance, navigation and control aspects of multiple distributed assets or space vehicles, including architectures, methodologies, and hardware components. Distributed networks include all types of multiple cooperating space vehicles, e.g., balloons, instruments and detectors, mirrors and satellites. Technologies are sought that enable coordinated constellations of spacecraft or other remote platforms that act as a single mission spacecraft for coordinated co-registered earth or planetary observations, act as single instrument (interferometry or distributed optical systems) or perform in situ coordinated measurements; Advanced autonomous guidance, navigation and control architectures; Formation acquisition, initialization and maintenance, fault detection and recovery; Satellite cross-link for communication.

22.01 Telecommunications and Data Management for Formation Flying
Lead Center: GSFC
Participating Center(s): none

Novel concepts and enabling technologies for the end-to-end interspacecraft communications architecture for multiple satellite formations with particular interest in the fusion of intelligent command, control, and navigation strategies with the communications architecture while addressing special issues such as protocols, robustness, routing, connectivity, latency, self-jamming/interference, and signal structure. Technologies enabling onboard distributed real-time computing and data management, sharing and storage concepts for numerous distributed vehicles over various separation distances and data rates (extreme case requiring Gbps) are also of interest. Innovations are expected to offer significant improvements in performance, weight, power efficiency, reliability and/or cost. Products are sought in the following areas:

- Latency-tolerant data communication protocols and enhanced Asynchronous Transfer Mode (ATM) and related network technologies for inter-spacecraft communication.
- Internet technologies to provide information among spacecraft in a formation and links to the ground for the end users. Innovative approaches to software simulation tools for upper atmospheric and inter-spacecraft interference and disturbances.
- Fault tolerant protocols that allow for data transfer recovery without a complete resend of the data.
- Software/hardware technologies to enhance configuration management, performance monitoring, fault isolation and security of data communications networks involving inter-satellite links.
- Network problem detection tools that help in fault detection and isolation.
- Low cost, low-weight, and low-power cross link transceivers with wide scan angles (+/- 60 degrees) for inter-spacecraft communications.
- Power and bandwidth efficient modems, combined modulation and coding schemes and digital transmission techniques for application in NASA space-based inter-spacecraft communication links. Innovative approaches to reduce size, mass, power and cost; single chip integration of multiple functions; use of digital technologies to enable multi-Gigabit/second throughputs; use of radiation hard components to support on-orbit operation.
- Hardware and software that support navigation methods for formation or constellation operations in Earth orbit based on the use of GPS and other RF signals.

22.02 Formation Control
Lead Center: GSFC
Participating Center(s): JPL

This subtopic calls for novel approaches to autonomous control of distributed spacecraft and the management of large fleets flying in formations. Techniques should include methods for initial formation acquisition, self-reorganization, collision avoidance, re-configurable control laws, algorithms for autonomous formation reconfigurations and maneuvers. Also of particular interest are fault detection and recovery techniques in a formation environment. Numerous future NASA missions include flying distributed non-homogeneous spacecraft for both Earth and Space Science applications.

Constellations such as large sparse antennas formed by a collection of miniature autonomous spacecraft containing the basic antenna elements arranged in an optimal geometric pattern represent an emerging novel approach to space-borne antenna design. 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 physical realization and operation of distributed spacecraft require new modeling techniques, new methodologies in autonomous, formation spacecraft control, configuration optimization, and development of high precision formation metrology and actuation systems. Techniques are needed to enable precision station keeping from coarse requirements (relative position control of any two spacecraft to less than a cm, and relative attitude of 1 arcmin over a large range of separation of a few meters to tens of kilometers) to fine requirements (nanometer relative position control, and relative attitude of .01 milliarcsecond) over a large range of separations of a few meters to tens of kilometers. In order to implement precision synchronized motions, high precision actuators are critical for both continuous and discrete control of spacecraft.

Tethered formation flying is another concept being considered for distributed sensing, co-observation platforms and interferometric instrumentation. Innovative concepts for distributed modeling and control for the deployment, retrieval, reconfiguration, tethered station keeping as well as techniques for tethered damping management are solicited.

Distributed spacecraft control systems also enable science investigations needed for the understanding of the total Earth system and the effects of natural and human-induced changes on the global environment. Some representative mission scenarios include maintaining a specified satellite formation geometry at key points in the trajectory, maintaining the relative motion and collective pointing among co-orbiting spacecraft throughout the orbit, or maintaining relative positioning and attitude for targeting points on the Earth or capturing reflected angles off the Earth's surface or atmosphere. Distributed spacecraft concepts of collective pointing (pointing the formation at a particular target) or coordinated pointing (pointing the formation to collect related data from different selected angles) are critical to many of these mission scenarios.

To support near-Earth observing missions and operations, and human exploration of space, distributed spacecraft capabilities must include navigation methods for formation or constellation proximity operations in Earth orbit based use of a "watch dog" satellite are of interest. The "watch dog" surveys targets of availability for a formation and notifies the fleet which targets are visible for observing, or performs other auxiliary functions for the fleet.

Distributed Spacecraft control systems should utilize, but are not limited to, expert systems, fuzzy logic, genetic algorithms, neural networks, discrete-event system methods, etc. to provide the formation with an onboard intelligence capable of: identifying and selecting science targets of opportunity while resolving mission and activity constraints; autonomously monitoring spacecraft functions and environmental conditions, assessing health status, and optimizing system performance through in-flight identification, fault detection, and stabilization; optimization of assets to target newly identified concerns or events; and autonomous fleet reconfiguration on using GPS and other RF signals. Concepts should consider the limited resources onboard - reduced memory and processing power when compared with ground systems.

23 High Rate Data Delivery

The future vision of this Cross Enterprise sees new communication and information technology breakthroughs enabling high rate data delivery, thereby establishing our virtual presence throughout our solar system. To achieve this will require the integration of advanced communications, networks and information technologies. The integration of these technologies, with high data rates, will enable a telepresence for near-earth and deep space scientific missions, and for human and robotic exploration. The transmission of data at high rates permits an increasingly rapid conversion of information to knowledge, and knowledge to new discoveries. Global interoperability among space-based assets and terrestrial telecommunications networks will diminish the gap between the sensors and the scientist. Information technology breakthroughs will enable the management of massive, diverse, multi-terabyte data sets needed to produce high-level information products. Technologies are sought that enable affordable virtual presence throughout the solar system; minimize the impact of communications subsystems on future spacecraft; enable cost-effective information extraction and compression; reduce cost through low cost lightweight high data rate system and low mass components; enable deep space and near earth optical communications; enable in situ communications for surface exploration; and improve communications components for Deep Space Communications and enable high rate communications among distributed information elements.

23.01 High Performance Communication Technologies for Interplanetary Missions
Lead Center: JPL
Participating Center(s): none

All NASA missions rely on the transmission of data for their successful completion. Future NASA missions require high data rates (greater than multi-Gbps) for backbone communications, internetworking among spacecraft constellations and direct data delivery to ground networks and users via the internet.

Innovative communications technologies are sought at the device, subsystem and system level in such areas as onboard data collection, processing and storage; microwave, millimeter wave and optical communications; digital processing, modulation and coding; communications architectures, and networks and system protocols. High performance and highly robust communication systems are needed for multi-year science data return from Earth orbit and Solar System bodies like the Mars telecommunications infrastructure. Also, satellite communications with small body and planetary landers and in situ rovers and sensors are of growing interest. Topics of interest include:

- System and component level optical and microwave technologies for highly efficient laser transmitters and modulation schemes for deep space (Q-switched solid-state) sources with > 1 W of average output power.
- Efficient, very low-thermal expansion, lightweight, multi-channel telescopes systems with 10-30 cm in aperture size where implementation of stray-light control and sunlight mitigation effects are of particular interest (an

example is a terminal at Neptune communicating with earth while the Sun is in the background for majority of the time.)

- Advanced technologies for sub-micro-radian level pointing of a laser beam at the Earth including high-bandwidth sensor (e.g., micro-g level gyro) feedback, and innovative acquisition and tracking algorithms.
- Focal plane array detectors incorporating on-chip processing for window control and features such as pixel gain/offset correction window, background/pattern noise calibration, bright spot location for initial acquisition, pixel summation mode, low power, low noise, high tracking bandwidth, multi-windowing, full random access, high QE, and electronic shutter.
- Modulation and coding techniques and network designs for deep-space communications that reduce cost, input power, mass, bandwidth requirements and complexity.
- For ground receivers, inexpensive, very large (> 10 m) innovative telescope designs. Also high gain, large area (> 3 mm diameter) avalanche photodiode detectors (APDs) with > 200 MHz bandwidth, > 40 percent QE at 1064 nm and very low noise (k factor.)
- Ultra-small, low cost, low power, deep-space RF transponders and components, including low voltage, high-efficiency integrated circuits such as microwave monolithic integrated circuits (MMICs) and MMIC filters.
- Signal processing circuits for receivers that provide carrier tracking, command and ranging capabilities.
- Low voltage, multi-function MMIC designs with integrated filters to provide low-noise down-conversion, automatic gain-control, up-conversion, and transceiver functions at Ka-band (32 GHz.)
- MMIC modulators to provide large linear phase modulation (above 2.5 radians), and high-data rate BPSK/QPSK modulation at Ka-band.
- Miniature, ultra-stable and voltage-controlled oscillators for deep space communications and GPS applications.
- Miniature, low-loss X-band (8.4 GHz) and Ka-band switches and diplexers.
- Miniature, X-or Ka-band high-efficiency power amplifiers and RF power devices, transmitters with output power levels ranging from 3 watts to 20 watts, and both innovative solid-state as well as thermionic devices that can survive the space environment with mean-time-to-failure of 10 years or more.
- MMICs supporting miniature, high-efficiency power amplifiers at Ka-band (primary focus) and X-band (secondary focus) such as gain blocks, multi-bit digital phase shifters and power cells.
- Support elements like low-loss, miniaturized isolators, high-efficiency integrated DC-DC power converters, and miniaturized power dividers and combiners.
- Low mass, high-gain, high-efficiency antennas typically with diameters less than 2 meters, integral with spacecraft surfaces, or that can be reliably stowed in low volumes.

24 Thinking Space Systems

The Thinking Systems Cross Enterprise has the goal of enabling better, faster, cheaper, more reliable space missions by extending the scope of decisions and actions that can be done under computer control. The Cross Enterprise enables unmanned missions to accomplish more by making better autonomous decisions, and better interpretation of the science data that is brought back. It enables manned missions to be cheaper and safer by providing more sophisticated interactions between astronaut and machines. Finally, it enables ground operations to be cheaper and faster, by allowing a reduced ground operations team to send more complex high-level instructions. In all cases, the Cross Enterprise will support both earth orbit and deep space missions. The Cross Enterprise also provides an infrastructure in model-based representation and reasoning, software validation and verification, and human-centered computing that will support a wide range of NASA programs. Technologies are sought that enable curious, self-reliant, self-commanding space systems that plan and conduct measurements based on current or historical observations or inputs; recognize desired phenomenon and concentrate observations or activities accordingly monitor and maintain desired status/configuration for long periods of time without frequent communication with ground.

24.01 Automated Reasoning for Autonomous Systems
Lead Center: ARC
Participating Center(s): GSFC, JPL

NASA is planning to fill space with robotic explorers, carrying our intelligence and our curiosity outward in ways never before possible. To survive decades of operation, these remote agents need to be smart, adaptable, curious, wary, and self-reliant in harsh and unpredictable environments. NASA is soliciting research in automated reasoning for autonomous systems that will enable the design, construction and operation of a new generation of remote agents that perform progressively more exploration at much lower cost than traditional approaches.

NASA also needs automated reasoning to improve its operations closer to home. For instance, software for monitoring shuttle and space station systems and diagnosing faults when they occur or software agents for processing, classifying and archiving the mountains of data from earth orbiting satellites. Specific areas of interest for automated reasoning include the following:

Agent Architectures
- Autonomy architectures that support plug and play of automated reasoning components.
- Architectures for homogeneous and heterogeneous distributed systems of agents.
- Capabilities related to Autonomous Performance.
- Planning and scheduling systems that support planning concurrent with execution, plan optimization, resource management and/or distributed plan creation capabilities.
- Model-based and statistical methods for monitoring, command confirmation, fault isolation, and diagnosis from sensor information.
- Methods for robust recovery & repair.
- Algorithms for real-time deduction and search.
- Novel environment sensing or mapping capabilities.
- Machine learning and adaptive control technologies.
- Methods for precisely and dynamically adjusting the level of human control.

Capabilities Related to Design
- Declarative specification of software and hardware behaviors, collaborative environments for large scale model building.
- Methods for code synthesis and controller generation from declarative specifications.
- Automated generation of test sequences from component models and analytic verification methods, including model checking and theorem proving.
- Methods for modeling, code synthesis, simulation, testing and validation, as above, that operate from hybrid discrete/continuous models.

24.02 Human-Centered Computing
Lead Center: ARC
Participating Center(s): JSC

NASA is planning to use 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 these 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 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.
- Agent-based tools for information gathering, reminding, and alerting; job performance aids that provide cognitive assistance in the context of daily activities.

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.
- "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; and d) the career trajectories of novices, experts, and retiring employees.
- 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.

25 Micro/Nano Sciencecraft

The micro/nano Sciencecraft Cross Enterprise marshals the work of a broad spectrum of mechanical and electrical science and engineering disciplines to produce an orders-of-magnitude reduction of the size and mass of NASA's spacecraft. Such reductions dramatically lower the size and cost of the launch vehicle required for a given mission. Alternatively, these same technology advances would allow a constellation of spacecraft to be launched on a single launch vehicle. In addition, these technology advances will yield such an increase of on-board computing capability that high levels of autonomy can be used to reduce the cost of operating spacecraft dramatically, thereby permitting real-time operations by the science instruments principal investigator and leading ultimately to space science that provides the investigator with a "virtual presence". Advances in technology are sought that will yield order of magnitude reductions of spacecraft mass and size, enabling large spacecraft constellations and/or more frequent flight opportunities for the same cost. Technologies are sought that enable a) small, individual, highly capable robotic spacecraft and b) capable multiple spacecraft working cooperatively in the collection, processing and transmission of science observations. These goals also require small lightweight easily deployed in situ instruments for satellite validation and field campaigns; smaller, lighter in weight, more resource-efficient, more capable spacecraft "bus" and "payload" components, efficiently integrated bus/payload spacecraft designs; high performance data compression technology; and low-power high-speed CMOS, rad hard FPGA, MEMS technology, fully integrated navigation, and MEMS based fluid handling and control for propulsion and thermal control.

25.01 Multifunctional Structure and Sensor Systems
Lead Center: JPL
Participating Center(s): none

NASA seeks innovative concepts for multifunctional structure and sensor 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, multifuntional 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 and a broadening of the tool set through the introduction of new kinds of design and analysis 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 with advanced lightweight materials for structure and propulsion.

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 are:

- 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 structural elements.
- Concepts and designs for test and validation of design integrity and performance of IP based ASICs, mixed signal ASICs and MEMS.

25.02 Nanotube Materials and Structures for Spacecraft and Nanobiotechnology Applications
Lead Center: JSC
Participating Center(s): ARC, JPL

This subtopic focuses on single-wall carbon nanotube applications and nanobiotechnology. NASA is moving toward smaller, lower mass and energy consumption aerospace systems. For planetary exploration the agency is moving toward 1-50 kg size, low cost spacecraft for space physics and earth science missions. Focus should also be on long-duration space missions and habitats. The intent is to revolutionize technology and expand functionality to enable new science investigations at acceptable costs using the extraordinary properties of single-wall carbon nanotubes (CNT). Unprecedented concepts for biotechnology at the nanoscale level using nanomaterials or nanodevices will aid in extending long duration human missions in space. Nanotube technology is expected to play a major role in developing future spacecraft and system needs of NASA.

To achieve these goals, significant advances in structural materials, nanoelectronics, data handling and storage, sensor systems and instrumentation are required. CNTs offer extraordinary mechanical and unique electronic properties and thus can meet demands in long term structural as well as electronics applications. Structural applications of CNTs could have significant impact on lower mass structures for space vehicles. Functionalization with molecules may lead to CNT-based sensors. Nanoelectromechanical systems (NEMS) based on CNT, such as actuators; accelerometers, motors, etc., can truly lead to a revolution in nanotechnology. Also of interest are innovative techniques for bulk production and large scale synthesis of exceptionally long and/or aligned or functionalized single-wall nanotubes, necessary for such applications as composites. Other areas of interest are the controlled nanotube growth on patterned substrates, control of nanotube diameter, helicity and properties, functionalization of nanotubes with chemical groups, chemical- gas- bio- sensors, storage of hydrogen, lithium fuel cell and battery applications, field display devices, in areas such as high strength materials and composites, energy storage, thermal protection, and rapid prototyping nanobiotechnology, nanobots (nano-scale robots) to monitor, repair or protect the human body in a hostile space environment, nanodevices operating at or below the cellular level to monitor radiation doses in organs, release medicinal substances at specified sites or intervals on command or programmed to operate independently using internal software, and other novel applications.

26 Next Generation Infrastructure

The Next Generation Infrastructure Cross Enterprise encompasses concepts and developments that make an Intelligent Synthesis Environment possible. This cross enterprise develops and implements tools and processes to revolutionize engineering practice and science integration in the design, development, and execution of NASA's missions. This technology enables advanced networked collaborations of geographically dispersed people and organizations using advanced simulation capabilities to define and evaluate the complete life-cycle performance of a mission or product, including mission definition, design, manufacture, operation and disposal.

Engineering and science tools are sought to provide virtual prototyping, synthetic mission environment development and life cycle simulation. Software capabilities are sought to provide intelligent knowledge capture and knowledge bases, collaboration technologies, intelligent networking, plug and play software architecture advanced and multi-sensory user interfaces. Moreover, technologies are sought that will significantly improve speed and/or accuracy of single discipline, deterministic, physics-based, and non-deterministic computational models and methods to support more efficient and cost-effective design of spacecraft components; improve multidisciplinary analysis and design procedures and methods to support the integration of design tools and computer architectures for concurrent engineering applications. Technologies are sought that enable the fusion of computationally intelligent algorithms into physics-based analysis methods, in order to improve accuracy, speed, software reuse, parameter sensitivities, user friendliness, and other aspects of the numerical computation process. These computer intelligence methods include the use of genetic algorithms, neural networks, fuzzy logic, and other similar technologies. Technologies are sought that enhance the application of virtual reality and other related advanced visualization tools to the design process, including developments in computer simulation methods that can be used to model the manufacturing, assembly, performance, repair, maintenance, and disposal of spacecraft products. Technologies are sought that enable collaboration amongst geographically dispersed groups of design engineers and mission scientists.

26.01 Life-Cycle Integration, Validation, and Distributed Collaboration Technologies
Lead Center: LaRC
Participating Center(s): KSC

The NASA Intelligent Synthesis Environment (ISE) seeks to address all aspects of design development and life-cycle management, including the ability to determine complete life-cycle requirements and costs early in the design cycle. There is a critical need for modeling, simulation, and asynchronous technologies that support integration throughout the entire life-cycle of a mission, project, or vehicle (a typical NASA life-cycle is on the order of 30 years). This integrated capability must be supported across diverse geographic, cultural, and computational environments and be used not only in the ISE but within other organizations as well. NASA ISE is focused on designing, delivering, supporting and commercializing advanced technologies, and collections of technologies, that support the advancement of engineering, engineering tools, and engineering methodologies. A goal is the development of tools that support the creation, storage, management, and retrieval of information over entire program life-cycles. Tools and technologies are expected to be de-coupled from the actual data storage elements to facilitate the separate evolution of various technologies. The architecture involved must support preservation of the data as well as operation on the data sets by multiple tools.

There are many emerging technological concepts that show promise as potential ISE technologies. Examples of some existing concepts, which HAVE NOT been incorporated into integrated data life-cycle management are: 1) Intelligent Agents (push/portals/information dissemination), 2) Threaded Discussions/Community of Interest Sites, 3) Data Mining, 4) Project Management Integration, 5) Document Collaboration, 6) Library, 7) Workflow/Status Checking, and 8) Information Compartmentalization to reduce information overload. Requirements exist for the following areas of interest:

- Software system architectures that enable life-cycle simulation systems to be assembled quickly and tailored for specific vehicles or missions. Such systems must be compatible with legacy software codes as well as permit the insertion of research technology by users.
- Rapid model assemblers technology that enables components and a knowledge base to assist the modeler in providing validated model data suitable for the simulation of the entire life-cycle of a product.
- Advanced rapid life cycle simulation tools.
- Advanced intelligent systems for knowledge capture of design and the design process, and engineering process assessment methodologies.
- Software systems and products that reduce the effort required for creating immersive visualization displays of intermediate simulations is necessary to validate the intermediate results. Such systems must be general enough to support the entire life-cycle of NASA's diverse missions and vehicles.
- Distributed collaboration tools that support the integration of life-cycle analysis in both modeling and simulation.
- New technologies that allow collection, storage, and retrieval of various forms of integrated data (graphical, text, photo, email, sound, etc.) associated with a process life-cycle (full life-cycle, greater than 30 years).

27 Surface Systems

Surface Systems Thrust research enables new exploration missions to planet, comet and asteroid surfaces. It leads to efficient exploration by means of autonomous robotic systems, and to the development of technology for safe, self-sufficient and self-sustaining robotic and human presence beyond Earth. Smarter, faster, and more maneuverable rovers and other types of robotic vehicles --along with the techniques for surface and subsurface exploration, in situ resource utilization and planetary protection -- are key to this Cross Enterprise. Technologies are sought that enable robotic outposts, distributed mobile arrays of robotic assets for measurement and communication, robotic deployment of permanent science stations on planetary surfaces, and setting up habitat and other surface infrastructures for subsequent human missions. Technologies are sought that enable scientific sample acquisition, handling and packaging, and for high-reliability long-life surface systems capable of operating in a wide range of temperatures.

27.01 Sensor Webs and Robotic Outposts
Lead Center: JPL
Participating Center(s): none

The Sensor Webs and Robotic Outposts subtopic seeks fundamental research contributions aimed at new types of surface systems consisting of distributed arrays of mobile robots equipped with multiple sensors for in situ measurement and communication. Closely related to the sensor-web concept is that of a robotic outpost in which multiple robots are coordinated to deploy and provide a permanent presence on the surface of planets and other bodies in the solar system. Examples of a robotic outpost are permanent science stations for long duration acquisition of scientific samples; exploratory teams of mobile robots to access and explore high-risk areas that have a high scientific payoff; robotic work crews for infrastructure deployment and preparation of sites for subsequent human missions; and robots for assisting humans in complex surface operations. The initial focus of the long term research is on the technology that enables long-duration and permanent presence, including the capability for autonomous robotic repair of major components, sub-assemblies and entire surface systems, miniaturized in situ resource utilization (ISRU) systems, and ISRU fueled surface systems. Examples of desired technologies are given below.

- Intelligent system software technologies to enable robotic colony formation for collective tasks such as site selection, site preparation, and habitat-deployment on planetary surfaces as a precursor to human exploration missions.
- Robotic excavation and tunneling systems.
- Systems that can repair/replace/reconfigure themselves, with minimal human intervention from the ground to respond to unexpected events or multiple mission objectives.
- Robotic systems to enable surface sampling from aerial vehicles.
- Robotic systems which develop and couple in situ generated propellants with new robotic vehicle designs whose mobility is based on these fuels, for both science and human exploration.
- Subsurface and submersible vehicle concepts and designs for deep exploration of planetary subsurfaces and ocean formations.
- High-speed, rough terrain, sensing and processing devices for autonomous navigation and science data acquisition.
- High-accuracy global surface positioning systems.
- Dexterous pointing, placement, manipulation, and excavation devices and processes.
- Inflatable rover technology.
- Dynamic simulation of multiple interacting autonomous robotic systems.
- Technologies for deep drilling and analysis.

28 Ultralight Structures and Space Observatories

The Ultra-Lightweight Structures and Space Observatories (ULSSO) thrust develops revolutionary technology in structures, materials, and optical systems to enable bold new missions of discovery for NASA. NASA is studying future missions requiring very large space observatories. Long-range plans are aimed at detection and characterization of planets in orbit around nearby stars to search for the chemical signatures of life. Achieving this goal will require arrays of space telescopes that have 1000x the light collecting area of the largest ground-based telescopes in operation today. Technologies are sought that enable very large telescopes for imaging extra-solar planets, studying the formation of large-scale structure in the early universe, and continuously monitoring the Earth from distant vantage points. Technologies are sought that enable large deployable and inflatable antennas for space-based radio astronomy, high-bandwidth communications from deep space, and Earth remote sensing with radar and radiometers; solar sails for low cost propulsion, station keeping in unstable orbits, and precursor interstellar exploration missions; Gossamer technology for kilometer-scale membrane spacecraft that weigh less per unit area than a sheet of paper.

28.01 Ultra-Light Structures and Materials
Lead Center: LaRC
Participating Center(s): JPL, MSFC

Revolutionary advances in ultra-lightweight structures and materials technology are needed to enable a broad range of future NASA missions. Applications include large aperture telescopes and antennas, solar sails and telescope sunshields, large solar arrays and solar concentrators, Earth and planetary balloons, planetary entry vehicles, and spacecraft operating in extreme environments. Technology breakthroughs in this area will also enable gossamer spacecraft, which are very large, ultra-lightweight, highly-integrated systems that can packaged into a small volume for launch. Technologies of specific interest are:

- Large (> 20 m) deployable and inflatable rigidizable booms and trusses.
- Innovative methods for in-space manufacture and self-assembly of lightweight structural elements and membranes. Membranes that can be made to grow like a biological system and that can 'self-heal' is a long-term goal.
- Thermal protection for hypersonic vehicles.
- Highly-integrated multifunctional membranes that incorporate electronics, MEMS devices, sensors, actuators, power sources, or other spacecraft components in thin-film materials.
- Ultra-lightweight, high-strength membrane materials for solar sails, sunshields, inflatables, and balloons. Materials should be resistant to ultraviolet radiation, particle radiation, and extreme temperatures (lifetime > 10 years).
- High surface precision thin-film materials and reflective coatings for membrane optics.
- Nano-particle (i.e., organoclays, carbon nanotubes, etc.) containing composite materials with substantially higher strength-to-weight ratio or thermal conductivity than state-of-the-art composites. Ideas should not be limited to filling polymers with nano-particles, but should include concepts such as chemically linking nano-particles together to form molecular 'net-like' structures. Applications include ultra-lightweight structural elements, electrically conductive elements, and efficient thermal management devices.

28.02 Adaptive Optical Structural Systems
Lead Center: LaRC
Participating Center(s): GSFC

Proposals are sought for the development of adaptive systems applicable to large, ultra-lightweight structures and apertures. Adaptive systems are needed for measuring and correcting surface figure and wavefront errors for large telescopes and antennas, for controlling the dynamics of large flexible structures, and for enabling gossamer spacecraft that can reconfigure themselves in response to changing environmental conditions or mission phases. Technologies of specific interest are:

- Smart inflatable structures with embedded actuators and sensors for controlling structural geometry and dynamics.
- Innovative methods for shape control of large membrane mirrors and antennas such as non-contact actuators.
- Concepts and components for active, adaptive wavefront control systems with correction to < 1 wavelength.
- Materials with controllable surface properties that could adapt to changing environmental conditions or mission needs.
- Novel concepts for gossamer spacecraft that could enable missions that were previously considered impossible, while keeping cost and risk within acceptable limits. An example concept is a gossamer spacecraft capable of modifying its shape or other functional characteristics so that it can adapt to different mission phases, such as atmospheric entry, descent, landing, and surface exploration.

28.03 Electrostatic Control and Measurement Technologies
Lead Center: KSC
Participating Center(s): LaRC

The development and use of solid state technologies has resulted in increased awareness and concern for the potential damage and costs due to uncontrolled electrostatic discharges (ESD) into electronic circuits and components. Within NASA, hazardous operations involving toxic and explosive vapors, and solid propellants as well as operating electronic components in space and extraterrestrial environments have created special concerns for understanding the nature of surface charging, charge transport and the likelihood of discharge or arcing due to the electrostatic properties of the myriad of materials used during the fabrication, processing, launch and operation of unique and expensive space flight and vehicle elements. Concerns for spacecraft also include charging due to corona and plasma and the effects of atomic oxygen. New and innovative methods of measuring the electrostatic charging properties of new and existing materials including polymer films, foam insulation, etc. are important safety areas of interest to NASA. In addition, finding temporary and/or permanent means to manage or mitigate the static charge buildup on material surfaces is another important area for improving the safety associated with hazardous operations and for application to the next generation of space vehicles. Specific interests for the 2000 solicitation include, but are not limited to, those listed below:

- 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, extraterrestrial and hazardous environments. Performance of the devices should be compared to similar data already collected by the Kennedy Space Center using existing technology. Proposals should focus on electric field detection equipment, digital scope electronics, air/gas ionization and motorized devices. 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 C (- 250 F) to 200 C (400 F), in various gaseous environments with pressures from 100 millitorr to 5000 torr and temperatures from -160 C (- 250 F) to 200 C (400 F) as well as terrestrial environments with temperatures from - 75 C (-100 F) to 65 C (150 F) and humidity from 10 percent to 100 percent. New concepts should give consideration to computer hardware and software to maximize capabilities to induce, detect, acquire, and record electric fields on material samples while plotting wave-forms in volts versus time.
- Development of miniature sensors for detecting and measuring spacecraft and landers electric potential and charge distribution. Developing software for modeling spacecraft and landers electric potentials based on previous flight experiment data and models.
- Improved anti-static coatings for application on various fabrics and polymer films as well as Propellant Handling Ensembles (PHE) suits. Proposals should utilize new concepts, current technologies, as well as EPA approved materials/chemicals to meet or exceed usage in 30 percent relative humidity and providing the safest controlled environment for life support personnel. The coating should have desirable properties which include a permanently smooth dry surface with sufficient durability to resist normal washing and other handling considerations. Proposals should focus on cost benefit analysis per application.
- Develop new materials that are inherently anti-static and/or anti-static coatings or static elimination/mitigation techniques for use on materials exposed to a vacuum or non-terrestrial gaseous environments with a wide range of temperatures and pressures equivalent to the requirements listed for test devices above. New materials should also enhance thermal control, be resistant to the effects of atomic oxygen and mitigate environmental effects on both spacecraft and landers. Develop techniques for grounding or charge elimination from spacecraft and landers including materials and concepts for shielding from charged particle radiation. Develop new concepts for solar arrays and power systems immune to plasma interactions and plasma contacting devices. Improved methods and processes should be developed to reduce the cost of current space qualified materials and coatings.
- Develop cost effective methods for ground based simulation of the environments of low earth orbit space, deep space and planetary surfaces.
- Develop techniques for measurement of the speed, charge and weight, either simultaneously or individually, of fine particles (less than 40 micron) under vacuum, atmospheric and/or other gas composition conditions over a broad range of temperatures and pressures. These techniques must be capable of supporting future development of electrostatic charge and discharge (ESD) characterization of materials during exposure to dust impingement in a vacuum, atmospheric and non-terrestrial atmospheric environments.

29 Atmospheric and In-Space Systems

The Atmospheric and In-Space Systems (AISS) Cross Enterprise concentrates on systems that operate in space and within planetary atmospheres. AISS is chartered to identify and develop fundamental technologies for this purpose. AISS develops aero-maneuvering technologies to descend into hostile planetary environments--aeroshells, balloon-assisted deployment which autonomously avoids the hazards of landing. AISS develops systems that decend and record the landscape--balloons, ballutes, rotorcraft; systems that dock with similar spacecraft; systems with the ability to return samples, or find their way back to base camp without human intervention. AISS also develops robotics to collect and catalog data on the planet environment. Technologies are sought that will improve the performances, efficiencies, and safety for operations in the Atmospheric Systems and In-space Operations (ascent, descent, docking, maneuvering). Of particular interest are Aero-maeuvering (ascent, entry and descent systems including aero-shell, hazard avoidance, balloon assisted deployment & ascent systems); Aerial systems (balloons, airplanes, rotocrafts, & gliders) and Operations (Rendezvous, docking and sample transfers systems).

29.01 Automated Rendezvous and Docking
Lead Center: JSC
Participating Center(s): none

In support of future robotic and human missions to Mars the need for automated rendezvous and docking has been identified.

Automated Proximity Operations. A key facet of this effort will involve the development, testing, and validation of a guidance, navigation, and control (GN&C) package to support final rendezvous and docking operations. When ranges between a chaser vehicle and target vehicle decrease to less than a few kilometers, the trajectory control needs include not only accounting for the affects of orbital mechanics, but now much more frequent control of the trajectory through numerous thruster firings is required. Whereas earlier in the rendezvous mission profile, maneuvers occurred perhaps every few days or hours, now manuever spacing will decrease to minutes or seconds. Additionally, spacecraft attitudes must be managed during the last 100 meters or so of the approach to support alignment and final docking needs.

Proposals are sought to develop guidance, navigation, and control software algorithms to support nominal and off-nominal conditions. Operational trajectory flight corridors should be identified and trajectory control methodologies should be formulated to fly these corridors and achieve a very high level of mission success. Contingency abort paths and recovery options should be developed. The primary emphasis will be on the development of guidance algorithms for nearly continuous control of the trajectory which offer approach and docking in a highly efficient (low propellant cost) manner.

Long Range Relative Navigation Sensor. Another key facet of this effort will involve the development, testing, and validation of a navigation sensor capable of detecting a passive but cooperative target at ranges from 50-100 km down through docking. The target can be considered to be passive in that it will not necessarily participate in active transponding with the chaser vehicle, and in fact, may be completely unpowered. However, it is cooperative in that the target spacecraft may contain reflective devices specifically designed to accommodate this long range sensor development activity. Specific accuracies for this sensor will be identified in the study, but will be on the order of 1 percent of the range. The sensor will need to provide range, range rate, and bearing information to the target. The sensor must be developed for "can't fail" mission critical scenarios. Additionally, because this sensor may be mounted to small spacecraft in orbit around the Moon or Mars, it must be capable of successful operations in these remote environments.

Planetary Navigation Sensor. A third key facet of this effort may involve the development, testing, and validation of a navigation sensor capable of determining where the spacecraft is in space around a remote astronomical body (e.g., Moon, Mars) utilizing in situ information, such as surface features on the astronomical body. With this sensor, a spacecraft launching from the surface of that body can achieve orbit and then self-determine its orbit accurately with little to no assistance from Earth. This "planetary nav sensor" must be sufficiently accurate, with supporting software, to navigate the spacecraft to within range of a long-range relative navigation sensor (as specified above).

9. Submission Forms and Certifications

Form 9A – Proposal Cover

Form 9B – Proposal Summary

Form 9C – Summary Budget

FORM 9A - PROPOSAL COVER

Subtopic Number

PROPOSAL NUMBER **00-** _ _ . _ _ _ _ _ _

SUBTOPIC TITLE ______________________________

PROPOSAL TITLE ______________________________

FIRM NAME ______________________________

MAIL ADDRESS ______________________________

CITY/STATE ______________________________ ZIP (9 digit)______________________________

PHONE ______________________________ FAX ______________________________

CEO E-MAIL ______________________________ PI E-MAIL ______________________________

ACN NAME ______________________________ ACN E-MAIL ______________________________
(Authorized Contract Negotiator)

EIN/TAX ID ______________________________

AMOUNT REQUESTED $ ____________ DURATION __ MONTHS NUMBER OF EMPLOYEES ___

OFFEROR CERTIFIES THAT:

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

a. Eligibility of the Principal Investigator	Yes	No
As defined in Section 2 of the Solicitation, the offeror qualifies as a:		
b. SBC	Yes	No
c. Socially and economically disadvantaged SBC	Yes	No
d. Women-owned SBC	Yes	No
As described in Section 3 of this solicitation, the offeror meets the following requirements completely:		
e. All eleven parts of the technical proposal included	Yes	No
f. Subcontracts/consultants proposed?	Yes	No
i) If yes, limits on subcontracts/consultants met	Yes	No
ii) If yes, copy of agreement enclosed	Yes	No
g. Government equipment or facilities required?	Yes	No
i) If yes, signed statement enclosed in Part 8	Yes	No

ENDORSEMENTS:

	Principal Investigator	Corporate/Business Official
NAME	______________________________	______________________________
TITLE	______________________________	______________________________
PHONE	______________________________	______________________________
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 Proposal Cover

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

Subtopic Title: Enter the title of the subtopic that this proposal will address. Use abbreviations as needed.

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".

Firm Name: Enter the full name of the company submitting the proposal. If a joint venture, list the company chosen to negotiate and receive contracts. If the name exceeds 40 keystrokes, please abbreviate.

Address:	Address where mail is received
City/State:	City name and 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
CEO E-mail:	Enter e-mail address for Business Official
PI E-mail:	Enter e-mail address for Principal Investigator
ACN Name and E-mail	Enter e-mail address for Authorized Contract Negotiator
EIN/Tax ID:	Employer Identification Number/Taxpayer ID

Amount Requested: Proposal amount from Budget Summary. The amount requested should not exceed $70,000; round to nearest dollar; do not enter cents (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).

Number of Employees: Enter number of employees for SBC.

Certifications: Answer Yes or No as applicable for 5a, 5b, 5c, 5d and 5e (see Sections 1 and 2 for definitions)

5f. 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.

5g. 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 Part 7, 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.

Endorsements: The proposal cover must be signed by an official of the firm and proposed Principal Investigator

The Proposal Cover is submitted with original signatures in paper form to NASA with the proposal.

FORM 9B - PROPOSAL SUMMARY

Subtopic Number

PROPOSAL NUMBER **00- _ _ . _ _ _ _ _ _**

PROPOSAL TITLE

TECHNICAL ABSTRACT (LIMIT 200 WORDS)

POTENTIAL COMMERCIAL APPLICATIONS

NAME AND ADDRESS OF PRINCIPAL INVESTIGATOR (Name, Organization Name, Mail Address, City/State/9 digit Zip)

NAME AND ADDRESS OF OFFEROR (Firm Name, Mail Address, City/State/9 digit Zip)

Guidelines for Completing Proposal Summary

Complete Form 9B electronically and print a copy for second page of the proposal.

Proposal Number: Same as Proposal Cover.

Proposal Title: Same as Proposal Cover.

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.

Potential Commercial Application(s): Summary of the direct or indirect commercial potential of the project, assuming the goals of the proposed R/R&D are achieved. Limit your response to 200 words.

Name and Address of Principal Investigator: Same as Proposal Cover.

Name and Address of Offeror: Same as Proposal Cover.

FORM 9C - 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) $ ______________

THIS PROPOSAL IS SUBMITTED IN RESPONSE TO THE 2000 NASA SBIR PROGRAM SOLICITATION AND REFLECTS OUR BEST ESTIMATES AS OF THIS DATE:

NAME AND TITLE (Typed):

SIGNATURE:
DATE:

Guidelines for Preparing Summary Budget

The offeror 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. Prepare electronically, print and sign a paper copy for submission to NASA with the proposal.

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 negotiating agency, if available. If no rate(s) has (have) been negotiated, a reasonable indirect cost (overhead) rate(s) may be requested for Phase-I that will be subject to approval by NASA. If a current negotiated rate(s) is (are) not available, NASA will negotiate an approved rate(s) with the offeror. 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.
- Equipment: List each item of permanent equipment to be purchased, its price, and explain its relation to the project.

  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 Phase-I that will be subject to approval by NASA. If a current negotiated rate is not available, NASA will negotiate an approved 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.

Name and Title of SBC Official:

Signature and Date

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 9A 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. Printed version of Forms 9A, 9B and 9C included in the postal submission.

9. Postal submission includes an original signed proposal with all forms plus three copies (Section 6.3).

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

11. Internet submission must be consistent with Postal submissions.

12. Proposals must be received by the NASA SBIR/STTR Program Support Office no later than 5:00 p.m. EDT on Friday, July 14, 2000. (Section 6.3.3).