National Aeronautics and Space Administration

Small Business

Technology Transfer (STTR)

Phase I

Fiscal Year 2022 Solicitation

Completed Proposal Package Due Date and Time:
March 9, 2022 - 5:00 p.m. ET

Contents

Executive Summary

This notice identifies the objectives for the Small Business Technology Transfer (STTR) Program Phase I projects, deadlines, funding information, eligibility criteria for projects and applicants, and proposal instructions. STTR facilitates cooperative R&D between small business concerns and U.S. research institutions – with potential for commercialization. The STTR program has a statutory requirement to stimulate a partnership of ideas and technologies between innovative Small Business Concerns (SBCs) and Research Institutions through federally funded research or research and development (R/R&D). STTR also adheres to SBA directives to increase participation by Women-Owned, Veteran-Owned and Small Disadvantaged Businesses and outreach to HBCUs and Minority Serving Institutions. Outreach is also made to underrepresented areas/regions of the country.

The NASA STTR program focuses on the following:

- Stimulate technological innovation in the private sector.
- Strengthen the role of SBCs in meeting Federal research and development needs.
- Foster and encourage participation of socially and economically disadvantaged persons and women-owned small businesses.
- Increase the commercial application of these research results.
- Foster technology transfer through cooperative R&D between small businesses and research institutions. (STTR only)

Different from most other investors, the NASA STTR Program funds early or "seed" stage research and development that has a commercial potential. The program provides equity-free funding and entrepreneurial support at the earliest stages of company and technology development.

NASA requests proposals for the Small Business Technology Transfer (STTR) Program Phase I for fiscal year (FY) 2022. **The STTR subtopics appear in an integrated list in Chapter 9 and each subtopic will indicate its program of origin.**

NASA uses an electronic submission system called the Electronic Handbook (EHB) and all Offerors must use the EHB for submitting a completed proposal package. The EHB guides firms through the steps for submitting a complete proposal package. All submissions are through a secure connection and most communication between NASA and the firm is through either the EHB or email. For more information see section 3.

1. Program Description

1.1 Legislative Authority and Background

The National Defense Authorization Act for Fiscal Year 2017 (Pub. L. 114–328, §1834(a) Extension of SBIR and STTR programs was amended in the Small Business Act (15 U.S.C. 638) and extended the implementation through September 30, 2022. Policy is provided by the Small Business Administration (SBA) through the combined SBIR/STTR Policy Directive. The main purpose of the legislation is to stimulate technological innovation in the Federal R/R&D sector and increase private sector commercialization in both programs. Accordingly, the NASA STTR program is in a unique position to meet both goals by transforming scientific discovery and innovation to be used in NASA programs and missions as well as emphasizing private sector commercialization.
The STTR program is Congressionally mandated to facilitate the transfer of technology developed by a research institution through the entrepreneurship of a small business concern (SBC).

1.2 Purpose and Priorities

This solicitation includes instructions for small business concerns (SBCs) in collaboration with a Research Institution (RI) to submit Phase I proposals to the NASA Small Business Technology Transfer (STTR) program. Furthermore, program background information, eligibility requirements for participants, information on the three program phases, information for submitting responsive proposals and NASA specific research subtopics are contained herein. **The fiscal year 2022 solicitation period for Phase I proposals begins on January 6, 2022 and ends at 5 p.m. Eastern Time on March 9, 2022.**

The NASA STTR Program does not fund proposals solely directed toward system studies, market research, routine engineering, development of existing product(s), proven concepts, or modifications of existing products without substantive innovation.

The Space Technology Mission Directorate (STMD) provides overall policy direction for implementation of the NASA STTR program. The NASA SBIR/STTR Program Management Office (PMO) hosted at the NASA Ames Research Center, operates the programs in conjunction with NASA mission directorates and centers. Additionally, the NASA Shared Services Center (NSSC) provides the overall procurement management for the programs.

For the STTR program, NASA research and technology areas to be solicited are identified annually by the Agency's Center Chief Technologists (CCTs). The CCTs identify high-priority research problems and technology needs for their respective programs and projects. The range of problems and technologies is broad, and the list of research subtopics varies in content from year to year to maintain alignment with current interests.

For details on the research subtopic descriptions by Focus Area, see Section 9.

1.3 Three-Phase Program

The NASA STTR program is carried out in three separate phases. The three phases are described in detail on the NASA SBIR/STTR website: http://sbir.nasa.gov/content/nasa-sbirsttr-basics.

Phase I

This solicitation is only for the preparation and submission of Phase I proposals. The aim of a Phase I project should be to demonstrate technical feasibility of the proposed innovation and the potential for infusion within a NASA program or mission and/or use in the commercial market.

Maximum value and period of performance for Phase I:

Phase I Contracts	STTR
Maximum Contract Value	$150,000
Period of Performance	13 months

Phase II

Phase II proposals continue the R&D developed under Phase I to bring the innovation closer to infusion into a NASA program or mission and/or commercialization of the innovation. Phase II will require a more comprehensive proposal, outlining the proposed effort in detail and the commercialization strategy for the effort. Only prior Phase I awardees are eligible to submit a Phase II proposal at the conclusion of the Phase I contract. A separate solicitation will be published for the preparation and submission of Phase II proposals.

Phase II Contracts	STTR
Maximum Contract Value	$750,000*
Maximum Period of Performance	24 months

*Depending on final appropriations, NASA may adjust the maximum contract value for Phase II awards upwards from $750,000 to $1,000,000. Phase I awardees will be notified of maximum value at the time of their Phase II submission and the Phase II solicitation will supersede the information provided above. Proposers should only plan to use the values above as a guide.

Post-Phase II Opportunities for Continued Technology Development

NASA recognizes that Phase I and II awards may not be sufficient in either dollars or time for the firm to complete the total R/R&D and the commercialization activities required to make the project ready for infusion or the commercial marketplace. Therefore, NASA has several initiatives for supporting its small business partners beyond their Phase I and Phase II awards.

Please refer to http://sbir.nasa.gov/content/post-phase-ii-initiatives for eligibility, application deadlines, matching requirements and further information.

Phase III

Phase III is the commercialization of innovative technologies, products, and services resulting from either a Phase I or Phase II contract. This includes further development of technologies for transition into NASA programs, other Government agencies, or the private sector. Phase III contracts are funded from sources other than the SBIR and STTR programs and may be awarded without further competition.

Please refer to https://sbir.nasa.gov/content/post-phase-ii-initiatives#Phase-III for Phase III information.

1.4 Availability of Funds

There is no commitment by NASA to fund any proposal or to make a specific number of awards and NASA may elect to make several or no awards in any specific research subtopic. Number of awards will be based on the level of appropriated funding provided to the program in FY 2022.

It is anticipated the STTR Phase I proposals will be selected for negotiation of firm-fixed-price contracts approximately during the month of May 2022 for a period of performance not to exceed thirteen (13) months. Historically, 27 percent of STTR Phase I proposal submissions receive awards.

Under this STTR Phase I solicitation, NASA will not accept more than 10 proposals from any one firm to ensure the broadest participation of the small business community. NASA does not plan to award more than five (5) STTR contracts to any offeror. See Section 3.1 and 4.

This SOLICITATION may be released prior to the passage of an appropriations act for FY 2022. Enactment of additional continuing resolutions or an appropriations act may affect the availability or level of funding for this program and may delay the start date of Phase I contracts.

1.5 Eligibility Requirements

1.5.1 Small Business Concern (SBC)

Each Phase I awardee must submit a certification stating that it meets the size, ownership, and other requirements of the STTR program at the time of a completed proposal package submission, award, and at any other time set forth in SBA's regulations at 13 CFR §§ 121.701-121.705. Socially and economically disadvantaged and women-owned SBCs are particularly encouraged to propose.

1.5.2 SBC Size

A Phase I awardee, combined with its affiliates, must not have more than 500 employees. The small business concern must be the primary performer of the proposed research effort.

1.5.3 STTR Restrictions on Level of Small Business Participation

To be awarded an STTR Phase I contract, at least 40% of the research or analytical effort must be performed by the Offeror, and at least 30% of the effort must be performed by a single research institution.

1.5.4 Place of Performance

All work shall be performed in the United States. (See http://sbir.nasa.gov/content/nasa-sbirsttr-program-definitions). However, based on a rare and unique circumstance (for example, if a supply, material, or other item or project requirement is not available in the United States), NASA may allow a particular portion of the research or work to be performed or obtained in a country outside of the United States. Completed proposal packages must clearly indicate if any work will be performed outside the United States, including subcontractor performance, and justification must be provided by downloading and completing the "Request to Used a Foreign Vendor/Purchase of Items from a Foreign Vendor" form found at https://sbir.gsfc.nasa.gov/submissions/learning-support/firm-templates.

Prior to award, approval by the Contracting Officer for such specific condition(s) must be in writing.

Note: NASA will not approve purchases from or work with countries that appear on the list of Designated Countries. For reference, please see https://www.nasa.gov/oiir/export-control.

1.5.5 Principal Investigator (PI) Employment Requirement

Requirements	**STTR**
Primary Employment	The primary employment of the Principal Investigator (PI) shall be with the SBC or the Research Institution (RI) under the STTR program.
Employment Certification	The offeror must certify in the proposal that the primary employment of the PI will be with the SBC or the RI at the time of award and during the conduct of the project. Primary employment means that more than 50 percent of the PI's total

	employed time (including all concurrent employers, consulting, and self-employed time) is spent with the SBC or RI at time of award and during the entire period of performance. Primary employment with an SBC precludes full-time employment at another organization. If the PI does not currently meet these primary employment requirements, then the offeror must explain how these requirements will be met if the proposal is selected for contract negotiations that may lead to an award.
Co-PIs	Not allowed
Deviation Request	Any deviation requests will be reviewed during negotiation of the award and either approved or declined before final award by the Funding Agreement officer
Misrepresentation of Qualifications	Shall result in rejection of the proposal or termination of the contract
Substitution of PIs	Requires a prior approval from NASA

Note: NASA considers a full-time workweek to be nominally 40 hours and considers a 19.9-hour or more workweek elsewhere to be in conflict with this rule. In rare occasions, minor deviations from this requirement may be necessary; however, any minor deviation must be approved in writing prior to the award by the Contracting Officer after consultation with the NASA SBIR/STTR Program Manager/Business Manager.

1.5.6 Restrictions on Venture-Capital-Owned Businesses

At the current time, small businesses owned in majority part by multiple venture capital operating companies, hedge funds, or private equity firms are not eligible to submit proposals under this NASA STTR Phase I solicitation.

1.5.7 Joint Ventures and Limited Partnerships

Both joint ventures and limited partnerships are permitted, provided the entity created qualifies as an SBC in accordance with the definition of an SBC here: http://sbir.nasa.gov/content/nasa-sbirsttr-program-definitions. A statement of how the workload will be distributed, managed, and charged should be included in the completed proposal package. See definitions for Joint Ventures along with examples at 13 CFR 121.103(h).

A copy or comprehensive summary of the joint venture agreement or partnership agreement should be included when uploading the completed proposal package.

1.5.8 Required Benchmark Transition Rate

The Phase I to Phase II transition rate requirement applies to STTR Phase I proposers that have received more than 20 (21 or more) Phase I awards over the past 5 fiscal years, excluding the most recent year. These companies must meet the required benchmark rate of transition from Phase I to Phase II. The current transition rate requirement, agreed upon and established by all 11 agencies that have SBIR/STTR programs and published for public comment at 77 FR 63410 in October 2012 and amended at 78 FR 30951 in May 2013, is that an awardee must have received an average of one Phase II for every four Phase I awards received during the most recent 5-year time period (which excludes the most recently completed fiscal year) to be eligible to submit a proposal for a new Phase I (or Direct-to-Phase II) award. That is, the ratio of Phase II to Phase I awards must be at least 0.25.

On June 1 of each year, the SBA assesses STTR awardees using STTR award information across all Federal agencies reported on www.sbir.gov to determine if they meet the benchmark requirements. Companies that failed to meet the transition rate benchmark on June 1, 2021, are not eligible to submit a Phase I proposal during the period June 1, 2021, through May 31, 2022. Companies were notified by the SBA if they failed to meet the benchmark and can find their status at any time on www.sbir.gov.

More information on the transition rate requirements is available at https://www.sbir.gov/faqs/performance-benchmarks.

1.6 NASA Technology Available (TAV) for STTR Use

Offerors have the option of using technology developed by NASA (Technology Available (TAV)) related to the subtopic to which they are proposing. NASA has over 1,400 patents available for licensing in its portfolio, including many patents related to sensors and materials. NASA has over 1,000 available software applications/tools listed in its Software Catalog (https://software.nasa.gov). While NASA scientists and engineers conduct breakthrough research that leads to innovations, the range of NASA's effort does not extend to commercial product development in any of its intramural research areas. Additional work is often necessary to exploit these NASA technologies for either infusion or commercial viability and likely requires innovation on behalf of the private sector. These technologies can be searched via the NASA Technology Transfer Portal, http://technology.nasa.gov, and may be a NASA-owned patent and/or computer software. Use of a TAV requires a patent license or Software Usage Agreement (SUA) from NASA. TAVs are available for use on STTR projects. NASA provides these technologies "as is" and makes no representation or guarantee that additional effort will result in infusion or commercial viability.

Whether or not a firm proposes the use of a NASA patent or computer software within its proposed effort will not in any way be a factor in the selection for award.

1.6.1 Use of NASA Software

If an Offeror intends to use NASA software, a Software Usage Agreement (SUA), on a nonexclusive, royalty-free basis, is necessary, and the clause at 48 C.F.R. 1852.227-88, Government-Furnished Computer Software and Related Technical Data, will apply to the contract. The SUA shall be requested from the appropriate NASA Center Software Release Authority (SRA), after contract award.

1.6.2 Use of NASA Patent

All Offerors submitting a completed proposal package that include the use of a NASA patent must apply for a nonexclusive, royalty-free evaluation license. After firms have identified a patent to license in the NASA patent portfolio (http://technology.nasa.gov), a link on the patent webpage ("Apply Now to License this Technology") will direct them to NASA's Automated Licensing System (ATLAS) to finalize their license with the appropriate field center technology transfer office. The completed evaluation license application must be provided with the proposal following the directions in section 3.5.3. Such grant of nonexclusive evaluation license will be set forth in the successful Offeror's STTR contract. The evaluation license will automatically terminate at the end of the STTR contract. License applications will be treated in accordance with Federal patent licensing regulations as provided in 37 CFR Part 404.

In addition to an evaluation license, if the proposed work includes the making, using, or selling of products or services incorporating a NASA patent, successful awardees will be given the opportunity to negotiate a nonexclusive commercialization license or, if available, an exclusive commercialization license to the NASA patent. Commercialization licenses are also provided in accordance with 37 CFR Part 404.

An STTR awardee that has been granted a nonexclusive, royalty-free evaluation license to use a NASA patent under the STTR award may, if available and on a noninterference basis, also have access to NASA personnel knowledgeable about the NASA patent. Licensing Executives located at the appropriate NASA field center will be available to assist awardees requesting information about a patent that was identified in the STTR contract and, if available and on a noninterference basis, provide access to the inventor or surrogate for the purpose of knowledge transfer.

Note: Access to the inventor for the purpose of knowledge transfer will require the requestor to enter into a Non-Disclosure Agreement (NDA) or other agreement, such as a Space Act Agreement. The awardee may be required to reimburse NASA for knowledge transfer activities. For Phase I completed proposal packages, this is a time-consuming process and is not recommended.

1.7 I-Corps™

NASA has partnered with the National Science Foundation (NSF) to allow Phase I awardees the opportunity to participate in the NSF Innovation Corps (I-Corps™) program. Phase I awardees are encouraged to participate in this training which is designed to lower the market risk inherent in bringing a product or innovation to market, thereby improving the chances for a viable business. The NASA I-Corps program enables small businesses, including startup firms, to increase the odds of accelerating the process of developing their STTR technologies into a repeatable and scalable business model. The program accomplishes this by putting the firms through a version of the Lean Launchpad/I-Corps process, which includes:

- Developing their business model hypotheses using the Business Model Canvas.
- Testing those hypotheses through the Customer Development Interview process.

The intended results of I-Corps are to enable firms to conduct customer discovery to learn their customers' needs, to obtain a better understanding of their company's value proposition as it relates to those customer needs, and to develop an outline of a business plan for moving forward. For more information on the NASA I-Corps program, see http://sbir.nasa.gov/content/I-Corps.

Offerors who are selected for Phase I contract negotiations will be provided the opportunity to participate in the NASA SBIR/STTR I-Corps program as indicated in Section 3.5.3.9. I-Corps awards will be made separately from the Phase I contract as a grant.

NASA will conduct an abbreviated competition for I-Corps after Phase I offerors are selected for Phase I STTR contracts. NASA anticipates awarding 10 STTR teams. The amount of funding is up to $25,000 for the full I-Corps program for STTR firms.

1.8 Technical and Business Assistance (TABA)

The Small Business Act 15 U.S.C. 631, Section 9 (q) Discretionary Technical and Business Assistance permits STTR Phase I and II awardees to enter into agreements with one or more vendors to provide Technical and Business Assistance (TABA). TABA allows an additional supplement to the award ($6,500 for Phase I) and is aimed at improving the commercialization success of STTR awardees. TABA may be obtained from entities such as public or private organizations, including an entity established or funded by a U.S. state that facilitates or accelerates the commercialization of technologies or assists in the creation and growth of private enterprises that are commercializing technology.

In accordance with the Small Business Act, NASA may authorize the recipient of a NASA Phase I STTR award to purchase technical and business assistance services through one or more outside vendors. These services may, as determined appropriate, include access to a network of non-NASA scientists and engineers engaged in a wide range of technologies, assistance with product sales, intellectual property protections, market research, market validation, and development of regulatory plans and manufacturing plans, or access to technical and business literature available through online databases, for the purpose of assisting such concerns in

1. Making better technical decisions concerning such projects;

2. Solving technical problems that arise during the conduct of such projects;
3. Minimizing technical risks associated with such projects; or
4. Commercializing new commercial products and processes resulting from such projects, including intellectual property protections.

For information on how to request TABA at Phase I, please see Section 3.5.3.8, Request for Use of Technical and Business Assistance Funds. Technical and business assistance does not count toward the maximum award amount of your Phase I contract. Approval of technical and business assistance is not guaranteed and is subject to review by the Contracting Officer and the SBIR/STTR Program Management Office. A description of any technical and business assistance obtained under this section and the benefits and results of the technical or business assistance provided will be a required deliverable of your contract.

1.9 NASA Procurement Ombudsman Program

The NASA Procurement Ombudsman Program is available under this solicitation as a procedure for addressing concerns and disagreements concerning the terms of the solicitation, the processes used for evaluation of proposals, or any other aspect of the STTR procurement. The clause at NASA Federal Acquisition Regulation (FAR) Supplement (NFS) 1852.215-84 ("Ombudsman") is incorporated into this solicitation.

The cognizant ombudsman is:

Jason Detko
Deputy Assistant Administrator for Procurement
Office of Procurement
NASA Headquarters
Washington, DC 20546-0001
Telephone: 202-358-4483
Fax: 202-358-3082
Email: agency-procurementombudsman@nasa.gov

Offerors are advised that, in accordance with NFS 1852.215-84, the ombudsman does not participate in any way with the evaluation of proposals, the source selection process, or the adjudication of formal contract disputes. Therefore, before consulting with the ombudsman, offerors must first address their concerns, issues, disagreements, and/or recommendations to the Contracting Officer for resolution. Offerors are further advised that the process set forth in this solicitation provision (and codified at NFS 1852.215-84) does not augment their right to file a bid protest or otherwise toll or elongate the period in which to timely file such a protest.

1.10 NASA Mentor-Protégé Program (MPP)

The purpose of the NASA Mentor-Protégé Program (MPP) is to provide incentives to NASA contractors, performing under at least one active approved subcontracting plan negotiated with NASA, to assist protégés in enhancing their capabilities to satisfy NASA and other contract and subcontract requirements. The NASA MPP established under the authority of Title 42, United States Code (U.S.C.) 2473(c)(1) and managed by the Office of Small Business Programs (OSBP), includes an Award Fee Pilot Program. Under the Award Fee Pilot Program, a mentor is eligible to receive an award fee at the end of the agreement period based upon the mentor's performance of providing developmental assistance to an active SBIR/STTR Phase II contractor in a NASA Mentor-Protégé agreement (MPA).

The evaluation criterion is based on the amount and quality of technology transfer and business development skills that will increase the protégé's Technology Readiness Levels (TRLs). TRLs measure technology readiness on a scale of 1 to 9. A mentor should attempt to raise the TRL of the protégé and outline the goals and objectives in the

MPA and the award fee plan. A separate award fee review panel set up by NASA OSBP will use the semiannual reports, annual reviews, and the award fee plan in order to determine the amount of award fee given at the end of the performance period of the agreement.

For more information on the Mentor-Protégé Program, please visit https://www.nasa.gov/osbp/mentor-protege-program.

1.11 Fraud, Waste and Abuse and False Statements

Fraud is described as "any false representation about a material fact or any intentional deception designed to deprive the United States unlawfully of something of value or to secure from the United States a benefit, privilege, allowance, or consideration to which an individual or business is not entitled."

Note: The Federal Government reserves the right to decline any completed proposal packages that include plagiarism and false claims.

Note: Knowingly and willfully making any false, fictitious, or fraudulent statements or representations may be a felony under the Federal Criminal False Statement Act (18 U.S.C., section 1001), punishable by a fine and imprisonment of up to 5 years in prison. The Office of the Inspector General (OIG) has full access to all completed proposal packages submitted to NASA.

Pursuant to NASA policy, any company representative who observes crime, fraud, waste, abuse, or mismanagement or receives an allegation of crime, fraud, waste, abuse, or mismanagement from a Federal employee, contractor, grantee, contractor, grantee employee, or any other source will report such observation or allegation to the OIG. NASA contractor employees and other individuals are also encouraged to report crime, fraud, waste, and mismanagement in NASA's programs to the OIG. The OIG offers several ways to report a complaint:

NASA OIG Hotline: 1-800-424-9183 (TDD: 1-800-535-8134)

NASA OIG Cyber Hotline: http://oig.nasa.gov/cyberhotline.html

Or by mail:
NASA Office of Inspector General
P.O. Box 23089
L'Enfant Plaza Station
Washington, DC 20026

1.12 NASA Procurement Ombudsman Program

The NASA Procurement Ombudsman Program is available under this solicitation as a procedure for addressing concerns and disagreements concerning the terms of the solicitation, the processes used for evaluation of completed proposal packages, or any other aspect of the STTR procurement. The clause at NASA Federal Acquisition Regulation (FAR) Supplement (NFS) 1852.215-84 ("Ombudsman") is incorporated into this solicitation.

The cognizant ombudsman is:

Jason Detko
Deputy Assistant Administrator for Procurement
Office of Procurement
NASA Headquarters

Washington, DC 20546-0001
Telephone: 202-358-4483
Fax: 202-358-3082
Email: agency-procurementombudsman@nasa.gov

Offerors are advised that, in accordance with NFS 1852.215-84, the ombudsman does not participate in any way with the evaluation of completed proposal packages, the source selection process, or the adjudication of formal contract disputes. Therefore, before consulting with the ombudsman, Offerors must first address their concerns, issues, disagreements, and/or recommendations to the Contracting Officer for resolution. Offerors are further advised that the process set forth in this solicitation provision (and described at NFS 1852.215-84) does not augment their right to file a bid protest or otherwise toll or elongate the period in which to timely file such a protest.

1.13 General Information

1.13.1 Questions About This Solicitation and Means of Contacting NASA STTR Program

To ensure fairness, questions relating to the intent and/or content of research subtopics in this solicitation cannot be addressed during the open solicitation period. Only questions requesting clarification of completed proposal package instructions and administrative matters will be addressed.

The cutoff date and time for receipt of Phase I solicitation procurement-related questions is March 2, 2022, at 5:00 p.m. ET.

Offerors that have questions requesting clarification of completed proposal package instructions and administrative matters should refer to the NASA SBIR/STTR website or contact the NASA SBIR/STTR helpdesk.

1. NASA SBIR/STTR website: http://sbir.nasa.gov

2. Help Desk: The NASA SBIR/STTR Help Desk can answer any questions regarding clarification of completed proposal package instructions and any administrative matters. The Help Desk may be contacted by:

    a. Email: sbir@reisystems.com
    b. 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.

1.14 Definitions

A comprehensive list of definitions related to the programs is available at http://sbir.nasa.gov/content/nasa-sbirsttr-program-definitions. These definitions include those from the combined SBIR/STTR policy directives as well as terms specific to NASA. Offerors are strongly encouraged to review these prior to submitting a proposal.

2. Registrations, Certifications and Other Completed Proposal Package Information

2.1 Small Business Administration (SBA) Firm Registry

All SBCs that are applying to any STTR solicitation are required to register with the STTR Firm Registry that is managed by the SBA. In addition, all SBCs must update their commercialization status through the STTR Firm Registry. Information related to the steps necessary to register with the STTR Firm Registry can be found at https://www.sbir.gov/registration.

After an SBC registers with SBA and/or updates their commercialization information, the Offeror needs to obtain a portable document format (PDF) copy of the SBC registration. In addition, the SBC must provide their unique SBC Control ID (assigned by SBA upon completion of the Company Registry registration) and must upload the PDF copy of the SBC registration in the EHB. Offerors should complete the Firm Certifications form in the EHB and will be provided instructions how to complete at time of submission. Firm Certifications are applicable across all completed proposal packages submitted by the SBC for the specific solicitation and the EHB will provide guidance on how to complete these certifications.

2.2 System for Award Management (SAM) Registration

Offerors are required to register with SAM prior to submitting a completed proposal package. To be eligible for SBIR awards, firms must be registered under the applicable North American Industry Classification System (NAICS) codes for the SBIR Phase I and II awards (codes 541713 or 541715). Offerors without an active SAM registration by the due date for a completed proposal package will be ineligible for award. Offerors who started the registration process but did not complete the registration by the due date for a completed proposal package will be ineligible for award.

Offerors who are not registered should consider applying for registration immediately upon receipt of this solicitation. Typically, SAM registration and updates to SAM registration have required a processing period of several weeks.

Offerors and contractors may obtain information on SAM registration and annual confirmation requirements at https://www.sam.gov/SAM/pages/public/index.jsf ***or by calling 866-606-8220.***

SAM is the primary repository for contractor information required for the conduct of business with NASA. It is maintained by the Department of Defense. To be registered in SAM, all mandatory information, including the Unique Entity Identifier (UEI), an existing Data Universal Numbering System (DUNS) or DUNS+4 number and a Commercial and Government Entity (CAGE) code, must be validated in SAM.

- By **April of 2022**, the federal government will stop using the DUNS number to uniquely identify entities. At that point, entities doing business with the federal government will use a Unique Entity Identifier (UEI) created in SAM.gov. They will no longer have to go to a third-party website to obtain their identifier. This transition allows the government to streamline the entity identification and validation process, making it easier and less burdensome for entities to do business with the federal government.
    - If your entity is registered in SAM.gov today, your Unique Entity ID (UEI) has already been assigned and is viewable in SAM.gov. This includes inactive registrations. The Unique Entity ID is currently located below the DUNS Number on your entity registration record. Remember, you must be signed in to your SAM.gov account to view entity records. To learn how to view your Unique Entity ID (UEI) go to this help article.

  - Refer to the Guide to Getting a Unique Entity ID if you want to get a Unique Entity ID (UEI) for your organization.

- The DUNS number is a 9-digit number assigned by Dun and Bradstreet Information Services to identify unique business entities. The DUNS+4 is similar but includes a 4-digit suffix that may be assigned by a parent (controlling) business concern. To obtain a DUNS number, please follow instructions at http://www.dnb.com.

- The CAGE code is assigned by the Defense Logistics Information Service (DLIS) to identify a commercial or Government entity. If an SBC does not have a CAGE code, one will be assigned during the SAM registration process.

Note: It is recommended to list Purpose of Registration as “All Awards” on your SAM Registration.

2.3 Certifications

Offerors must complete the Firm and Proposal Certifications section in the Electronic Handbook (EHB), answering “Yes” or “No” to certifications as applicable. Firms should carefully read each of the certification statements. The Federal Government relies on the information to determine whether the business is eligible for a STTR program award. A similar certification will be used to ensure continued compliance with specific program requirements at time of award and during the life of the Funding Agreement. The definitions for the terms used in this certification are set forth in the Small Business Act, SBA regulations (13 CFR Part 121), the SBIR/STTR Policy Directives, and any statutory and regulatory provisions referenced in those authorities.

> For Phase I awards, in addition to the final invoice certification and as a condition for payment of the final invoice. The life cycle certification is preset in the EHB, and it shall be completed along with the final invoice certification before uploading the final invoice in the Department of Treasury’s Invoice Processing Platform (IPP).

If the Contracting Officer believes that the business may not meet certain eligibility requirements at the time of award, the business is required to file a size protest with the SBA, who will determine eligibility. At that time, SBA will request further clarification and supporting documentation in order to assist in the eligibility determination. Additionally, the Contracting Officer may request further clarification and supporting documentation regarding eligibility to determine whether a referral to SBA is required.

2.4 Federal Acquisition Regulation (FAR) Certifications

SAM contains required certifications Offerors may access at https://www.acquisition.gov/browsefar as part of the required registration (see FAR 4.1102). Offerors must complete these certifications to be eligible for award.

Offerors should be aware that SAM requires all Offerors to provide representations and certifications electronically via the website and to update the representations and certifications as necessary, but at least annually, to keep them current, accurate, and complete. NASA will not enter into any contract wherein the contractor is not compliant with the requirements stipulated herein.

In addition, there are clauses that Offerors will need to be aware of if selected for a contract. For a complete list of FAR and NASA clauses see Appendix D.

2.5 Software Development Standards

Offerors proposing projects involving the development of software may be required to comply with the requirements of NASA Procedural Requirements (NPR) 7150.2A, NASA Software Engineering Requirements, available online at https://nodis3.gsfc.nasa.gov/npg_img/N_PR_7150_002C_/N_PR_7150_002C_.pdf.

2.6 Human and/or Animal Subject

Offerors should be aware of the requirement that an approved protocol by a NASA review board is required if the proposed work includes human or animal subject. An approved protocol shall be provided to the Contracting Officer prior to the initiation of any human and/or animal subject research. Offerors shall identify the use of human or animal subject in the Proposal Certifications form. For additional information, contact the NASA SBIR/STTR Program Support Office at sbir@reisystems.com. Reference 14 CFR 1230 and 1232.

Note: Due to the complexity of the approval process, use of human and/or animal subjects is not allowed for Phase I contracts.

2.7 HSPD-12

Firms that require access to Federally controlled facilities or access to a Federal information system (Federally controlled facilities and Federal information system are defined in FAR 2.101(b)(2)) for 6 consecutive months or more must adhere to Homeland Security Presidential Directive 12 (HSPD-12), Policy for a Common Identification Standard for Federal Employees and Contractors, and Federal Information Processing Standards Publication (FIPS PUB) Number 201, Personal Identity Verification (PIV) of Federal Employees and Contractors, which require agencies to establish and implement procedures to create and use a Government-wide secure and reliable form of identification no later than October 27, 2005. See https://nvlpubs.nist.gov/nistpubs/FIPS/NIST.FIPS.201-2.pdf.

This is in accordance with FAR clause 52.204-9, Personal Identity Verification of Contractor Personnel, which states in part that the contractor shall comply with the requirements of this clause and shall ensure that individuals needing such access shall provide the personal background and biographical information requested by NASA.

Note: Additional information regarding PIV credentials can be found at https://csrc.nist.gov/Projects/PIV.

3. Proposal Preparation Instructions and Requirements

3.1 Multiple Proposal Submissions

Each proposal submitted must be based on a unique innovation, must be limited in scope to just one subtopic, and shall be submitted only under that one subtopic within each program. An Offeror shall not submit more than 10 proposals to the STTR program. An Offeror may submit more than one unique proposal to the same subtopic; however, an Offeror shall not submit the same (or substantially equivalent) proposal to more than one subtopic. Submitting substantially equivalent proposals to several subtopics may result in the rejection of all such proposals. To enhance SBC participation, NASA does not plan to select more than 5 STTR proposals from any one Offeror under this solicitation.

Note: Offerors are advised to be thoughtful in selecting a subtopic to ensure the proposal is responsive to the NASA need as defined by the subtopic. The NASA SBIR/STTR program will NOT move a proposal between subtopics or programs.

3.2 Understanding the Patent Landscape

Offerors should indicate in the proposal that a comprehensive patent review has been completed to ensure that there is no existing patent or perceived patent infringement based on the innovation proposed. The U.S. Patent and Trade Office (USPTO) has an online patent search tool that can found at https://www.uspto.gov/patents-application-process/search-patents.

3.3 Proprietary Information in the Proposal Submission

Information contained in unsuccessful proposals will remain the property of the Offeror. The Federal Government may, however, retain copies of all proposals. Public release of information in any proposal submitted will be subject to existing statutory and regulatory requirements. If proprietary information is provided by an Offeror in a proposal, which constitutes a trade secret, commercial or financial information, it will be treated in confidence, to the extent permitted by law, provided that the proposal is clearly marked by the Offeror as follows:

(A) The following "italicized" legend must appear on the title page of the proposal:

This proposal contains information that shall not be disclosed outside the Federal Government and shall not be duplicated, used, or disclosed in whole or in part for any purpose other than evaluation of this proposal, unless authorized by law. The Government shall have the right to duplicate, use, or disclose the data to the extent provided in the resulting contract if award is made as a result of the submission of this proposal. The information subject to these restrictions is contained on all pages of the proposal except for pages [insert page numbers or other identification of pages that contain no restricted information]. (End of Legend); and

(B) The following legend must appear on each page of the proposal that contains information the Offeror wishes to protect:

Use or disclosure of information contained on this sheet is subject to the restriction on the title page of this proposal.

Information contained in unsuccessful proposals will remain the property of the Offeror. However, the Government will retain copies of all proposals in accordance with its records retention schedule.

3.4 Release of Certain Proposal Information

In submitting a proposal, the Offeror agrees to permit the Government to disclose publicly the information contained in the Contact Information form and Proposal Summary form, which includes the Technical Abstract and Briefing Chart. Other proposal data is considered to be the property of the Offeror, and NASA will protect it from public disclosure to the extent permitted by law, including requests submitted under the Freedom of Information Act (FOIA).

3.5 Requirements to Submit a Phase I Completed Proposal Package

3.5.1 General Requirements

Completed proposals packages contain a Technical Proposal as described in section 3.5.3.5 below. A Technical Proposal must clearly and concisely:

1. Describe the proposed innovation relative to the current state of the art;
2. Address the scientific, technical, and commercial merit and feasibility of the proposed innovation as well as its relevance and significance to NASA interests as described in section 9 of this solicitation; and
3. Provide a preliminary strategy that addresses key technical, market, and business factors pertinent to the successful development and demonstration of the proposed innovation and its transition into products and services for NASA mission programs, the NASA relevant commercial markets, and other potential markets and customers.

3.5.2 Format Requirements

Note: The Government administratively screens all elements of a completed proposal package and will decline any proposal package that does not conform to the following formatting requirements.

Page Limitations and Margins

Note: Technical proposal uploads with any page(s) going over the required page limit will not be accepted.
A Phase I technical proposal shall not exceed a total of 19 standard 8.5- by 11-inch (21.6- by 27.9-cm) pages which will include all 10 parts of the technical proposal including all graphics and table of contents.

Margins must be 1.0 inch (2.5 cm). Offerors must ensure that the margins are in compliance before uploading the Phase I technical proposal.

The additional EHB forms required for completed proposal package submission will not count against the 19-page limit.

Suggested Page Limits for Proposal Sections

Within each section is a suggested page limit for each part of the technical proposal. These are guidelines and are not strict requirements. Offerors are still required to meet the total page limit requirements as described above.

Type Size

No type size smaller than 10 point shall be used for text or tables, except as legends on reduced drawings. Completed proposal packages prepared with smaller font sizes will be declined during the administrative review and will not be considered.

Header/Footer Requirements

Headers must include firm name, proposal number, and project title. Footers must include the page number and proprietary markings if applicable. Margins can be used for header/footer information.

Classified Information

NASA will reject any proposal package that contains classified information.

Project Title

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 subtopic title must not be used as the proposal title.

3.5.3 Completed Proposal Package

Each completed proposal package submitted shall contain the following items:

1. Proposal Contact Information
2. Proposal Certifications, electronically endorsed
3. Proposal Summary (must not contain proprietary data)
4. Proposal Budget (including letters of commitment for Government resources and subcontractors/consultants and foreign vendor form, if applicable)
5. Technical Proposal
6. Briefing Chart (must not contain proprietary data)
7. STTR Research Agreement and endorsement of this agreement by the Research Institution (RI) official
8. NASA Evaluation License Application, only if TAV is being proposed
9. Technical and Business Assistance (TABA) request (optional)
10. I-Corps Interest Form
11. Firm-Level Forms (completed once for all proposals submitted to a single solicitation)
    a. Firm Certifications
    b. Audit Information
    c. Prior Awards Addendum
    d. Commercial Metrics Survey (CMS)
12. Electronic Endorsement by the designated small business representative and Principle Investigator (PI) and Research Institution (RI) official

Note: Letters expressing general technical interest or letters of funding support commitments (for Phase I) are not required or desired and will not be considered during the review process. However, if submitted, such letter(s) will count against the proposal page limit.

Note: The EHB will not allow the upload of relevant technical papers, product samples, videotapes, slides, or other ancillary items, and they will not be considered during the review process.

3.5.3.1 Proposal Contact Information Form

The Offeror shall provide complete information for each contact person and submit the form as required in the EHB. ***Note: Contact Information is public information and may be disclosed.***

3.5.3.2 Proposal Certifications Form

The Offeror shall provide complete information for each item and submit and electronically endorse the form as required in the EHB.

3.5.3.3 Proposal Summary Form

The Offeror shall provide complete information for each item and submit the form as required in the EHB.

Note: The Proposal Summary, including the Technical Abstract, is public information and may be disclosed. Do not include proprietary information in this form.

3.5.3.4 Proposal Budget Form
The Offeror must complete the Proposal Budget form following the instructions provided. The total requested funding for the Phase I effort shall not exceed $150,000 or $156,500 (if requesting $6,500 for TABA, see section 1.8 and 3.5.3.8).

Note:

- ***The Government is not responsible for any monies expended by the firm before award of any contract.***
- ***NASA and the Office of Management and Budget (OMB) has issued a policy that requires a review of any request to purchase materials or supplies from foreign vendors. Due to the short timeframe to issue a Phase I contract, NASA is strongly encouraging Offerors to consider purchasing materials and supplies from domestic vendors only. If a foreign vendor is proposed, the Phase I contract may be delayed or not awarded.***

In addition, the following information must be submitted in the Proposal Budget form, as applicable:

Proposal Budget Requirements for Use of Government Resources
In cases where an Offeror seeks to use Government resources as described in Part 8 of the technical proposal instructions, the Offeror shall provide the following:

1. Statement, signed by the appropriate Government official at the affected Federal department or agency, verifying that the resources should be available during proposed period of performance.
2. Signed letter on company letterhead from the SBC's designated small business representative explaining why the STTR research project requires the use of Government resources (such as, but not limited to, Federal services, equipment, or facilities, etc.) including data that verifies the absence of non-Federal facilities or personnel capable of supporting the research effort, a statement confirming that the facility proposed is not a Federal laboratory, if applicable, and the associated cost estimate.

Note: Use of Federal laboratories/facilities for Phase I contracts is highly discouraged as these arrangements will in most cases cause significant delays in making the final award. Approval for use of Federal facilities and laboratories for a Phase I technical proposal requires a strong justification at time of submission and will require approval by the Contracting Officer during negotiations if selected for award.

See Part 8 of the Technical Proposal instructions for additional information on use of Government resources.

Use of Subcontractors and Consultants
Subject to the restrictions set forth in section 1.5.3 and below, the SBC may establish business arrangements with other entities or individuals to participate in performance of the proposed R/R&D effort. Subcontractors' and consultants' work have the same place-of-performance restrictions as stated in section 1.5.4.

The RI's budget must be submitted at the time of proposal submission, and if the RI is an educational institution, the RI must submit a letter from the institution's Office of Sponsored Programs.

Note:

1. ***Offerors should list consultants by name and specify, for each, the number of hours and hourly costs.***
2. ***Breakdown of subcontractor budget should mirror the SBC's own breakdown in the Proposal Budget form and include breakdowns of direct labor, other direct costs, and profit, as well as indirect rate agreements.***

3. ***A signed letter of commitment is required for each subcontractor and/or consultant. For educational institutions, the letter must be from the institution's Office of Sponsored Programs.***

The following restrictions apply to the use of subcontractors/consultants, and the formula below must be used in preparing budgets with subcontractors/consultants:

A minimum of 40 percent of the research or analytical work must be performed by the proposing SBC, and a minimum of 30 percent must be performed by the RI on a STTR project. Any subcontracted business effort other than that performed by the RI shall not exceed 30 percent of the research and/or analytical work [as determined by the total cost of the subcontracting effort (to include the appropriate overhead (OH) and general and administrative expenses (G&A) in comparison to the total effort funded by the government (total contract price including cost sharing, if any, less profit, if any)].

Deviations from these STTR requirements are not allowed, as the performance of work requirements are specified in statute at 15 U.S.C. 638(e). Note: The percentage of research and/or analytical work does not take into consideration any cost sharing. The percentage is based on the total amount of funding the offeror is requesting from the Federal Government.

Example:	Total Project price to include profit	$150,000.00
	Minimum of 40% for SBC costs	$60,000
	Minimum of 30% for RI cost	$45,000
	Cap of 30% for Subcontractor costs	$45,000 (maximum amount allowed)

Note – Offerors will need to determine if they plan to add General and administrative (G&A) expenses to subcontractor cost. If an Offeror plans to add these costs, then these costs are applied towards the subcontractor cap of 30%.

Example: In this example it's assumed the subcontractor cost is $29,500

G&A	5%
G&A on subcontractor cost	$29,500 x 5% = $1,475
Subcontractor cost plus G&A	$29,500 + $1,475 = $30,975
Percentage of subcontracting effort*	**$30,975/$150,000 = 20.6%**

***Subcontractor cost plus G&A/Total price less profit**

For an STTR Phase I, this is acceptable because it is below the limitation of 30 percent for subcontractors.

See Part 9 of the Technical Proposal for additional information on the use of subcontractors and consultants.

Travel in Phase I

Due to the intent and short period of performance of the Phase I contracts, along with their limited budget, travel during the Phase I contract is highly discouraged unless it is required to successfully complete the proposed effort. If the purpose of the meeting cannot be accomplished via videoconference or teleconference, the Offeror must provide a rationale for the trip in the proposal budget form. All travel must be approved by the Contracting Officer and concurred by the Technical Monitor.

3.5.3.5 Technical Proposal

This part of the submission should not contain any budget data and **must consist of all 10 parts listed below in the given order. All 10 parts of the technical proposal must be numbered and titled. A completed proposal package**

omitting any part will be considered nonresponsive to this solicitation and declined without further consideration. Parts that are not applicable must be included and marked "Not applicable."

The completed proposal package shall provide all information needed for a complete evaluation. Evaluators will not seek additional information. Any pertinent references or publications should be noted in Part 5 of the technical proposal.

The required table of contents is provided below:

Part 1: Table of Contents *(Suggested page limit – 0.5 page and counts toward the 19-page limit)*
The technical proposal must begin with a brief table of contents indicating the page numbers of each of the parts of the completed proposal package (see below for an example).

Phase I Table of Contents

Part 2: Identification and Significance of the Proposed Innovation *(Suggested page limit – 5 pages)*
Succinctly describe:

- The proposed innovation.
- The relevance and significance of the proposed innovation to an interest, need, or needs, within a subtopic described in section 9.
- The proposed innovation relative to the current state of the art.

Part 3: Technical Objectives *(Suggested page limit – 1 page)*
State the specific objectives of the Phase I R/R&D effort as it relates to the problem statement(s) posed in the subtopic description and the types of innovations being requested.

Indicate the proposed deliverables at the end of the Phase I effort and how these align with the proposed subtopic deliverables described within a subtopic found in section 9.

Note: All Offerors submitting completed proposal packages who are planning to use NASA TAV including Intellectual Property (IP) must describe their planned developments with the IP. The NASA Evaluation License Application should be added as an attachment in the Proposal Certifications form (see section 1.6).

Part 4: Work Plan *(Suggested page limit – 5 pages)*
Include a detailed description of the Phase I R/R&D plan to meet the technical objectives. The plan shall indicate what will be done, where it will be done, and how the R/R&D will be carried out. Discuss in detail the methods planned to achieve each task or objective. The plan shall also include task descriptions, schedules, resource allocations, estimated task hours for each key personnel, and planned accomplishments (including project

milestones). Offerors shall ensure that the estimated task hours provided in the work plan for key personnel are consistent with the hours reported in the Proposal Budget form. If the Offeror is a joint venture or limited partnership, a statement of how the workload will be distributed, managed, and charged must be included here.

Part 5: Related R/R&D *(Suggested page limit – 1 page)*
Describe significant current and/or previous R/R&D that is directly related to the technical proposal including any conducted by the PI or by the Offeror. Describe how it relates to the proposed effort and any planned coordination with outside sources. The Offeror must persuade reviewers of his or her awareness of key recent R/R&D conducted by others in the specific subject area.

Part 6: Key Personnel and Bibliography of Directly Related Work *(Suggested page limit – 2.5 pages)*
Identify all key personnel involved in Phase I activities whose expertise and functions are essential to the success of the project. Provide biographical information, including directly related education and experience. Where the resume/vitae are extensive, summaries that focus on the most relevant experience or publications are desired and may be necessary to meet completed proposal package size limitation.

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

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

Qualifications: The qualifications and capabilities of the proposed PI and the basis for PI selection are to be clearly presented in the completed proposal package. NASA has the sole right to accept or reject a PI based on factors such as education, experience, demonstrated ability and competence, and any other evidence related to the specific assignment.

Eligibility: This part shall also establish and confirm the eligibility of the PI and shall indicate the extent to which existing projects and other proposals recently submitted or planned for submission in fiscal year 2022 commit the time of the PI concurrently with this proposed activity. Any attempt to circumvent the restriction on PIs working more than half time for an academic or a nonprofit organization by substituting an ineligible PI will result in the proposal package being declined.

Part 7: The Market Opportunity *(Suggested page limit – 1 page)*
The purpose of this section is for Phase I Offerors to describe the potential commercialization opportunities for the innovation. The STTR program is mandated to move funded innovations into commercial markets including both federal markets and private sector commercial markets. In addition, Offerors who start to address the market opportunities early will be better positioned to address additional commercialization metrics under future STTR efforts including Phase II and Phase III.

Phase I Offerors should address each of the following:

- Discuss the business economics and market drivers in the target industry.
- How has the market opportunity been validated?
- Describe your customers and your basic go-to-market strategy to achieve the market opportunity.

- Describe the competition.
- How do you expect the competitive landscape may change by the time your innovation enters the market?
- What are the key risks in bringing your innovation to market?
- Describe your commercialization approach.
- Discuss the potential economic benefits associated with your innovation and provide estimates of the revenue potential, detailing your underlying assumptions.
- Describe the resources you expect will be needed to implement your commercialization approach.

Part 8: Facilities/Equipment *(Suggested page limit – 1 page)*
Describe the types, location, and availability of physical facilities necessary to carry out the work proposed.

Describe the types, location, and availability of equipment necessary to carry out the work proposed. Items of equipment to be purchased must be fully justified under this section. **When purchasing equipment or a product under the STTR funding agreement, the small business should purchase only American-made items whenever possible.**

Government-furnished laboratory equipment, facilities, or services (collectively, "Government resources") the Offeror shall describe in this part why the use of such Government resources is necessary and not reasonably available from the private sector. See sections 3.5.3.4 and 5.13 for additional requirements when proposing use of such Government resources. The narrative description of resources should support the proposed approach and documentation in the Proposal Budget form.

Note: Use of Federal laboratories/facilities for Phase I contracts is highly discouraged. Approval for use of Federal facilities and laboratories for a Phase I completed proposal package requires Program Executive approval during negotiations if selected for award.

Part 9: Subcontractors and Consultants *(Suggested page limit – 1 page)*
The Offeror must describe all subcontracting or other business arrangements and identify the relevant organizations and/or individuals with whom arrangements are planned. The expertise to be provided by the entities must be described in detail, as well as the functions, services, and number of hours. Offerors are responsible for ensuring that all organizations and individuals proposed to be utilized are available for the time periods proposed. Subcontract costs shall be documented in the Subcontractors/Consultants section of the Proposal Budget form and supporting documentation should be uploaded for each (appropriate documentation is specified in the form). The narrative description of subcontractors and consultants in the technical proposal should support the proposed approach and documentation in the Proposal Budget form.

Note: Offerors who do not plan to have a subcontractor or consultants need to indicate this in the EHB.

Part 10: Related, Essentially Equivalent, and Duplicate Proposals and Awards *(Suggested page limit – 1 page)*
WARNING: While it is permissible with proper notification to submit identical proposals or proposals containing a significant amount of essentially equivalent work for consideration under numerous Federal program solicitations, it is unlawful to enter into funding agreements requiring essentially equivalent work.

If an Offeror elects to submit identical proposals or proposals containing a significant amount of essentially equivalent work under other Federal program solicitations, a statement must be included in each proposal indicating the following:

1. The name and address of the agencies to which proposals were submitted or from which awards were received.
2. Date of proposal submission or date of award.
3. Title, number, and date of solicitations under which proposals were submitted or awards received.
4. The specific applicable research subtopics for each proposal submitted or award received.
5. Titles of research projects.
6. Name and title of principal investigator or project manager for each proposal submitted or award received.

Offerors are at risk for submitting essentially equivalent proposals and therefore are strongly encouraged to disclose these issues to the soliciting agency to resolve the matter prior to award.

A summary of essentially equivalent work information, as well as related research and development on proposals and awards, is also required on the Proposal Certifications form (if applicable).

3.5.3.6 Briefing Chart

The 1-page briefing chart is required to assist in the ranking and advocacy of technical proposals prior to selection and contains the following sections with summary information:

- Identification and Significance of Innovation
- Technical Objectives
- Proposed Deliverables
- NASA Applications
- NASA Relevant Commercial Market Applications
- Graphic

It shall not contain any proprietary data or ITAR-restricted data. An electronic form will be provided during the submissions process. For more inforamtin on ITAR see https://www.sbir.gov/tutorials/itar/.

Note: The briefing chart is public information and may be disclosed. Do not include proprietary information in this form.

3.5.3.7 NASA Evaluation License Application, only if TAV is being proposed

If you have applied for TAV by following the instructions found at http://technology.nasa.gov, upload the application of the TAV request with your completed proposal package.

3.5.3.8 Request for Use of Technical and Business Assistance (TABA) Funds at Phase I

Offerors may request Phase I TABA and can choose their own TABA vendor. NASA does not have a TABA preferred vendor. All requests for Phase I TABA must be submitted in the Phase I completed proposal package submission. However, Offerors are not required to request TABA at Phase I, and there is no prerequisite that an Offeror must use Phase I TABA funding to obtain a Phase II award or request TABA funding at Phase II.
Requests for TABA funding are not reviewed under the technical evaluation of the completed proposal package, and the request for TABA funds will not be part of the decision to make an award. All TABA requests will be reviewed after a completed proposal package is selected for award and during the contract negotiation process.

Offerors selected for Phase I contract negotiations can receive up to $6,500 as a TABA supplement to the Phase I award.

Although an Offeror can use TABA funding for services they choose, NASA is encouraging Offerors to use the limited amount of $6,500 Phase I TABA funds for the following activities:

1. Development of a Phase II TABA Needs Assessment – If a Phase I Offeror plans to request TABA funding at Phase II, the Offeror should secure a TABA vendor that can provide services to support the development of a Phase II TABA needs assessment. The goal of the TABA Needs Assessment is to determine and define the types of TABA services and costs the Offeror would need if the project was selected for a future Phase II award. The Offeror could request up to $50,000 for these Phase II TABA services.
2. Development of a Phase II Commercialization and Business Plan – Offerors that are planning to submit a future proposal for Phase II funding will be required to submit a commercialization and business plan that meets the requirements of a future Phase II submission. NASA is encouraging Offerors to use Phase I TABA funding to secure a TABA vendor that can help develop the required elements of the commercialization and business plan so that NASA can evaluate a firm's ability to commercialize the innovation and provide a level of confidence regarding the firm's future and financial viability.

If requesting Phase I TABA funding, Offerors are required to provide the following TABA information by following the directions found in the Budget forms in the EHB:
The following information must be provided for each TABA vendor

- Name of vendor
- Contact information of the vendor
- Vendor DUNS number
- Vendor website address
- Description of vendor(s) expertise and knowledge of providing technical and business assistance services to develop and complete a TABA Needs Assessment for a future Phase II submission, to develop a Commercialization Plan for a future Phase II submission, or other TABA services. If requesting TABA for other services, the Offeror must describe the vendor(s) expertise in providing the requested services
- Itemized list of services and costs the TABA vendor will provide. **This applies to all vendors.**
- Describe the deliverables the TABA vendor will provide and a plan to submit a deliverable summarizing the outcome of the TABA services with expected supporting information.
- TABA costs reflected in the budget forms.

Note: All TABA vendors must be a legal business in the United States and NASA will review the U.S. Government-wide System for Award Management (SAM) excluded parties list to ensure the proposed TABA vendor can receive Federal funds. NASA will consider TABA requests that are missing any requested TABA information (e.g., DUNS number, etc.) as incomplete and will not review the TABA request or provide TABA approval under the award.

NASA reserves the right to withhold funds requested for TABA until a formal review and approval of the requested vendor is completed.

In addition to the review of the TABA request in the completed proposal package, NASA may also consider additional information, such as a review the vendor's website, Duns and Bradstreet reports, and SAM.gov, to verify the existence of the vendor(s) and to assess the capability of the vendor(s).

NASA will only approve TABA funding if the completed proposal package is selected for a Phase I award and the Offeror adequately demonstrates the existence and capability of the selected vendor(s) as determined at the sole discretion of NASA. Notification of the approval or denial of TABA funding will be provided to the Offeror prior to award.

Any TABA funding **will be in addition to the Phase I contract award value, is not subject to any profit or fee by the requesting firm, and cannot be used in the calculation of indirect cost rates or general and administrative expenses (G&A).** The TABA cost(s) and service(s) to be provided by each vendor will be based on the original Phase

I period of performance. Requests for TABA funding outside of the Phase I period of performance or after a completed proposal package submission will not be considered.

Schedule of Deliverables and Payments for TABA—Offerors that are approved to receive TABA under a Phase I award will be reimbursed for TABA expenses. Reimbursement for TABA will be based on the awardee providing a TABA end-of-contract report at the end of the contract period of performance. Reimbursement will not be provided for any amounts incurred over the TABA funding amount approved by the Government prior to award. For additional TABA information see https://www.sbir.gov/node/2088581.

3.5.3.9 I-Corps Interest Form

A complete proposal package will require Offerors to complete a short I-Corps interest form (see section 1.7 for additional information on the I-Corps program) as part of their submission. This form is found in the EHB and NASA uses this form to determine the level of interest from Phase I Offerors to participate in the NASA I-Corps program. Offerors are encouraged to complete the form in its entirety.

Based on the initial level of interest in the I-Corps program, NASA plans to open the opportunity to all Phase I awardees to ensure a successful cohort of teams participate in the program. Phase I awardees will receive information from the SBIR/STTR PMO during contract negotiations describing the process to provide a 5-page proposal to participate in the I-Corps program. Directions for completing the proposal including due dates, training dates, and available grant funding will be provided via email.

Additional details on the program can be found at http://sbir.nasa.gov/content/I-Corps.

The Government reserves the right to limit the number of Offerors to participate in the I-Corps program based on the assessment of the I-Corps proposals and funding availability.

3.5.3.10 Firm Level Forms

All form submissions shall be completed electronically within the EHB and do not count toward the 19-page limit for the technical proposal. For many of these forms, Offerors can view sample forms located in the NASA SBIR/STTR Resources section: http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html.

A. Firm Certifications

Firm certifications that are applicable across all completed proposal package submissions submitted to this solicitation must be completed via the Firm Certifications section of the Proposal Submissions Electronic Handbook (EHB). The Offeror shall answer “Yes” or “No” as applicable. An example of the certifications can be found in the NASA SBIR/STTR Resources section: http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html. An electronic form will be provided during the submissions process.

Note: The designated firm administrator, typically the first person to register your firm, is the only individual authorized to update the certifications.

B. Audit Information

Although firms are not required to have an approved accounting system, knowledge that a firm has an approved accounting system facilitates NASA’s determination that rates are fair and reasonable. To assist NASA, the SBC shall complete the questions in the Audit Information form regarding the firm’s rates and upload the Federal agency audit report or related information that is available from the last audit. There is a separate Audit Information section in the Proposal Budget form that shall also be completed. If your firm has never been audited by a federal agency, then answer "No" to the first question and you do not need to complete the remainder of the form. An electronic form will be provided during the submissions process.

The Contracting Officer will use this Audit Information to assist with negotiations if the completed proposal package is selected for award. The Contracting Officer will advise Offerors what is required to determine reasonable cost and/or rates in the event the Audit Information is not adequate to support the necessary determination on rates.

Note: The designated firm administrator, typically the first person to register your firm, is the only individual authorized to update the audit information.

C. Prior Awards Addendum

If the SBC has received more than 15 Phase II awards in the prior 5 fiscal years, submit the name of the awarding agency, solicitation year, phase, date of award, Funding Agreement/contract number, and subtopic title for each Phase II. If your firm has received any SBIR or STTR Phase II awards, even if it has received fewer than 15 in the last 5 years, it is still recommended that you complete this form for those Phase II awards your firm did receive. This information will be useful when completing the Commercialization Metrics Survey (CMS) and in tracking the overall success of the NASA SBIR and STTR programs. Any NASA Phase II awards your firm has received will be automatically populated in the electronic form, as well as any Phase II awards previously entered by the SBC during prior submissions (you may update the information for these awards). An electronic form will be provided during the submissions process.

Note: The designated firm administrator, typically the first person to register your firm, is the only individual authorized to update the addendum information.

D. Commercialization Metrics Survey (CMS)

NASA has instituted a comprehensive commercialization survey/data-gathering process for firms with prior NASA SBIR/STTR awards to allow NASA to track the overall commercialization success of its SBIR and STTR programs. The Commercialization Metrics Survey is a required part of the completed proposal package submissions process and must be completed via the Proposal Submissions EHB electronic form. Companies with no SBIR/STTR awards or awards within the last 3 to 5 years will not be penalized under past performance for the lack of past SBIR/STTR commercialization.

If an Offeror has received any Phase III awards resulting from work on any NASA SBIR or STTR awards, provide the related Phase I or Phase II contract number, name of Phase III awarding agency, date of award, Funding Agreement number, amount, project title, and period of performance. The survey will also ask for firm financial, sales, and ownership information, as well as any commercialization success the firm has had because of SBIR or STTR awards. This information must be updated annually during completed proposal package submission via the EHB.

Note: Information received from Offerors via the survey is kept confidential and will not be made public except in broad aggregate, with no firm-specific attribution. Password protected documents may not be submitted in response to the survey.

4. Method of Selection and Evaluation Criteria

All Phase I proposals will be evaluated and judged on a competitive basis. Proposals will be initially screened to determine responsiveness. Proposals passing this initial screening will be technically evaluated by engineers or scientists to determine the most promising technical and scientific approaches. Each proposal will be judged on its own merit. NASA is under no obligation to fund any proposal or any specific number of proposals in a given topic. It also may elect to fund several or none of the proposed approaches to the same topic or subtopic.

4.1 Evaluation Process and Evaluation Criteria

NASA conducts a multi-stage review process of all completed proposal packages to determine if the proposal package can be moved forward to be evaluated and ranked on a competitive basis:

1. **Administrative Review.** All complete proposal packages received by the published deadline will undergo an administrative review to determine if the proposal package meets the requirements found in section 3, Proposal Preparation Instructions and Requirements and section 6 Submission of Proposals. A complete proposal package that is found to be noncompliant with the requirements in sections 3 and 6 will be declined and no further evaluations will occur. The Offeror will be notified of NASA's decision to eliminate the proposal package from consideration and the reason(s) for the decision. Incomplete proposal packages will be automatically declined, and no further evaluations will occur.

2. **Technical Responsiveness.** Complete proposal packages that pass the administrative review will be screened to determine technical responsiveness to the subtopic of this solicitation. Complete proposal packages that are determined to be nonresponsive to the subtopic will be declined and no further evaluations will occur. The Offeror will be notified that NASA declined the complete proposal package and will receive written feedback.

   Note: Offerors are advised to be thoughtful in selecting a subtopic to ensure the technical proposal is responsive to the NASA need as defined by the subtopic. The NASA STTR program will NOT evaluate a technical proposal under a subtopic that was not selected by the firm and will not switch a complete proposal package from one subtopic to another during the award period of performance, or between Phase I and Phase II or to another program such as Small Business Innovation Research (SBIR).

3. **Technical Evaluation**. Complete proposal packages determined to be responsive to the administrative requirements and technically responsive to the subtopic of this solicitation, as evidenced by the technical abstract and technical proposal, will be fully evaluated by Subject Matter Experts to determine the most promising technical and scientific approaches.

   Factor 1: Scientific/Technical Merit and Feasibility

   The proposed R/R&D effort will be evaluated on:

   - The technical approach and the anticipated agency and commercial benefits that may be derived from the research.
   - The adequacy of the proposed effort, and its relationship to the fulfillment of requirements of the research subtopic.
   - The soundness and technical merit of the proposed approach and its incremental progress toward subtopic solution.
   - The proposal should describe an innovative and feasible technical approach to the identified NASA problem area/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 qualifications of the proposed Principal Investigators/Project Managers, supporting staff and consultants and subcontractors, if any, will be evaluated for consistency with the research effort and their degree of commitment and availability.

The proposed necessary instrumentation or facilities required to accomplish the proposed technical approach will be evaluated to determine if they are adequate. In addition, any proposed reliance on external sources, such as Government-furnished equipment or facilities (section 3.5.3.4 and part 8 of the technical proposal), will be evaluated for reasonableness.

Factor 3: Effectiveness of the Proposed Work Plan
The proposed work plan should describe the methods planned to achieve each objective or task in detail. The work plan will be evaluated for comprehensiveness, its proposed effective use of available resources and approach to labor distribution. In addition, the work plan's proposed schedule for meeting the Phase I objectives will be evaluated to make sure they are reasonable and consistent with the proposed technical approach.

Factor 4: Commercial Potential
The evaluation factor will consider: the Offeror's record of commercializing STTR or other research; the existence of Phase II funding commitments from private sector or non-STTR funding sources; the existence of Phase III follow-on commitments for the subject of the research; and the presence of other indicators of the commercial potential of the idea.

In addition, the evaluation will consider whether the Offeror's proposal has demonstrated a knowledge of whether NASA mission programs and/or other Government agency programs and/or non-Government markets/programs could be applied to the proposed innovation. If known, Offerors should indicate if there are any existing and projected commitments for funding of the innovation beyond Phase I and II (this can include investment, sales, licensing, and other indicators of commercial potential).

4. **Price Evaluation.**
Utilizing the procedures set forth in FAR 15.404-1, the Offeror's budget proposal form will be evaluated to determine whether the offeror's proposed pricing is fair and reasonable. NASA will only make an award when the price is fair and reasonable and approved by the NASA Contracting Officer.

If a proposal is selected for award, the Contracting Officer will review all the evaluations for the proposal and will address any pricing issues identified during negotiation of the final award.

4.2 Scoring of Factors and Weighting to Determine the Most Highly Rated Proposals

Factors 1, 2, and 3 will be scored numerically and Factor 4 will be assigned an adjectival rating (Excellent, Very Good, Good, Fair, or Poor). Factor 1 is worth 50 points and Factors 2 and 3 are each worth 25 points. The sum of the scores for Factors 1, 2, and 3 will constitute the Technical Merit score.

The most highly technical rated proposals will be eligible for prioritization. To determine the most highly rated technical proposals, the Technical Merit score (Factors 1, 2 and 3) is significantly more important than the Commercial Potential rating (Factor 4).

4.3 Prioritization

For the most highly rated proposals, NASA will prioritize those proposals that offer the best solutions to the technical needs as defined in the subtopics to make recommendations to the Source Selection Official (SSO). In making such a determination, NASA may consider a variety of additional programmatic balance factors such as portfolio balance across NASA Programs, Centers and Mission Directorates, available funding, first-time awardees/participants, historically underrepresented communities including minority and women-owned small businesses, geographic distribution, and/or balance across ideation/point solutions/market stimulation when making recommendations.

4.4 Selection

Those proposals recommended for negotiations will be forwarded to the SBIR/STTR PMO for analysis and presented to the mission directorate representatives and SSO for review. The SSO has the final authority for choosing the specific proposals for contract negotiation. Each completed proposal package selected for negotiation by the SSO will be evaluated by the Contracting Officer to determine eligibility for an award. The terms and conditions of the contract will be negotiated based on the SBIR/STTR Small Business Act (15 U.S.C. 638), FAR and NASA FAR requirements, and a responsibility determination made. The Contracting Officer will advise the SSO on matters pertaining to cost reasonableness, responsibility, and known past performance issues.

The list of completed proposal packages selected for negotiation will be posted on the NASA SBIR/STTR website (http://sbir.nasa.gov). All firms will receive a formal notification letter. A Contracting Officer will negotiate an appropriate contract to be signed by both parties before work begins.

Under this solicitation, NASA will not accept more than 10 completed proposal packages from any one firm to ensure the broadest participation of the small business community. NASA does not plan to award more than 5 STTR contracts to any Offeror.

4.5 I-Corps Evaluation Process

For awardees invited to submit an I-Corps proposal pursuant to sections 1.7 and 3.5.3.9, NASA will provide a programmatic assessment of firms based on the following criteria:

- Proposed team members demonstrate a commitment to the requirements of the I-Corps program.
- The proposed team includes the proper composition and roles as described in the I-Corps proposal requirements.
- The I-Corps proposal defines that the small business is at a stage that fits the goals of the program and aligns with the NASA STTR program goals.
- The I-Corps proposal demonstrates that there is potential for commercialization in both NASA and NASA Relevant Commercial markets.

Based on the assessment of the above criteria the NASA SBIR/STTR PMO will provide a recommendation of I-Corps proposals to receive grants to the SSO. The SSO will make the final selections for I-Corps. NASA anticipates a total of approximately 10 STTR firms will be selected for participation in the I-Corps program for Phase I.

4.6 Technical and Business Assistance (TABA)

NASA conducts a separate review of all Phase I Offeror requests for TABA after the SSO makes the final selection of projects to enter negotiation for a Phase I contract. The SBIR/STTR PMO conducts the initial evaluation of the TABA request to determine if the request meets the requirements found in sections 1.8 and 3.5.3.8. The Contracting Officer makes the final determination to allow TABA funding under the contract.

The review of Phase I TABA requests will include the following:

- A review to determine if the awardee will use the funding to develop a Phase II TABA Needs Assessment and a Phase II Commercialization and Business Plan and/or if there are additional services being requested.
- Verification of TABA vendors by reviewing the vendor information and websites.
- A review of the vendor(s) expertise and knowledge in providing technical and business assistance services to develop and complete a TABA Needs Assessment, a Commercialization and Business Plan, or other proposed TABA services.
- A review of the costs to be provided to the TABA vendor(s).
- Proposed plans to submit a deliverable summarizing the outcome of the TABA services with expected supporting information.
- Verification that TABA costs are reflected in the budget forms.
- There is no evidence of Fraud, Waste and Abuse for these funds.

4.7. Access to Proprietary Data by Non-NASA Personnel

4.7.1 Non-NASA Reviewers

In addition to utilizing Government personnel in the review process, NASA, at its discretion and in accordance with 1815.207-71 of the NASA FAR Supplement, may utilize individuals from outside the Government with highly specialized expertise not found in the Government. Qualified experts outside of NASA (including industry, academia, and other Government agencies) may assist in performing evaluations as required to determine or verify the merit of a completed proposal package. Offerors should not assume that evaluators are acquainted with the Offeror, key individuals, or with any experiments or other information. Any decision to obtain an outside evaluation shall take into consideration requirements for the avoidance of organizational or personal conflicts of interest and any competitive relationship 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 completed proposal package will be used only for evaluation purposes and will not be further disclosed.

4.7.2 Non-NASA Access to Confidential Business Information

In the conduct of completed proposal package processing and potential contract administration, the Agency may find it necessary to provide access to the completed proposal package to other NASA contractor and subcontractor personnel. NASA will provide access to such data only under contracts that contain an appropriate NFS 1852.237-72 Access to Sensitive Information clause that requires the contractors to fully protect the information from unauthorized use or disclosure.

4.8 Notification and Feedback to Offerors

After Phase I selections for negotiation have been made, a notification will be sent to the designated small business representative identified in the completed proposal package according to the processes described below.

Note: Due to the competitive nature of the program and limited funding, recommendations to fund or not fund a completed proposal package will be final. Any notification or feedback provided to the Offeror is not an opportunity to reopen selection decisions or obtain additional information regarding the final decision. Offerors

are encouraged to use the written feedback to understand the outcome and review of their completed proposal package and to develop plans to strengthen future proposals.

4.8.1 Phase I Feedback

NASA uses a two-stage process to notify Phase I Offerors of the outcome of their completed proposal package.

1. At the time of the public selection announcement, the designated small business representative will receive an email indicating the outcome of the completed proposal package.

2. NASA will automatically email proposal feedback to the designated small business representative within 60 days of the announcement of selection for negotiation. If you have not received your feedback within 60 days after the announcement, contact the NASA SBIR/STTR Program Support Office at sbir@reisystems.com. **Due to the sensitivity of this feedback, NASA will only provide feedback to the designated small business representative and will not provide this to any other parties.**

5. Considerations

5.1 Requirement for Contracting

Upon award of a Funding Agreement, the Awardee will be required to make certain legal commitments through acceptance of numerous clauses in Phase I Funding Agreements. The outline that follows is illustrative of the types of clauses to which the contractor would be committed. This list is not a complete list of clauses to be included in Phase I Funding Agreements and is not the specific wording of such clauses. Copies of complete terms and conditions are available by following the links in appendix D.

(1) Standards of Work. Work performed under the Funding Agreement must conform to high professional standards.
(2) Inspection. Work performed under the Funding Agreement is subject to Government inspection and evaluation at all times.
(3) Examination of Records. The Comptroller General (or a duly authorized representative) must have the right to examine any pertinent records of the Awardee involving transactions related to this Funding Agreement.
(4) Default. The Federal Government may terminate the Funding Agreement if the contractor fails to perform the work contracted.
(5) Termination for Convenience. The Funding Agreement may be terminated at any time by the Federal Government if it deems termination to be in its best interest, in which case the Awardee will be compensated for work performed and for reasonable termination costs.
(6) Disputes. Any dispute concerning the Funding Agreement that cannot be resolved by agreement must be decided by the contracting officer with right of appeal.
(7) Contract Work Hours. The Awardee may not require an employee to work more than 8 hours a day or 40 hours a week unless the employee is compensated accordingly (for example, overtime pay).
(8) Equal Opportunity. The Awardee will not discriminate against any employee or Offeror for employment because of race, color, religion, sex, or national origin.
(9) Equal Opportunity for Veterans. The Awardee will not discriminate against any employee or application for employment because he or she is a disabled veteran or veteran of the Vietnam era.
(10) Equal Opportunity for People with Disabilities. The Awardee will not discriminate against any employee or Offeror for employment because he or she is physically or intellectually disabled.
(11) Officials Not to Benefit. No Federal Government official may benefit personally from the SBIR/STTR Funding Agreement.
(12) Covenant Against Contingent Fees. No person or agency has been employed to solicit or secure the Funding Agreement upon an understanding for compensation except bona fide employees or commercial agencies maintained by the Awardee for the purpose of securing business.
(13) Gratuities. The Funding Agreement may be terminated by the Federal Government if any gratuities have been offered to any representative of the Government to secure the award.
(14) Patent Infringement. The Awardee must report each notice or claim of patent infringement based on the performance of the Funding Agreement.
(15) American Made Equipment and Products. When purchasing equipment or a product under the SBIR/STTR Funding Agreement, purchase only American-made items whenever possible.

To simplify making contract awards and to reduce processing time, all contractors selected for Phase I contracts will ensure that:

1. All information in your completed proposal package is current (e.g., your address has not changed, the proposed PI is the same, etc.). If changes have occurred since submittal of your completed proposal package, notify the Contracting Officer immediately.
2. Your firm is registered with System for Award Management (SAM) (section 2.2).
3. Your firm complies with the FAR 52.222-37 Employment Reports on Special Disabled Veterans, Veterans of the Vietnam Era, and Other Eligible Veterans (VETS-4212) requirement (See Appendix D). Confirmation that a VETS-4212 report has been submitted to the Department of Labor, and is current, shall be provided to the Contracting Officer within 10 business days of the notification of selection for negotiation.
4. Your firm HAS NOT proposed a Co-Principal Investigator.
5. Your firm will provide timely responses to all communications from the NSSC Contracting Officer.
6. All proposed cost is supported with documentation, such as a quote, previous purchase order, published price lists, etc. All letters of commitment are dated and signed by the appropriate person with contact information. If a university is proposed as a subcontractor or a RI, the signed letter shall be on the university letterhead from the Office of Sponsored Programs. If an independent consultant is proposed, the signed letter should not be on a university letterhead. If the use of Government facilities or equipment is proposed, your firm shall submit a signed letter from the Government facility authorizing the use of the facility and stating the availability and the cost, if any, together with a signed letter from your firm justifying the need to use the facility.

From the time of completed proposal package notification of selection for negotiation until the award of a contract, all communications shall be submitted electronically to NSSC-SBIR-STTR@nasa.gov.

Note: Costs incurred prior to and in anticipation of award of a contract are entirely the risk of the contractor if a contract is not subsequently awarded. A notification of selection for negotiation is not to be misconstrued as an award notification to commence work.

5.2 Awards

5.2.1 Anticipated number of Awards

NASA does not estimate an exact number of anticipated Phase I contract awards; however, the table below reflects the historical information for the program.

Year	Number of STTR Phase I Proposals Reviewed	Number of STTR Phase I Awards	Percentage of STTR Phase I Awards
2021	192	56	29.1%
2020	265	59	22.2%
2019	204	48	23.5%

5.2.2 Award Conditions

NASA awards are electronically signed by a NASA Contracting Officer and transmitted electronically to the organization via email. NSSC will distribute the NASA STTR award with the following items.

Phase I:

- SF26—Contract Cover Sheet
- Contract Terms and Conditions—to include reference to the completed proposal package and budget
- Attachment 1: Contract Distribution List
- Attachment 2: Template of the Final Summary Chart

- Attachment 3: IT Security Management Plan Template
- Attachment 4: Applicable Documents List
- Negotiation Confirmation
- Phase I Frequently Asked Questions (FAQs)

5.2.3 Type of Contract

NASA STTR Phase I awards are made as firm fixed price contracts.

5.2.4 Model Contracts

Examples of the NASA STTR contracts can be found in the NASA SBIR/STTR Resources section: http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html. ***Note: Model contracts are subject to change.***

5.3 Reporting and Required Deliverables

An IT Security Management Plan is required at the beginning of the contract. Contractors interested in doing business with NASA and/or providing IT services or solutions to NASA should use the list found at the website of the Office of the Chief Information Officer (OCIO) as a reference for information security requirements: https://www.nasa.gov/content/security-requirements-policies. An example of an IT Security Management Plan can be found in the NASA SBIR/STTR Resources section: http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html. For more information, see NASA FAR Supplement clause 1852.204-76

All contracts shall require the delivery of technical reports that present (1) the work and results accomplished; (2) the scientific, technical, and commercial merit and feasibility of the proposed innovation and project results; (3) the proposed innovation's relevance and significance to one or more NASA interests (section 9); and (4) the strategy for development and transition of the proposed innovation and project results into products and services for NASA mission programs and other potential customers. Deliverables may also include the demonstration of the proposed innovation and/or the delivery of a prototype or test unit, product, or service for NASA testing and utilization if requested under Phase I.

The technical reports and other deliverables are required as described in the contract and are to be provided to NASA. These reports shall document progress made on the project and activities required for completion. Periodic certification for payment will be required as stated in the contract. A final report must be submitted to NASA upon completion of the Phase I R/R&D effort in accordance with applicable contract provisions.

A final New Technology Summary Report (NTSR) is due at the end of the contract, and New Technology Report(s) (NTR) are required if technology(ies) is/are developed under the award prior to submission of the final invoice. For additional information on NTSR and NTR requirements and definitions, see section 5.9.

If TABA is requested, Phase I contracts will require TABA deliverables that summarize the outcome of the TABA services with expected supporting information.

Report deliverables shall be submitted electronically via the EHB. For any reports that require an upload, NASA requests the submission in PDF or Microsoft Word format.

Note: To access contract management in the EHB, you will be required to have an identity in the NASA Access Management System (NAMS). This is the Agency's centralized system for requesting and maintaining accounts for NASA IT systems and applications. The system contains user account information, access requests, and account maintenance processes for NASA employees, contractors, and remote users such as educators and

foreign users. A basic background check and completion of NASA IT Security Training is required for this account. Instructions to create an identity in NAMS will be provided during contract negotiations.

It is recommended that you begin this process immediately upon notification, as this access will be required to submit deliverables and invoices.

5.4 Payment Schedule

All NASA STTR contracts are firm-fixed-price contracts. The exact payment terms will be included in the contract.

Although invoices are submitted electronically through the Department of Treasury's Invoice Processing Platform (IPP), as a condition for payment, invoice certifications shall be completed in the EHB for each individual invoice. The certification is preset in the EHB, and it shall be completed before uploading each invoice in IPP. Upon completion of the certification, a link to IPP is automatically provided in the EHB.

If TABA is requested, Phase I awardees will be required to submit TABA vendor invoices for reimbursement per the payment schedule in section 3.5.3.8.

5.5 Profit or Fee

Contracts may include a reasonable profit. The reasonableness of proposed profit is determined by the Contracting Officer during contract negotiations. Reference FAR 15.404-4.

5.6 Cost Sharing

Cost sharing is permitted for completed proposal packages under this program solicitation; however, cost sharing is not required. Cost sharing will not be an evaluation factor in consideration of your completed proposal package or will not be used in the determination of the percentage of Phase I work to be performed on the contract.

5.7 Rights in Data Developed Under SBIR/STTR Funding Agreements

The SBIR/STTR program provides specific rights for data developed under STTR awards. Please review the full text at the following FAR 52.227-20 Rights in Data-SBIR Program and PCD 21-02 FEDERAL ACQUISITION REGULATION (FAR) CLASS DEVIATION – PROTECTION OF DATA UNDER THE SMALL BUSINESS INNOVATIVE RESEARCH/SMALL TECHNOLOGY TRANSFER RESEARCH (SBIR/STTR) PROGRAM

5.8 Copyrights

The contractor may copyright and publish (consistent with appropriate national security considerations, if any) material developed with NASA support. NASA receives a royalty-free license for the Federal Government and requires that each publication contain an appropriate acknowledgment and disclaimer statement.

5.9 Invention Reporting, Election of Title, Patent Application Filing, and Patents

Awardees under the STTR program are required to provide New Technology Reports (NTR) for any new subject inventions, and the New Technology Summary Reports (NTSR) for the interim and final contract periods. Please review full text at the following https://www.sbir.gov/sites/default/files/SBA_SBIR_STTR_POLICY_DIRECTIVE_OCT_2020_v2.pdf to understand these requirements.

5.10 Government-Furnished and Contractor-Acquired Property

In accordance with the SBIR/STTR Policy Directive, the Federal Government may transfer title to property provided by the STTR Participating Agency to the awardee, or acquired by the awardee for the purpose of fulfilling the contract, where such transfer would be more cost effective than recovery of the property.

5.11 Essentially Equivalent Awards and Prior Work

If an award is made pursuant to a proposal or completed proposal package submitted under a STTR solicitation, the firm will be required to certify with every invoice 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 report essentially equivalent or duplicate efforts can lead to the termination of contracts and/or civil or criminal penalties.**

5.12 Additional Information

5.12.1 Precedence of Contract Over this Solicitation

This program solicitation reflects current planning. If there is any inconsistency between the information contained herein and the terms of any resulting STTR contract, the terms of the contract take precedence over the solicitation.

5.12.2 Evidence of Contractor Responsibility

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 (e.g., financial capability, workforce, and facilities).

5.13 Use of Government Resources

Federal Departments and Agencies

Use of STTR funding for unique Federal/non-NASA resources from a Federal department or agency that does not meet the definition of a Federal laboratory as defined by U.S. law and in the SBA Policy Directive on the STTR program requires a waiver from the SBA. Completed proposal packages requiring waivers must include an explanation of why the waiver is appropriate. NASA will provide the Offeror’s request, along with an explanation to SBA, during the negotiation process. NASA cannot guarantee that a waiver can be obtained from SBA. Specific instructions to request use of Government Resources are in sections 3.5 of the solicitation.

Note: NASA facilities qualify as Federal laboratories.

Support Agreements for Use of Government Resources

Note: Use of Federal laboratories/facilities for Phase I contracts is highly discouraged as these arrangements will in most cases cause significant delays in making the final award. Approval for use of Federal facilities and laboratories for a Phase I technical proposal requires a strong justification at time of submission and will require approval by the Contracting Officer during negotiations if selected for award.

All Offerors selected for award who require the use of any Federal facility shall, within 20 business days of notification of selection for negotiations, provide to the NSSC Contracting Officer an agreement by and between the Contractor and the appropriate Federal facility/laboratory, executed by the Government official authorized to approve such use. The agreement must delineate the terms of use, associated costs, and facility responsibilities and liabilities. Having a signed agreement for use of Government resources is a requirement for award.

For proposed use of NASA resources, a NASA SBIR/STTR Support Agreement template is available in the Resources section (http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html) and must be executed before a contractor can use

NASA resources. Offerors shall only include a signed letter of commitment from an authorized NASA point of contact in the completed proposal packages. NASA expects selected Offerors to finalize and execute their NASA SBIR/STTR Support Agreement during the negotiation period with the NSSC.

Contractor Responsibilities for Costs

In accordance with FAR Part 45, it is NASA's policy not to provide services, equipment, or facilities (resources) (capital equipment, tooling, test, and computer facilities, etc.) for the performance of work under STTR contracts. Generally, any contractor will furnish its own resources to perform the proposed work on the contract.

In all cases, the contractor shall be responsible for any costs associated with services, equipment, or facilities provided by NASA or another Federal department or agency, and such costs shall result in no increase in the price of this contract.

Note: The SBIR/STTR Support Agreement has been updated to include additional requirements related to NASA IT Security. The new additions are found under Section C. Part 3 of the Terms and Conditions of the Support Agreement and are below.

> 3. If Contractor’s use of NASA resources includes use of or access to NASA Information Technology (IT) resources, the Contractor will at all times remain in compliance with and adhere to all NASA IT security requirements and processes, including those set forth in the Contractor’s IT Security Plan. The Contractor’s failure to do so may result in NASA’s unilateral termination of this Use Agreement.

6. Submission of Proposals

6.1 How to Apply for STTR Phase I

NASA uses electronically supported business processes for the STTR program. An Offeror must have internet access and an email address. Paper submissions are not accepted.
To apply for a NASA STTR Phase I contract all SBCs are required to follow the steps found below.

6.1.1 Electronic Submission Requirements via the EHB

NASA uses an electronic submission system called the Electronic Handbook (EHB) and all Offerors must use the EHB for submitting a completed proposal package. The EHB guides firms through the steps for submitting a complete proposal package. All submissions are through a secure connection and most communication between NASA and the firm is through either the EHB or email. To access the EHB go to https://sbir.gsfc.nasa.gov/submissions/login.

New SBCs must register in the EHB to begin the submission process. Returning firms can use the same account they have used for previous submissions unless the business name has changed. Firms are encouraged to start the EHB registration process early to allow sufficient time to complete the submissions process.

It is recommended that the designated small business representative, or an authorized representative designated by the designated small business representative, be the first person to register for the SBC. The SBC's Employer Identification Number (EIN)/Taxpayer Identification Number is required during registration.

Note: The designated small business representative, typically the first person to register your firm, will become the firm administrator and will be the only individual authorized to update and change the firm-level forms in the EHB.

For successful completed proposal package submission, SBCs shall complete all forms online, upload their required documents in an acceptable format, and have the designated small business representative and Principal Investigator (PI) electronically endorse the proposal package within the EHB system.

6.1.2 Deadline for Phase I Completed Proposal Package

A complete proposal package for Phase I shall be <u>received</u> no later than 5:00 p.m. ET on Wednesday, March 9, 2022, via the EHB. See Section 3. Proposal Preparation Instructions and Requirements.

Offerors are responsible for ensuring that all files constituting the complete proposal package be uploaded prior to the deadline. **If a complete proposal package is not received by the 5:00 p.m. ET deadline, the proposal package will be determined to be incomplete and will not be evaluated.** Offerors are strongly encouraged to start the submission process early to allow sufficient time to upload their complete proposal package. An Offeror that waits to submit a proposal package near the deadline is at risk of not completing the required uploads and endorsements of their completed proposal package by the required deadline, resulting in the rejection of the proposal package.

6.1.3 Complete Proposal Package Submission

Firms will upload all components of a complete proposal package using the Proposal Submissions module in the EHB. Directions are found within the EHB to assist users. All transactions via the EHB are encrypted for security purposes.

A complete proposal package consists of online forms and associated documentation that must be submitted in PDF format via the EHB. Below is what a completed proposal package includes. See section 3 for additional information on how to complete each of these sections

1. Proposal Contact Information
2. Proposal Certifications, electronically endorsed
3. Proposal Summary (must not contain proprietary data)
4. Proposal Budget (including letters of commitment for Government resources and subcontractors/consultants and foreign vendor form, if applicable)
5. Technical Proposal
6. Briefing Chart (must not contain proprietary data)
7. STTR Research Agreement and endorsement of this agreement by the Research Institution (RI) official
8. NASA Evaluation License Application, only if TAV is being proposed
9. Technical and Business Assistance (TABA) request (optional)
10. I-Corps Interest Form
11. Firm-Level Forms (completed once for all proposals submitted to a single solicitation)
    a. Firm Certifications
    b. Audit Information
    c. Prior Awards Addendum
    d. Commercial Metrics Survey (CMS)
12. Electronic Endorsement by the designated small business representative and Principle Investigator (PI) and Research Institution (RI) official

Firms cannot submit security/password-protected PDF files, as reviewers may not be able to open and read these files. Proposal packages containing security/password-protected PDF files will be declined and not considered.

Offerors are responsible for virus checking all files prior to submission. NASA may reject any completed proposal package that contains a file with a detected virus.

You may upload a complete proposal package multiple times, with each new upload replacing the previous version, but only the final uploaded and electronically endorsed version will be considered for review. If you have already completed a prior upload and endorsed the proposal package, any new uploads will require a re-endorsement of the new completed proposal package.

Before you can submit the final completed proposal package, the EHB will ask you to download the entire completed proposal package and certify that you have reviewed it to ensure that you have met the requirements in this solicitation and have uploaded the correct documentation.

A proposal package that is missing the final endorsements will be considered an incomplete proposal package and will be declined and will not be reviewed.

Note: Embedded animation or video, as well as reference technical papers for "further reading," will not be considered for evaluation.

6.1.4 Acknowledgment of a Completed Proposal Package Receipt

NASA will acknowledge receipt of electronically submitted and completed proposal package upon endorsement by the designated small business representative by sending an email to the designated small business representative email address as provided on the completed proposal package cover sheet, as well as to the user who created the completed proposal package, if different. ***If a completed* proposal package *acknowledgment is not received after submission, the Offeror should immediately contact the NASA SBIR/STTR Program Support Office at sbir@reisystems.com*.**

6.1.5 Withdrawal of Completed Proposal Packages

Prior to the close of submissions, completed proposal packages may be withdrawn via the Proposal Submissions module in the EHB. In order to withdraw a completed proposal package after the deadline, the designated small business representative must send written notification via email to sbir@reisystems.com.

6.1.6 Service of Protests

Protests, as defined in section FAR 33.101 of the Federal Acquisition Regulation, that are filed directly with an agency, and copies of any protests that are filed with the Government Accountability Office (GAO), shall be served on the Contracting Officer (addressed as follows) by obtaining written and dated acknowledgment of receipt from:

Theresa Stanley
NASA Shared Services Center
Building 1111, Jerry Hlass Road
Stennis Space Center, MS 39529
Agency-SBIR-STTRSolicitation@mail.nasa.gov

The copy of any protest shall be received in the office designated above within one day of filing a protest with the GAO.

7 Information Sources

7.1 NASA Organizational and Programmatic Information

General sources relating to organizational and programmatic information at NASA is available via the following websites:

NASA Budget Documents, Strategic Plans, and Performance Reports:
http://www.nasa.gov/about/budget/index.html
NASA Organizational Structure: http://www.nasa.gov/centers/hq/organization/index.html
NASA SBIR/STTR Programs: http://sbir.nasa.gov

Information regarding 2020 NASA Technology Taxonomy and the NASA Strategic Integration Framework can be obtained at the following websites:

Office of the Chief Technologist	
2020 NASA Technology Taxonomy	https://www.nasa.gov/offices/oct/taxonomy/index.html

NASA Mission Directorates	
Aeronautics Research	http://www.aeronautics.nasa.gov/
Human Exploration and Operations	http://www.nasa.gov/directorates/heo/home/
Science	http://nasascience.nasa.gov
Space Technology	http://www.nasa.gov/directorates/spacetech/home/index.html

NASA Centers	
Ames Research Center (ARC)	http://www.nasa.gov/centers/ames/home/index.html
Armstrong Flight Research Center (AFRC)	http://www.nasa.gov/centers/armstrong/home/index.html
Glenn Research Center (GRC)	http://www.nasa.gov/centers/glenn/home/index.html
Goddard Space Flight Center (GSFC)	http://www.nasa.gov/centers/goddard/home/index.html
Jet Propulsion Laboratory (JPL)	http://www.nasa.gov/centers/jpl/home/index.html
Johnson Space Center (JSC)	http://www.nasa.gov/centers/johnson/home/index.html
Kennedy Space Center (KSC)	http://www.nasa.gov/centers/kennedy/home/index.html
Langley Research Center (LaRC)	http://www.nasa.gov/centers/langley/home/index.html
Marshall Space Flight Center (MSFC)	http://www.nasa.gov/centers/marshall/home/index.html
Stennis Space Center (SSC)	http://www.nasa.gov/centers/stennis/home/index.html
NASA Shared Services Center (NSSC)	https://www.nssc.nasa.gov/

7.2 United States Small Business Administration (SBA)

The SBA oversees the Federal SBIR and STTR programs. The SBA has resources that small businesses can take advantage of in learning about the program and obtaining help in developing a proposal to a Federal SBIR/STTR program. Proposers are encouraged to review the information that is provided at the following links: www.sbir.gov, https://www.sba.gov/local-assistance, and at https://www.sbir.gov/resources.

The SBA issues a SBIR/STTR Policy Directive which provides guidance to all Federal Agencies that have a SBIR/STTR program. The Policy Directives for the SBIR/STTR programs may be obtained from the SBA at www.sbir.gov or at the following address:

U.S. Small Business Administration
Office of Technology – Mail Code 6470
409 Third Street, S.W.

Washington, DC 20416
Phone: 202-205-6450

7.3 National Technical Information Service

The National Technical Information Service (NTIS) is an agency of the Department of Commerce and is the Federal Government's largest central resource for Government-funded scientific, technical, engineering, and business-related information. For information regarding various NTIS services and fees, call or write:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Phone: 703-605-6000
URL: http://www.ntis.gov

8. Submission Forms

Note: Previews of all forms and certifications are available via the NASA SBIR/STTR Resources section, located at http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html.

8.1 STTR Phase I Checklist

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

1. The proposal and innovation is submitted for one subtopic only.
2. The entire proposal package is submitted consistently with the requirements outlined in section 3.
    a. Proposal Contact Information
    b. Proposal Certifications, electronically endorsed
    c. Proposal Summary (must not contain proprietary data)
    d. Proposal Budget
        i. Including letters of commitment for Government resources and subcontractors/consultants (if applicable)
        ii. Foreign Vendor form (if applicable) – Note: NASA and the Office of Management and Budget (OMB) has issued a policy that requires a review of any request to purchase materials or supplies from foreign vendors. Due to the short timeframe to issue a Phase I contract, NASA is strongly encouraging Offerors to consider purchasing materials and supplies from domestic vendors only. If a foreign vendor is proposed, the Phase I contract may be delayed or not awarded.
    e. Technical Proposal including all 10 parts as stated in section 3.
    f. Briefing Chart (must not contain proprietary data)
    g. STTR Research Agreement and endorsement of this agreement by the Research Institution (RI) official
    h. NASA Evaluation License Application, only if TAV is being proposed
    i. Technical and Business Assistance (TABA) request (optional)
    j. I-Corps Interest Form
    k. Firm-Level Forms (completed once for all proposals submitted to a single solicitation)
        i. Firm Certifications
        ii. Audit Information
        iii. Prior Awards Addendum
        iv. Commercial Metrics Survey (CMS)
    l. Electronic Endorsement by the designated small business representative and Principle Investigator (PI) and Research Institution (RI) official
3. **The technical proposal shall not exceed a total of 19 standard 8.5- by 11-inch pages with one-inch margins and shall follow the format requirements (section 3.5.2).**
4. The technical proposal contains all 10 parts in order (section 3.5.3).
5. Any additional required letters/documentation.
    a. A letter of commitment from the appropriate Government official if the research or R&D effort requires use of Government resources (sections 3.5 and 5.13).
    b. Letters of commitment from subcontractors/consultants.
    c. If the firm is an eligible joint venture or a limited partnership, a copy or comprehensive summary of the joint venture agreement or partnership agreement is included.
    d. NASA Evaluation License Application if proposing the use of NASA technology (TAV).

e. Supporting documentation of budgeted costs.

6. Proposed funding does not exceed $150,000 (section 1.4), and if requesting TABA, the cost for TABA does not exceed $6,500 (sections 1.8 and 3.5.3.8).
7. Proposed project duration does not exceed thirteen (13) months (section 1.4).
8. Proposal package electronically endorsed by the designated small business representative and the Principal Investigator (PI) at the published deadline.
9. **Complete proposal packages and all endorsements shall be received no later than 5:00 p.m. ET on March 9, 2022 (section 6.1.2).**

9. Research Subtopics for STTR

Introduction
The STTR subtopics are organized into groupings called Focus Areas. Focus Areas are a way of grouping NASA interests and related technologies with the intent of making it easier for proposers to understand related needs across the Agency and thus identify subtopics where their research and development capabilities may be a good match. In addition, there are some STTR subtopics that may be closely aligned with the NASA SBIR program. Offerors should consider both programs when planning to apply. To find the NASA SBIR and STTR solicitations, click this link: https://sbir.nasa.gov/solicitations.

Notes:
Offerors are advised to be thoughtful in selecting a subtopic to ensure the proposal is responsive to the NASA need as defined by the subtopic. The NASA STTR program will NOT move a proposal between STTR subtopics other programs such as SBIR.

NASA uses a Subtopic numbering convention for the STTR program and maintains this from year to year. The mapping is as follows:

For STTR Subtopics:
T – Small Business Technology Transfer (STTR)

Proposers should think of the subtopic lead/participating centers as potential customers for their STTR proposals. Multiple centers may have interests across the subtopics within a Focus Area.

Related subtopic pointers are identified in the subtopic headers when applicable to assist proposers with identifying related subtopics that also potentially seek related technologies for different customers or applications. As stated in section 2.2, an offeror shall not submit the same (or substantially equivalent) proposal to more than one subtopic. It is the offeror's responsibility to select which subtopic to propose to.

Focus Area 3 Autonomous Systems for Space Exploration

The exploration of space requires the best of the nation's technical community to provide the technologies that will enable human and robotic exploration beyond Low Earth Orbit (LEO): to establish a lunar presence, to visit asteroids, to extend human reach to Mars, and for increasingly ambitious missions. Examples of such missions include robotic platforms like the Europa Lander or crewed missions with extended periods of dormancy such as Gateway. Gateway represents a vital component of NASA’s Artemis program, which will serve as a multi-purpose orbital lunar outpost that provides essential support for a long-term human return to the lunar surface. It will serve as a staging point for deep space exploration. Autonomous Systems technologies provide the means of migrating mission control from Earth to spacecraft, habitats, and robotic explorers. This is enhancing for missions in the Earth-Lunar neighborhood and enabling for deep space missions. Long light-time delays, for example up to 42 minutes round-trip between Earth and Mars, require time-critical control decisions to be closed on-board autonomously, rather than through round-trip communication to Earth mission control. For robotic explorers this will be done through automation, while for human missions this will be done through astronaut-automation teaming.

Long-term crewed spacecraft and habitats, such as the International Space Station, are so complex that a significant portion of the crew's time is spent keeping it operational even under nominal conditions in low-Earth orbit, while still requiring significant real-time support from Earth. The considerable challenge is to migrate the knowledge and capability embedded in current Earth mission control, with tens to hundreds of human specialists ready to provide instant knowledge, to on-board automation that teams with astronauts to autonomously manage spacecraft and habitats. For outer planet robotic explorers, the opportunity is to autonomously and rapidly respond to dynamic environments in a timely fashion.

Specific innovations being sought in this solicitation are described below:

- Deep neural nets and neuromorphic processing have substantial benefit for in-space autonomy and cognition. Advances in signal and data processing for neuromorphic processors promise to enable artificial intelligence and machine learning for autonomous spacecraft operations.

- Intelligent autonomous agent cognitive architectures are sought after as an onboard spacecraft capability. Their open, modular framework has the potential to enable decision-making under uncertainty and learn in a manner that the performance of the system is assured and improves over time.
- Onboard fault management capabilities, such as onboard sensing, computing, algorithms, and models are a critical element of health management for future spacecraft. Offboard components that contribute to onboard fault management are also relevant.
- Improvements in autonomous systems performance are needed, in the context of multi-agent Cyber-Physical-Human (CPH) teams with either some independence under general human direction or complete independence. This capability will help to address the need for integrated data uncertainty management and a robust representation of “trustworthy and trusted” autonomy in space.
- The control and coordination of swarms such as planetary rovers, flyers, and in-space vehicles in dynamic environments is emerging as a critical technological need for future space missions.
- Gateway is seeking capabilities using autonomy and artificial intelligence for operations and health management individually and/or jointly under crewed and un-crewed conditions.

Please refer to the description and references of each subtopic for further detail to guide development of proposals within this technically diverse focus area.

T10.03 Coordination and Control of Swarms of Space Vehicles (STTR)

Lead Center: JPL
Participating Center(s): ARC, LaRC

Scope Title: Enabling Technologies for Swarm of Space Vehicles

Scope Description:
This subtopic is focused on developing and demonstrating technologies that enable cooperative operation of swarms of space vehicles in a realistic dynamic environment with limited and realistic communications. Primary interest is in technologies appropriate for low-cardinality (4- to 15-vehicle) swarms of small spacecraft, planetary rovers, and flyers (e.g., Mars helicopter), and underwater vehicles (e.g., Ocean Worlds explorers of the future). Large swarms and other platforms are of interest if well motivated in connection to NASA’s Strategic Plan and needs identified in decadal surveys.

The proposed technology must be motivated by a well-defined design reference mission (DRM) presented in the proposal with clear connection to the needs identified in decadal surveys. The proposed DRM is used to derive the high-level requirements for the technology development effort. Examples of such DRMs can be found in the NASA Science Mission Directorate Autonomy workshop.

Areas of high interest are:

- Distributed estimation for exploration and inspection of a target object or phenomena by various assets with heterogeneous sensors and from various vantage points.
- High-precision relative localization and time synchronization in orbit and on the planet's surface.
- Operations concepts and tools that provide situational awareness and commanding capability for a team of spacecraft or swarm of robots on another planet.
- Coordinated task recognition and planning, operation, and execution with realistic communication limitations.

The proposed technology (hardware and software) should be modular with well-defined interfaces that can be integrated in a variety of missions. Simulation software and general control architectures and technology outside of the areas of interest, identified above, are out of scope for this call.

NASA has plans to purchase services for delivery of payloads to the Moon through the Commercial Lunar Payload Services (CLPS) contract. Under this subtopic, proposals may include efforts to develop payloads for flight demonstration of relevant technologies in the lunar environment. The CLPS payload accommodations will vary depending on the particular service provider and mission characteristics. Additional information on the CLPS program and providers can be found at this link: https://www.nasa.gov/content/commercial-lunar-payload-services. CLPS missions will typically carry multiple payloads for multiple customers. Smaller, simpler, and more self-sufficient payloads are more easily accommodated and would be more likely to be considered for a NASA-sponsored flight opportunity. Commercial payload delivery services may begin soon, and flight opportunities are expected to continue well into the future. In future years, it is expected that larger and more complex payloads will be accommodated. Selection for an award under this solicitation will not guarantee selection for a lunar flight opportunity.

Expected TRL or TRL Range at completion of the Project: 4 to 6

Primary Technology Taxonomy:
Level 1: TX 10 Autonomous Systems
Level 2: TX 10.3 Collaboration and Interaction

Desired Deliverables of Phase I and Phase II:

- Research
- Software
- Prototype

Desired Deliverables Description:
Phase I awards will be expected to develop theoretical frameworks, algorithms, and software simulation and to demonstrate feasibility (TRL 3). Phase II awards will be expected to demonstrate capability on a hardware or hardware-in-the-loop (HIL) testbed (TRL 4 to 6).

- Phase I and Phase II: Algorithms and research results clearly depicting metrics and performance of the developed technology in comparison to state of the art (SOA). **Software implementation of the developed solution along with simulation platform must be included as a deliverable.**
- Phase II only: Prototype of the sensor or similar if the proposal is to develop such subsystem as a Phase II deliverable.

State of the Art and Critical Gaps:
Technologies developed under this subtopic enable and are critical for multi-robot missions for collaborative planetary exploration. Distributed task recognition, allocation, and execution, collaborative motion planning for larger science return, and distributed estimation and shared common operational picture are examples of technology needs in this area. We are interested in technologies that are robust under realistic space environment communication limitations, frequency, and dropouts.

These technologies also enable successful formation flying spacecraft missions, robust distributed guidance, navigation, and control (GNC), precision relative navigation, distributed tasking and execution, and distributed estimation of the swarm state as well as the science target are examples of the technology gaps in this area.

Relevance / Science Traceability:
Subtopic technology directly supports NASA Space Technology Roadmap TA4 (4.5.4 Multi-Agent Coordination, 4.2.7 Collaborative Mobility, and 4.3.5 Collaborative Manipulation) and Strategic Space Technology Investment Plan (Robotic and Autonomous Systems: Relative GNC and Supervisory control of an S/C team). SMD's 2018 Workshop on Autonomy for Future NASA Science Missions [17] has identified a number of DRMs with science enabling multi-spacecraft systems.

In addition, the technology developed is also relevant to the following concepts:

- Cooperative Autonomous Distributed Robotic Explorers (CADRE) is a STMD-funded lunar multi-agent autonomy technology demonstration where a group of robots collaboratively explore the lunar surface. This promises a low-cost swarm of networked robots that can collaboratively explore lava tubes and other hard-to-reach areas on planet surfaces.
- Distributed Spacecraft Autonomy is a technology demonstration mission to show multiple spacecraft can be autonomously tasked and execute decentralized measurement of scientific data.
- Multi-robot follow-on to the Mars 2020 and Mars helicopter programs are likely to necessitate close collaboration among flying robots as advanced scouts and rovers.
- A convoy of spacecraft is being considered in which the lead spacecraft triggers detailed measurement of a very dynamic event by the following spacecraft.
- Multiple concepts for distributed space telescopes and distributed synthetic apertures are proposed that rely heavily on coordination and control technologies developed under this subtopic.

References:

1. D. P. Scharf, F. Y. Hadaegh and S. R. Ploen, "A survey of spacecraft formation flying guidance and control (part 1): guidance," Proceedings of the 2003 American Control Conference, Denver, CO, USA, 2003, pp. 1733-1739.
2. D. P. Scharf, F. Y. Hadaegh and S. R. Ploen, "A survey of spacecraft formation flying guidance and control (part II): control," Proceedings of the 2004 American Control Conference, Boston, MA, USA, vol. 4, 2004, pp. 2976-2985.
3. Evan Ackerman, "PUFFER: JPL's Pop-Up Exploring Robot; This little robot can go where other robots fear to roll," https://spectrum.ieee.org/automaton/robotics/space-robots/puffer-jpl-popup-exploring-robot (link is external).
4. "Precision Formation Flying," https://scienceandtechnology.jpl.nasa.gov/precision-formation-flying
5. "Mars Helicopter to Fly on NASA's Next Red Planet Rover Mission," https://www.nasa.gov/press-release/mars-helicopter-to-fly-on-nasa-s-next-red-planet-rover-mission/
6. Duncan Miller, Alvar Saenz-Otero, J. Wertz, Alan Chen, George Berkowski, Charles F. Brodel, S. Carlson, Dana Carpenter, S. Chen, Shiliang Cheng, David Feller, Spence Jackson, B. Pitts, Francisco Pérez, J. Szuminski and S. Sell, "SPHERES: A Testbed for Long Duration Satellite Formation Flying In MicroGravity Conditions." Proceedings of the AAS/AIAA Space Flight Mechanics Meeting, AAS 00-110, Clearwater, FL, Jan. 2000.
7. S. Bandyopadhyay, R. Foust, G. P. Subramanian, S.-J. Chung and F. Y. Hadaegh, "Review of Formation Flying and Constellation Missions Using Nanosatellites," Journal of Spacecraft and Rockets, vol. 53, no. 3, 2016, pp. 567-578.
8. S. Kidder, J. Kankiewicz and T. Vonder Haar, "The A-Train: How Formation Flying is Transforming Remote Sensing," https://atrain.nasa.gov/publications.php
9. T. Huntsberger, A. Trebi-Ollennu, H. Aghazarian, P. Schenker, P. Pirjanian and H. Nayar, "Distributed Control of Multi-Robot Systems Engaged in Tightly Coupled Tasks," Autonomous Robots 17, 79–92, 2004.
10. Space Studies Board, "Achieving Science with CubeSats: Thinking Inside the Box," National Academies of Sciences, Engineering, and Medicine, 2016, http://sites.nationalacademies.org/SSB/CompletedProjects/SSB_160539
11. Planetary Science Decadal Survey 2013-2022, https://solarsystem.nasa.gov/science-goals/about/
12. Astro2010: The Astronomy and Astrophysics Decadal Survey, https://science.nasa.gov/astrophysics/special-events/astro2010-astronomy-and-astrophysics-decadal-survey
13. Astro2020: Decadal Survey on Astronomy and Astrophysics 2020, https://www.nationalacademies.org/our-work/decadal-survey-on-astronomy-and-astrophysics-2020-astro2020
14. Decadal Survey for Earth Science and Applications from Space 2018, https://www.nationalacademies.org/our-work-decadal-survey-for-earth-science-and-applications-from-space

15. R. Levinson, R. Burton, S. Gridnev, C. Adams, D. Celluci, N. Cramer and J. Frank, "Autonomous Consistency Planning for Distributed Space Systems," Proceedings of 35th Annual Small Satellite Symposium, 2021.
16. H. Sanchez, D. McIntosh, H. Cannon, C. Pires, J. Sullivan, S. D'Amico and B. O'Connor, "Starling1: Swarm Technology Demonstration," 2018.
17. F. Tan and M. Seablom, 2018 Workshop on Autonomy for Future NASA Science Missions: Output and Results. https://science.nasa.gov/technology/2018-autonomy-workshop/output-results

T10.04 Autonomous Systems and Operations for the Lunar Orbital Platform-Gateway (STTR)

Lead Center: ARC
Participating Center(s): JSC, KSC, SSC

Scope Title: Artificial Intelligence for the Gateway Lunar Orbital Platform

Scope Description:
Gateway is a planned lunar-orbit spacecraft that will have a power and propulsion system, a small habitat for the crew, a docking capability, an airlock, and logistics modules. Gateway is expected to serve as an intermediate way station between the Orion crew capsule and lunar landers as well as a platform for both crewed and un-crewed experiments. Gateway is also intended to test technologies and operational procedures for suitability on long-duration space missions such as a mission to Mars. As such, it will require new technologies such as autonomous systems to run scientific experiments onboard, including biological experiments; perform system health management, including caution and warning; autonomous data management; and other functions. In contrast to the International Space Station, Gateway is much more representative of lunar and deep space missions—e.g., the radiation environment.

This subtopic solicits autonomy, artificial intelligence, and machine learning technologies to manage and operate engineered systems to facilitate long-duration space missions, with the goal of testing proposed technologies on Gateway. The current concept of operations for Gateway anticipates un-crewed (dormant) periods of up to 9 months. For this reason, technologies developed under this subtopic must be capable of or enable long-term, mostly unsupervised autonomous operation. While crews are present, technologies need to augment the crews' abilities, allow more autonomy from Earth-based Mission Control, and learn how to perform or improve their performance of autonomous operations by observing the crews. Additionally, the technologies may need to allow for coordination with the Orion crew capsule, lunar landers, Earth, and their various systems and subsystems.

Examples of needs include but are not limited to:
1. Autonomous operations and tending of science payloads, including environmental monitoring and support for live biological samples, and in situ automated analysis of science experiments.
2. Prioritizing data for transmission from Gateway—Given communications limitations, it may be necessary to determine what data can be stored for transmission when greater bandwidth is available, and what data can be eliminated as it will turn out to be useless, based on criteria relevant to the conduct of science and/or maintenance of the physical assets. Alternatively, it may be useful to adaptively compress data for transmission from the Gateway, which could include scientific experiment data and status, voice communications, scientific experiment data and status, and/or systems health management data.
3. Autonomous operations and health management of Gateway—When Gateway is unoccupied, unexpected events or faults may require immediate autonomous detection and response, demonstrating this capability in the absence of support from Mission Control (which is enabling for future Mars missions and time-critical responses in the lunar environment as well). Efforts to develop smart habitats that will allow long-term human presence on the Moon and Mars such as the Space Technology Research Institutes (https://www.nasa.gov/press-release/nasa-selects-two-new-space-tech-research-institutes-for-smart-habitats) are relevant.

Expected TRL or TRL Range at completion of the Project: 2 to 6

Primary Technology Taxonomy:
Level 1: TX 10 Autonomous Systems
Level 2: TX 10.3 Collaboration and Interaction

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Software
- Hardware

Desired Deliverables Description:
The deliverables range from research results to prototypes demonstrating various ways that autonomy and artificial intelligence (e.g., automated reasoning, machine learning, and discrete control) can be applied to aspects of Gateway operations and health management individually and/or jointly. The deliverables also must demonstrate variable levels of autonomy allowing work during long periods of un-crewed operation and in concert with crews as appropriate. As one example, for autonomous biological science experiments, the prototype could include hardware to host live samples for a minimum of 30 days that provide monitoring and environmental maintenance, as well as software to autonomously remedy issues with live science experiments. As another example, software that monitors the Gateway habitat while un-crewed, automatically notifies of any off-nominal conditions, and when the crew arrives, transitions Gateway from quiescent status to a status capable of providing the crew with life support. As another example, machine learning from the data stream of Gateway sensors to determine anomalous versus nominal conditions and prioritize and compress data communications to Earth.

Phase I deliverables minimally include a detailed concept for autonomy technology to support Gateway operations such as experiments. Prototypes of software and/or hardware are strongly encouraged.

Phase II deliverables will be full technology prototypes that could be subsequently matured for deployment on Gateway.

State of the Art and Critical Gaps:
The current state of the art in human spaceflight allows for autonomous operations of systems of relatively limited scope, involving only a fixed level of autonomy (e.g., amount of human involvement needed), and learning at most one type of function (e.g., navigation). Gateway will require all operations and health management to be autonomous at different levels (almost fully autonomous when no astronauts are on board versus limited autonomy when astronauts are present), the autonomy to learn from human operations, and the autonomy across all functions. The autonomy will also need to adapt to new missions and new technologies. Proposers should be aware of and consider potential interfaces and interactions such as those between Gateway and smart habitats. Proposers may want to be aware of pertinent related efforts such as those being conducted by the Space Technology Research Institutes.

As NASA continues to expand with the eventual goal of Mars missions, the need for autonomous tending of science payloads will grow substantially. To address the primary health concerns for the crews on these missions, it is necessary to conduct science in the most relevant environment. Acquisition of this type of data will be challenging while the Gateway and Artemis missions are being performed due to limited crewed missions and limited crew time.

Relevance / Science Traceability:

Gateway and other space-station-like assets in the future will need the ability to execute an increasingly large number of autonomous operations over longer durations with higher degrees of complexity and less ability to have human intervention due to increasing duration space missions such as missions to Mars.

References:

1. Basic Moon to Mars Background: https://www.nasa.gov/topics/moon-to-mars/lunar-outpost
2. Basic Gateway Background: https://www.nasa.gov/topics/moon-to-mars/lunar-gateway
3. Crusan, J. C.; Smith, R. M.; Craig, D. A.; Caram, J. M.; Guidi, J.; Gates, M.; Krezel, J. M.; and Herrmann, N., 2018. Deep Space Gateway concept: extending human presence into cislunar space. In *Proceedings of the IEEE Aerospace Conference*. https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=8396541
4. Autonomous Biological Systems (ABS) Experiments: https://aip.scitation.org/doi/pdf/10.1063/1.54854 (link is external).
5. Deep Space Gateway Science Opportunities: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20180001581.pdf
6. Conducting Autonomous Experiments in Space: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20180004314.pdf
7. Space Technology Research Institutes: https://www.nasa.gov/press-release/nasa-selects-two-new-space-tech-research-institutes-for-smart-habitats

T10.05 Integrated Data Uncertainty Management and Representation for Trustworthy and Trusted Autonomy in Space (STTR)

Lead Center: LaRC
Participating Center(s): ARC, GSFC, JPL

Scope Title: Integrated Data Uncertainty Management and Representation for Trustworthy and Trusted Autonomy in Space

Scope Description:
Multi-agent Cyber-Physical-Human (CPH) teams in future space missions must include machine agents with a high degree of autonomy. In the context of this subtopic, by “autonomy” we mean the capacity and authority of an agent (human or machine) for independent decision making and execution in a specified context. We refer to machine agents with these attributes as autonomous systems (AS). In multi-agent CPH teams, humans may serve as remote mission supervisors or as immediate mission teammates, along with AS. AS may function as teammates with specified independence, but under the ultimate human direction. Alternatively, AS may exercise complete independence in decision making and operations in pursuit of given mission goals; for instance, for control of un-crewed missions for planetary infrastructure development in preparation for human presence, or maintenance and operation of crew habitats during the crew’s absence.

In all cases, trustworthiness and trust are essential in CPH teams. The term “trustworthiness” denotes the degree to which the system performs as intended and does not perform prohibited actions in a specified context. “Trust” denotes the degree of readiness by an agent (human or machine) to accept direction or advice from another agent (human or machine), also in a specified context. In common sense terms, trust is a confidence in a system’s trustworthiness, which in turn, is the ability to perform actions with desired outcomes.

Because behind every action lies a decision-making problem, trustworthiness of a system can be viewed in terms of the soundness of decision making by the system participants. Accurate and relevant information forms the basis of sound decision making. In this subtopic, we focus on data that inform CPH team decision making, both in human-machine and machine-machine interactions, from two perspectives: the quality of the data and the representation of the data in support of trusted human-machine and machine-machine interactions.

We consider data exchanges in multi-agent CPH teams that include AS. Data exchanges in multi-agent teams must be subject to the following conditions:

- Known data accuracy, noise characteristics, and resolution as a function of the physical sensors in relevant environments.
- Known data accuracy, noise characteristics, and resolution as a function of data interpretation if the contributing sensors have a perception component or if data are delivered to an agent via another perception engine (e.g., visual recognition based on deep learning).
- Known data provenance and integrity.
- Dynamic anomaly detection in data streams during operations.
- Comprehensive uncertainty quantification (UQ) of data from a single source.
- Data fusion and combined UQ if multiple sources of data are used for decision making.
- If data from either a single source or fused data from multiple sources are used for decision making by an agent (human or machine), the data and the attendant UQ must be transformed into a representation conducive to and productive for decision making. This may include data filtering, compression, or expansion, among other approaches.
- UQ must be accompanied by a sensitivity analysis of the mission/operation/action goals with respect to uncertainties in various data, to enable appropriate risk estimation and risk-based decision making by relevant agents, human or machine.
- Tools for real-time, a priori, and a posteriori data analysis, with explanations relevant to participating agents. For instance, if machine learning is used for visual data perception in decision making by humans, methods of interpretable or explainable AI (XAI) may be in order.

We note that deep learning and machine learning, in general, are not the chief focus of this subtopic. The techniques are mentioned as an example of tools that may participate in data processing. If such tools are used, the representation of the results to decision makers (human or machine) must be suitably interpretable and equipped with UQ.

Addressing the entire set of the conditions listed above would likely be impractical in a single proposal. Therefore, proposers may offer methods and tools for addressing a subset of conditions.

Proposers should offer both a general approach to achieving a chosen subset of the listed conditions and a specific application of the general approach to appropriate data types. The future orbiting or surface stations are potential example platforms, because the environment would include a variety of AS used for habitat maintenance when the station is uninhabited, continual system health management, crew health, robotic assembly, and cyber security, among other functions. However, the proposers may choose any relevant design reference mission for demonstration of proposed approaches to integrated data uncertainty management and representation, subject to a convincing substantiation of the generalizability and scalability of the approach to relevant practical systems, missions, and environments.

Expected TRL or TRL Range at completion of the Project: 2 to 4

Primary Technology Taxonomy:
Level 1: TX 10 Autonomous Systems
Level 2: TX 10.1 Situational and Self Awareness

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Software

Desired Deliverables Description:
Since UQ and management in data is an overarching theme in this subtopic, an analysis of uncertainties in the processes and data must be present in all final deliverables, both in Phases I and II.

Phase I: For the areas selected in the proposal, the following deliverables would be in order:

1. Thorough but succinct analysis of the state of the art in the proposed area under investigation.
2. Detailed description of the problem used as the context for algorithm development, including substantiation for why this is a representative problem for a set of applications relevant to NASA missions.
3. Detailed description of the approach, including pseudocode, and the attendant design of experiments for testing and evaluation.
4. Hypotheses about the scalability and generalizability of the proposed approach to realistic problems relevant to NASA missions.
5. Preliminary software and process implementation.
6. Preliminary demonstration of the software.
7. Thorough analysis of performance and gaps.
8. Detailed plan for Phase II, including the design reference mission and the attendant technical problem.
9. Items 1 to 8 documented in a final report for Phase I.

Phase II:

1. Detailed description and analysis of the design reference mission and the technical problem selected in Phase I, in collaboration with NASA Contracting Officer Representative (COR)/Technical Monitor (TM).
2. Detailed description of the approach/algorithms developed further for application to the Phase II design reference mission and problem, including pseudocode and the design of experiments for testing and evaluation.
3. Demonstration of the algorithms, software, methods, and processes.
4. Thorough analysis of performance and gaps, including scalability and applicability to NASA missions.
5. Resulting code.
6. Detailed plan for potential Phase III.
7. Items 1 to 5 documented in a final report for Phase II.

State of the Art and Critical Gaps:
Despite progress in real-time data analytics, serious gaps remain that will present an obstacle to the operation of systems in NASA missions that require heavy participation of AS, both in human-machine teams and in un-crewed environments, whether temporary or permanent. The gaps come under two main categories:

1. Quality of the information based on various data sources—Trustworthiness of the data is essential in making decisions with desired outcomes. This gap can be summarized as the lack of reliable and actionable UQ associated with data, as well as the difficulty of detecting anomalies in data and combining data from disparate sources, ensuring appropriate quality of the result.
2. Representation of the data to decision makers (human or machine) that is conducive to trustworthy decision making—We distinguish raw data from useful information of appropriate complexity and form. Transforming data, single-source or fused, into information productive for decision making, especially by humans, is a challenge.

Specific gaps are listed under the Scope Description as conditions the subsets of which must be addressed by proposers.

Relevance / Science Traceability:
The technologies developed as a result of this subtopic would be directly applicable to the Space Technology Mission Directorate (STMD), Science Mission Directorate (SMD), Human Exploration and Operations Mission Directorate (HEOMD), and Aeronautics Research Mission Directorate (ARMD), as all of these mission directorates are heavy users of data and growing users of AS. For instance, the Gateway mission will need a significant presence of AS, as well as human-machine team operations that rely on AS for habitat maintenance when the station is uninhabited, continual system health management, crew health, robotic assembly, among other functions. Human presence on the Moon surface will require similar functions, as well as future missions

to Mars. All trustworthy decision making relies on trustworthy data. This topic addresses gaps in data trustworthiness, as well as productive data representation to human-machine teams for sound decision making.

The subtopic is also directly applicable to ARMD missions and goals because future airspace will heavily rely on AS. Thus, the subtopic is applicable to such projects as Airspace Operations and Safety Program (AOSP)/Advanced Air Mobility (AAM) and Air Traffic Management—eXploration (ATM-X). The technologies developed as a result of this subtopic would be applicable to the National Airspace System (NAS) in the near future as well, because of the need to process data related to vehicle and system performance.

References:

1. Frontiers on Massive Data Analysis, NRC, 2013.
2. NASA OCT Technology Roadmap, NASA, 2015.
3. NASA AIST Big Data Study, NASA/JPL, 2016.
4. IEEE Big Data Conference, Data and Computational Science Big Data Challenges for Earth and Planetary Science Research, IEEE, 2016.
5. Planetary Science Informatics and Data Analytics Conference, April 2018.
6. David L. Hall, Alan Steinberg: Dirty Secrets in Multisensor Data Fusion, The Pennsylvania State University Applied Research Laboratory. https://apps.dtic.mil/dtic/tr/fulltext/u2/a392879.pdf
7. Martin Keenan: The Challenge and the Opportunity of Sensor Fusion, a Real Gamechanger, 5G Technology World, February 20, 2019. https://www.5gtechnologyworld.com/the-challenge-and-the-opportunity-of-sensor-fusion-a-real-gamechanger/

Focus Area 4 Robotic Systems for Space Exploration

This focus area includes development of robotic systems technologies (hardware and software) that will enable and enhance future space exploration missions. In the coming decades, robotic systems will continue to change the way space is explored. Robots will be used in all mission phases: as independent explorers operating in environments too distant or hostile for humans, as precursor systems operating before crewed missions, as crew helpers working alongside and supporting humans, and as caretakers of assets left behind. As humans continue to work and live in space, they will increasingly rely on intelligent and versatile robots to perform mundane activities, freeing human, and ground control teams to tend to more challenging tasks that call for human cognition and judgment. Technologies are needed for robotic systems to improve transport of crew, instruments, and payloads on planetary surfaces, on and around small bodies, and in-space. This includes hazard detection, sensing/perception, active suspension, grappling/anchoring, legged locomotion, robot navigation, end-effectors, propulsion, and user interfaces.

Innovative robot technologies provide a critical capability for space exploration. Multiple forms of mobility, manipulation and human-robot interaction offer great promise in exploring planetary bodies for science investigations and to support human missions. Enhancements and potentially new forms of robotic systems can be realized through advances in component technologies, such as actuation and structures (e.g. 3D printing). Mobility provides a critical capability for space exploration. Multiple forms of mobility offer great promise in exploring planetary bodies for science investigations and to support human missions. Manipulation provides a critical capability for positioning crew members and instruments in space and on planetary bodies. Robotic manipulation allows for the handling of tools, interfaces, and materials not specifically designed for robots, and it provides a capability for drilling, extracting, handling, and processing samples of multiple forms and scales. This increases the range of beneficial tasks robots can perform and allows for improved efficiency of operations across mission scenarios. Furthermore, manipulation is important for human missions, human precursor missions, and unmanned science missions. Moreover, sampling, sample handling, transport, and distribution to instruments, or instrument placement directly on in-place rock or regolith, is important for robotic missions to locales too distant or dangerous for human exploration.

Future space missions may rely on co-located and distributed teams of humans and robots that have complementary capabilities. Tasks that are considered "dull, dirty, or dangerous" can be transferred to robots, thus relieving human crew members to perform more complex tasks or those requiring real-time modifications due to contingencies. Additionally, due to the limited number of astronauts anticipated to crew planetary exploration missions, as well as their constrained schedules, ground control will need to remotely supervise and assist robots using time-delayed and limited bandwidth communications. Advanced methods of human-robot interaction over time delay will enable more productive robotic exploration of the more distant reaches of the solar system. This includes improved visualization of alternative future states of the robot and the terrain, as well as intuitive means of communicating the intent of the human to the robotic system.

T4.01 Information Technologies for Intelligent and Adaptive Space Robotics (STTR)

Lead Center: ARC
Participating Center(s): GSFC, JSC

Scope Title: Develop Information Technologies to Improve Space Robots

Scope Description:
Extensive and pervasive use of robots can significantly enhance space exploration and space science, particularly for missions that are progressively longer, complex, and distant. The performance of these robots is directly linked to the quality and capability of the information technologies used to build and operate them. With few exceptions, however, current information technology used for state-of-the-art robotics is designed only to meet the needs of terrestrial applications and environments.

The objective of this subtopic, therefore, is to encourage the adaptation, maturation, and retargeting of terrestrial information technologies for space robotics. Proposals should address at least one of the following research areas:

1. **Perception systems for autonomous robot operations** in man-made environments (inside spacecraft or habitats) and unstructured, natural environments (Earth, Moon, Mars). The primary objective is to significantly increase the performance and robustness of perception capabilities such as object/hazard identification, localization, mapping, etc., through new avionics (including commercial-off-the-shelf (COTS) processors for use in space), sensors, and/or software. Proposals for small size, weight, and power (SWAP) systems or technology that can operate on existing radiation hardened and tolerant processors are particularly encouraged.
2. **Robot user interfaces** that facilitate distributed human-robot teams, summarization and notification, and explanation. The primary objective is to enable more effective and efficient interaction with autonomous and remotely operated robots via discrete commands or supervisory control. User interface technology that helps optimize operator workload or improve human understanding of autonomous robot actions are particularly encouraged. Note: proposals to develop user interfaces for direct teleoperation (manual control), augmented/virtual reality, or telepresence are not solicited and will be considered nonresponsive.
3. **Robot Operating System v2 (ROS 2) for space robots**. The primary objective is to reduce the risk of deploying, integrating, and verifying and validating the open-source ROS 2 for future space missions. Proposals that develop software technology that can facilitate integration of ROS 2 with common flight software (Core Flight Software, Integrated Test and Operations System (ITOS), etc.), methods to improve the suitability of ROS 2 for use with current flight computing (i.e., radiation hardened and tolerant processors), or tools/process to make ROS 2 (or a subset) ready for near-term flight missions are particularly encouraged. Note: proposals should consider compatibility with the Space ROS project (STMD Game Changing Development program, ACO award).

Proposals are particularly encouraged to develop technologies applicable to robots of similar archetypes and capabilities to current NASA robots, such as Astrobee, Perseverance (Mars 2020), VIPER, etc.

Expected TRL or TRL Range at completion of the Project: 4 to 6

Primary Technology Taxonomy:
Level 1: TX 04 Robotics Systems
Level 2: TX 04.6 Robotics Integration

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Hardware
- Software

Desired Deliverables Description:
Desired Deliverables (Phase I)
Proposers should develop technologies that can be demonstrated with or integrated into existing NASA research robots or projects to maximize relevance and infusion potential.

1. Identify scenarios, use cases, and requirements.
2. Define specifications.
3. Develop preliminary design.

Desired Deliverables (Phase II)

1. Develop prototypes (hardware and/or software).
2. Demonstrate and evaluate prototypes in real-world settings.
3. Deliver prototypes to NASA.

State of the Art and Critical Gaps:
Future exploration and science missions will require robots to operate in more difficult environments, carry out more complex tasks, and handle more dynamic and varying operational constraints than the current state of the art, which relies on low-performance, rad-hard computing and execution of preplanned command sequences. To achieve these capabilities, numerous new information technologies need to be developed, including high-performance space computing, autonomy algorithms, and advanced robot software systems (onboard and offboard).

For example, in contrast to the International Space Station, which is continuously manned, the Gateway is expected to only be intermittently occupied—perhaps as little as 8% of the time. Consequently, there is a significant need for the facility to be robotically tended, to maintain and repair systems in the absence of a human crew. These robots will perform a wide range of caretaking work including inspection, monitoring, routine maintenance, and contingency handling. To do this, significant advances will need to be made in autonomous perception and robot user interfaces, particularly to handle mission-critical and safety-critical operations.

As another example, a mission to explore and map interior oceans beneath the ice on Europa will require a robot to penetrate an unknown thickness of ice, autonomously carry out a complex set of activities, and navigate back to the surface in order to transmit data back to Earth. The robot will need to perform these tasks with minimal human involvement and while operating in an extremely harsh and dynamic environment. To do this, significant advances will need to be made in autonomous perception and onboard software, particularly to compensate for poor (bandwidth-limited, high-latency, intermittent) communications and the need for high-performance autonomy.

Relevance / Science Traceability:
The development of information technology for intelligent and adaptive space robotics is well aligned with NASA goals for robotics. This development directly addresses multiple areas (TA4, TA7, TA11) of the 2015 NASA Technology Roadmap and multiple areas (TX4, TX10, TX11) of the 2020 NASA Technology Taxonomy.

Additionally, this development is directly aligned with multiple portions of the NASA Autonomous Systems SCLT (Systems Capability Leadership Team) technology taxonomy. Moreover, this development directly addresses a core capability "Autonomous Systems and Robotics" of the Space Technology Mission Directorate (STMD) technology development. Finally, the technology is directly aligned with the needs of numerous projects and programs in the Aeronautics Research Mission Directorate (ARMD), Human Exploration and Operations Mission Directorate (HEOMD), Science Mission Directorate (SMD), and STMD.

- ARMD: The technology can be applied to a broad range of unmanned aerial systems (UAS), including both small-scale drones and Predator/Global Hawk type systems. The technology can also be potentially infused into other flight systems that include autonomous capabilities, such as Urban Air Mobility vehicles.
- HEOMD: The technology is directly relevant to "caretaker" robots, which are needed to monitor and maintain human spacecraft (such as the Gateway) during dormant/uncrewed periods. The technology can also be used by precursor lunar robots to perform required exploration work prior to the arrival of humans on the Moon.
- SMD: The technology is required for future missions in Earth Science, Heliophysics, and Planetary Science (including the Moon, icy moons, and ocean worlds) that require higher performance and autonomy than currently possible. In particular, missions that must operate in dynamic environments, or measure varying phenomena, will require the technology developed by this subtopic.
- STMD: The technology is directly applicable to numerous current mid-TRL (Game Changing Development program) and high-TRL (Technology Demonstration Mission program) Research and Development (R&D) activity.

References:

1. https://www.nasa.gov/astrobee
2. M. Bualat, et al., "Astrobee: A new tool for ISS operations." In Proceedings of AIAA SpaceOps, Marseille, France, 2018.
3. https://mars.nasa.gov/mars2020
4. https://www.nasa.gov/viper
5. T. M. Lovelly, "Comparative Analysis of Space-Grade Processors." University of Florida dissertation, 2017.
6. G. Lentaris, et al., "High-Performance Embedded Computing in Space: Evaluation of Platforms for Vision-Based Navigation." In Journal of Aerospace Information Systems, Vol. 15, No. 4, April 2018.

T7.04 Lunar Surface Site Preparation (STTR)

Lead Center: KSC
Participating Center(s): LaRC

Scope Title: Bulk Regolith Infrastructure

Scope Description:
It is envisioned that some of the first possible lunar infrastructure will be structures composed of bulk regolith and rocks. The intent of this subtopic is to develop lunar civil engineering technologies (designs, processes, etc.) that produce such structures, and to develop concepts of operations (ConOps) for their construction in the south polar region of the Moon. This is the lunar equivalent of terrestrial “Earth Works.” Earth-based civil engineering processes and related technologies are not directly applicable to the lunar environment, therefore new lunar civil engineering technologies must be developed.

The desired outcome of this effort is “Regolith Works,” which are engineered surface features and structures that function as Artemis Program risks mitigation infrastructure. Regolith Works are sought for scaled lunar construction demonstrations and to guide the development of robotic equipment that will build the infrastructure. The following lunar civil engineered structures are of interest to NASA. Proposers are welcome to suggest other regolith-based infrastructure concepts. Construction materials and processes that go beyond manipulation of bulk regolith and rocks are not in scope for this subtopic.

- Bulk regolith-based launch/landing zones designed to minimize risks associated with landing/launching on unprepared surfaces for (Commercial Lunar Payload Services) CLPS and (Human Landing System) HLS vehicles.
- Rocket Plume Surface Interaction (PSI) ejecta and blast protection structures.
- Regolith base and subgrade for supporting hardened launch/landing pads, towers, habitats and other in situ constructed structures.
- Pathways for improved trafficability.
- Solar Particle Event (SPE) and Galactic Cosmic Ray (GCR) shielding structures.
- Structures for access to subgrade (e.g., trenches, pits).
- Emplaced regolith overburden on structures and equipment.
- Meteoroid impact protection structures.
- Topographical features for terrain relative guidance for flight and surface vehicles.
- Flat and level operational surfaces for equipment positioning, regularly accessed locations, and dust mitigation applications.
- Sloped regolith ramps for access to challenging locations.
- Utility corridors (e.g., electrical, comm, fluids).
- Shade structures.
- Elevated operational surfaces.

Exact requirements for the full-scale bulk regolith structures are not yet known. Assumptions should be made with supporting rationale to enable initial designs. Specification of lunar civil engineering design criteria should be provided including geotechnical properties.

Tests and validated models/simulations should be developed to characterize the regolith infrastructure performance in its intended applications in lunar environments. For example, effects of ejecta impingement upon proposed PSI ejecta protection structures should be characterized including phenomenon such as erosion or secondary ejecta trajectories.

Development of PSI modeling capabilities is not in scope for this subtopic, but collaboration with ongoing PSI modeling efforts is welcome. Information on PSI characteristics can be obtained in the peer-reviewed literature and public NASA reports in the reference section.

ConOps should be developed to define the sequence of steps to complete construction tasks. The ConOps should begin with the natural lunar surface including hills, valleys, and surface and subsurface rocks, and end with the completed bulk regolith infrastructure verified to meet design criteria. A sequence of all required functions of robotic systems and implements should be defined to achieve the task. References to recommended existing spaceflight or protype hardware should be provided for each function. In cases where hardware does not exist, conceptual implement designs should be proposed, and critical functions demonstrated in laboratory environments. Concepts should be appropriate for a CLPS scale demonstration mission on the lunar surface (e.g., 25 kg overall mass, 8 kg budget for implements). Assume that the implements would attach to an existing modular mobility platform with interfaces at the forward and aft position. A depiction of the integrated construction system concept should be provided.

Proposers may select one or more structures of interest to develop. Infrastructure designs that maximize risk reduction for the Artemis Program will be prioritized. ConOps that show promise for implementation by a single, compact, robotic construction system will rank high. Additionally, concepts that employ the high TRL implements will be prioritized. NASA is seeking bulk regolith infrastructure that can be demonstrated in the near term.

Research institute partnering is anticipated to provide analytical, research, and engineering support to the proposers. Examples may include applying civil engineering principles and planning methods, identification and development of needed standards or specifications for lunar structures and operations, regolith interaction modeling, development of analytical models and simulations for verification of system performance, and methods for the design and prototyping of hardware and associated software.

Expected TRL or TRL Range at completion of the Project: 2 to 5

Primary Technology Taxonomy:
Level 1: TX 07 Exploration Destination Systems
Level 2: TX 07.2 Mission Infrastructure, Sustainability, and Supportability

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Hardware
- Software

Desired Deliverables Description:
Phase I must include the civil engineered design of bulk regolith infrastructure including associated testing, modeling, and simulations. Phase I must also include a concept of operations for constructing the infrastructure and verifying the as-built characteristics meet design criteria. An overall construction system concept must be provided. Phase I proposals should target a TRL of 3 for structures and implements.

Phase II deliverables must include prototype demonstration of construction and characterization of bulk regolith infrastructure. This infrastructure construction must be achievable using civil engineering technologies adaptable to robotic systems and implements. Proof of critical functions of the infrastructure and systems must be demonstrated. Structures and systems must be developed to a minimum of TRL 5. Phase II must also include updates to the bulk regolith infrastructure designs, tests, modeling, and simulation based on Artemis Program needs refinement and new information that will be provided by NASA to the selected awardees.

State of the Art and Critical Gaps:
While civil engineering and construction are well established practices on Earth, lunar applications remain at low TRLs. The design requirements and functional capabilities of bulk regolith-based lunar infrastructure are not well defined. To date, very few studies have performed civil engineering designs of bulk regolith infrastructure for lunar surface applications. Tests have been performed on Earth but only for short periods of time and with limited environmental and operational fidelity.

Relevance / Science Traceability:
Construction of bulk regolith infrastructure directly addresses the STMD Strategic Thrust “Land: Increase Access to Planetary Surfaces.” It also addresses the strategic thrust of “Explore: Expand Capabilities Through Robotic Exploration and Discovery.”

References:

1. Plume Surface Interaction (PSI)
   https://www.nasa.gov/directorates/spacetech/game_changing_development/projects/PSI
2. Rocket Plume Interactions for NASA Landing Systems
   https://ntrs.nasa.gov/api/citations/20200000979/downloads/20200000979.pdf
3. Gas-Particle Flow Simulations for Martian and Lunar Lander Plume-Surface Interaction Prediction
   https://doi.org/10.1061/9780784483374.009
4. Understanding and Mitigating Plume Effects During Powered Descents on the Moon and Mars
5. https://baas.aas.org/pub/2021n4i089?readingCollection=7272e5bb

Focus Area 5 Communications and Navigation

NASA seeks proposals to produce innovative technologies in the communications and navigation discipline to support Exploration, Operations, Science, and Space Technology missions, including the eventual return of humans to the Lunar surface. Missions are generating ever-increasing data volumes that require increased performance from communications systems while minimizing spacecraft impact. This requires higher peak throughput from the communications systems with lower flight communication system cost, mass, and power per bit transmitted. Missions to the Moon, Mars, and beyond will require reliable, autonomous, and secure communications systems operating in the radio frequency bands and optical wavelengths to reduce mission operations burden and support data-intensive operations. These missions will rely on enhanced autonomous navigation techniques to support rendezvous and docking; on-orbit servicing, assembly, and manufacturing; and precision landing. This focus area supports the development of novel communications and navigation technologies spanning from radio frequency to optical to quantum communications systems, applications of autonomy and cognition to navigation and networking, data routing and security, and positioning, timing, guidance, navigation, and control techniques that will provide a significant improvement over the current state of the art.

T5.04 Quantum Communications (STTR)

Lead Center: GRC
Participating Center(s): GSFC

Scope Title: Quantum Communications

Scope Description:
NASA seeks to develop quantum networks to support the transmission of quantum information for aerospace applications. This distribution of quantum information could potentially be utilized in secure communication, sensor arrays, and quantum computer networks. Quantum communications may provide new ways to improve sensing the entangling of distributed sensor networks to provide extreme sensitivity for applications such as astrophysics, planetary science, and Earth science. Also of interest are ideas or concepts to support the communication of quantum information between quantum computers over significant free-space distances (greater than 10 km up to geosynchronous equatorial orbit (GEO)) for space applications or supporting linkages between terrestrial fiber-optic quantum networks. Technologies that are needed include quantum memory, quantum entanglement distribution systems, quantum repeaters, high-efficiency detectors, and quantum processors for distributed arrays and integrated systems that bring several of these aspects together using Integrated Quantum Photonics. A key need for all of these are technologies with low size, weight, and power that can be utilized in aerospace applications. Some examples (not all inclusive) of requested innovation include:

- Photonic waveguide integrated circuits for quantum information processing and manipulation of entangled quantum states; requires phase stability, low propagation loss, i.e., <0.1 dB/cm, and efficient fiber coupling, i.e., coupling loss <1.5 dB.
- Waveguide-integrated single-photon detectors for >100 MHz incidence rate, 1-sigma time resolution of <25 ps, dark count rate <100 Hz, and single-photon detection efficiency >50% at highest incidence rate.
- Quantum metrology systems for free space quantum communication sources (state tomography, joint spectrum, coherence, etc.).
- Quantum memory with high buffering efficiency (>50%), storage time (>10 ms), and high fidelity (>0.9), including heralding capability as well as scalability.
- Nondestructive Bell-state measurements.
- Quantum communications via optical orbital angular momentum states.
- High-speed and high-data-rate electronics for recording photon events.

Expected TRL or TRL Range at completion of the Project: 2 to 4

Primary Technology Taxonomy:
Level 1: TX 05 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems
Level 2: TX 05.5 Revolutionary Communications Technologies

Desired Deliverables of Phase I and Phase II:

- Hardware
- Analysis
- Research
- Prototype

Desired Deliverables Description:
Phase I research should (highly encouraged) be conducted to demonstrate technical feasibility with preliminary hardware (i.e., beyond architecture approach/theory; a proof-of-concept) being delivered for NASA testing, as well as show a plan toward Phase II integration.

Phase II new technology development efforts shall deliver components at the TRL 4 to 6 level with mature hardware and preliminary integration and testing in an operational environment. Deliverables are desired that substantiate the quantum communication technology utility for positively impacting the NASA mission. The quantum communication technology should impact one of three key areas: information security, sensor networks, and networks of quantum computers. Deliverables that substantiate technology efficacy include reports of key experimental demonstrations that show significant capabilities, but in general, it is desired that the deliverable include some hardware that shows the demonstrated capability.

State of the Art and Critical Gaps:
There is a critical gap between the United States and other countries, such as Japan, Singapore, Austria, and China, in quantum communications in space. Quantum communications is called for in the 2018 National Quantum Initiative (NQI) Act, which directs the National Institute of Standards and Technology (NIST), National Science Foundation (NSF), and Department of Energy (DOE) to pursue research, development, and education activities related to Quantum Information Science. Applications in quantum communications, networking, and sensing, all proposed in this subtopic, are the contributions being pursued by NASA to integrate the advancements being made through the NQI.

Relevance / Science Traceability:
This technology would benefit NASA communications infrastructure as well as enable new capabilities that support its core missions. For instance, advances in quantum communications would provide capabilities for added information security for spacecraft assets as well as provide a capability for linking quantum computers on the ground and in orbit. In terms of quantum sensing arrays, there are a number of sensing applications that could be supported through the use of quantum sensing arrays for dramatically improved sensitivity.

References:

1. Evan Katz, Benjamin Child, Ian Nemitz, Brian Vyhnalek, Tony Roberts, Andrew Hohne, Bertram Floyd, Jonathan Dietz, and John Lekki: “Studies on a Time-Energy Entangled Photon Pair Source and Superconducting Nanowire Single-Photon Detectors for Increased Quantum System Efficiency,” SPIE Photonics West, San Francisco, CA (Feb. 6, 2019).
2. M. Kitagawa and M. Ueda: “Squeezed Spin States," Phys. Rev. A 47, 5138–5143 (1993).
3. Daniel Gottesman, Thomas Jennewein, and Sarah Croke: “Longer-Baseline Telescopes Using Quantum Repeaters,” Phys. Rev. Lett., 109 (Aug. 16, 2012).
4. Nicolas Gisin and Rob Thew: “Quantum Communication,” Nature Photonics, 1, 165–171 (2007).
5. H. J. Kimble: “The Quantum Internet,” Nature, 453, 1023–1030 (June 19, 2008).
6. C. L. Degen, F. Reinhard, and P. Cappellaro: “Quantum Sensing,” Rev. Mod. Phys., 89 (July 25, 2017).
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Francisco, CA (March 1, 2019).

T5.05 Advanced Solar Sailing Technologies (STTR)

Lead Center: MSFC
Participating Center(s): GRC

Scope Title: Embedded Sail Antenna Technology for Enhanced Sailing and Beyond

Scope Description:
The Mars Cube One (MarCO) mission demonstrated the potential of SmallSat spacecraft to perform interplanetary missions. NASA's Space Technology Mission Directorate (STMD) and Science Mission Directorate (SMD) are continuing to invest in technologies and interplanetary missions due to the high science value enabled by SmallSat spacecraft; several of those being solar-sail-based missions. However, MarCO was extremely limited in communication rates. Also, future interplanetary missions will be carrying science instrumentation with higher data requirements. This solicitation is seeking deployable embedded technology solutions for large aperture and higher gain, enabling higher data rate communications for interplanetary small spacecraft with an emphasis on applicability to solar sail missions (very low SWaP-C (size, weight, power, and cost)). In particular, gossamer technlogies are of interest—both printed and touch labor designs as well as both fixed and electronically steerable. The Near-Earth Asteroid Scout (NEAScout) solar sail architecture can be used as a sample gossamer design reference for the proposed technologies. However, the proposed technologies should be extensible to solar sails in general (i.e., not be tied to NEAScout-specific requirements) as well as to stand-alone devices (i.e., to be applicable to nonsolar sail missions).

Requirements:

- Frequency band: X, Ka, K
- Gain: scalable from ~30 to >50 dBi
- Specific mass: >185 dBi/kg
- Deployable, highly stowable (specific volume dBi/m^3 is to be determined as mission applications progress)

Expected TRL or TRL Range at completion of the Project: 2 to 5

Primary Technology Taxonomy:
Level 1: TX 05 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems
Level 2: TX 05.5 Revolutionary Communications Technologies

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Hardware

Desired Deliverables Description:
The anticipated Phase I product would be a proof-of-concept demonstration of the technology with determination of the Key Performance Parameters by test and/or analyses leading to a higher fidelity prototype(s) and relevant environmental demonstrations in Phase II.

State of the Art and Critical Gaps:
The current state of the art for SmallSat/CubeSat missions is led by ISARA (Integrated Solar Array and Reflectarray Antenna) flown on MarCO. Using a combination reflectarray and patch array, it demonstrated an 8-kbps X-band downlink from Mars orbit with a 28-dB-gain design in a small form factor of <1 kg and 272 cm^3 at 5 W. For reference, the Mars Reconnaissance Orbiter is a large spacecraft communicating from

approximately the same distance as MarCO with a 46.7-dB 3-m dish that varies from 500- to 4,000-kbps X-band downlink at 100 W.

Outside of ISARA, various arrays of 16 patch antennas or fewer are available from places like Endurosat and Clyde Space with gains from 11.5 to 16 dB. Thin-film solutions such as the Lightweight Integrated Solar Array and anTenna (LISA-T) are in development. However, the ultimate scalability (mechanically, mass, stowage volume, etc.) is limited. Thus, a critical technology gap exists in higher data rate communication solutions for SmallSats outside Earth orbit. The current NASA Small Spacecraft Strategic Technology Plan states this need in several ways including large deployable apertures. This gap is especially critical for deployable solar sail missions such as interstellar probe and potentially for second- and third-generation space weather monitoring platforms. In short, low SWaP-C, high-gain communication techniques that will push small spacecraft data rates towards their larger spacecraft brothers and sisters are needed. To enhance future solar sail missions, these concepts should be amenable if not directly embedded onto the solar sail itself.

Relevance / Science Traceability:
The Small Innovative Missions for Planetary Exploration (SIMPLEx) solicitation opportunities would benefit significantly from higher data rate communication solutions for SmallSat missions. Further specific solar sail missions such as the High-Inclination Solar Polar Image mission and second- and third-generation space weather monitoring missions would be enhanced by this technology, and specific solar sail missions such as the interstellar probe would be enabled by this technology.

References:
1. Review of CubeSat Antenna for Deep Space: https://pureadmin.qub.ac.uk/ws/portalfiles/portal/174234474/IEEE_Magazine.pdf
2. LISA-T: https://docs.google.com/viewer?a=v&pid=sites&srcid=ZGVmYXVsdGRvbWFpbnxqb2huYW50aG9ueWNhcnJ8Z3g6YzcxMGZjY2Y4MDYwMmJl

Scope Title: Scalable, Low-Mass Sail Attitude Control Technology for Enhanced Sailing

Scope Description:
As solar sails continue to grow in size, so is the need for direct, propellantless, sail-embedded methods attitude control of the sail craft. A primary example of this capability is the so-called reflectivity control devices (RCD), which alter their reflectivity in response to an applied voltage. When embedded in a solar sail system (e.g., near the distal end of a boom), useful momentum transfer and more importantly differentials in momentum that transfer between the on and off states can be captured. RCDs were originally demonstrated for solar sailing by the Japan Aerospace Exploration Agency (JAXA) on the IKAROS (Interplanetary Kite-craft Accelerated by Radiation of the Sun) mission and are currently being further developed by NASA in the Solar Cruiser program. As sails are scaled beyond the Solar Cruiser class and taken into more and more extreme environments, stronger and more robust sail-embedded attitude control devices will be needed. More specifically, devices that can provide greater "on-to-off ratios" (greater attitude control) while utilizing less power and surviving a broader, more extreme temperature range are needed.

Key Performance Parameters:
1. Consider two sail point designs, consisting of two areas and two masses (0.12 mm/sec2, 0.24 mm/sec2):
    - Area1 = 1650 m^2, Mass1 = 115 kg
    - Area1 = 7000 m^2, Mass2 = 240 kg
2. Mass of the solution should not exceed 3% of sail mass (3.45 kg, 7.2 kg).
3. Torque as a function of SIA meeting or exceeding the following:

Case	Out-of-Plane (Roll) Torque [N-m]	In-Plane (Pitch/Yaw) Torque [N-m]

Solar Cruiser (1650 m^2) 0° SIA	$4.7x10^{-6}$	$5.5x10^{-4}$
Solar Cruiser (1650 m^2) 35° SIA	$4.9x10^{-5}$	$2.4x10^{-3}$
SPI (7000 m^2) 0° SIA	$7.7x10^{-5}$	$4.6x10^{-3}$
SPI (7000 m^2) 17° SIA	$6.4x10^{-4}$	$4.7x10^{-2}$

4. Power requirements (if any) should also be defined as a part of the proposed solution.
5. Assessment of space environmental survivability—especially for expected temperature survivability (large range of hot-cold survivability is needed).

Expected TRL or TRL Range at completion of the Project: 2 to 5

Primary Technology Taxonomy:
Level 1: TX 01 Propulsion Systems
Level 2: TX 01.4 Advanced Propulsion

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Hardware

Desired Deliverables Description:
The anticipated Phase I product of this solicitation would be a proof-of-concept demonstration of the technology with determination of the Key Performance Parameters by test and/or analyses leading to a higher fidelity prototype(s) and relevant environmental demonstrations in Phase II.

State of the Art and Critical Gaps:
The current state of the art for embedded attitude control devices are defined by RCDs developed by JAXA (see references) as well as Dakang Ma et al. (in partnership with NASA). These "first-generation" devices are being advanced to second generation by both NASA and industry; however, results have not been published. These devices are appropriate for medium-class solar sail missions (e.g., <1600 m^2). Advanced devices would be enhancing for this class and potentially enabling for scaling to large class sails (e.g., >7000 m^2) as well as for sails that will travel into more extremes environments (e.g., hot or cold cases).

Relevance / Science Traceability:
Large-class solar sails (e.g., >7000 m^2) are important in achieving not currently possible heliophysics missions such as the High Inclination Solar Imaging missions as well as significantly enhancing for fast transit to deeper space, which is needed for the Interstellar Probe mission.

References:

1. Dakang Ma: Measurement of Radiation Pressure and Tailored Momentum Transfer Through Switchable Photonic Device, https://drum.lib.umd.edu/handle/1903/19291
2. Hirokazu Ishida, et al.: Optimal Design of Advanced Reflectivity Control Device for Solar Sails Considering Polarization Properties of Liquid Crystal, https://www.semanticscholar.org/paper/Optimal-Design-of-Advanced-Reflectivity-Control-for-Hirokazu-Sh%C3%ADd%C3%A0/cfbc675862ca232e0d52b5cfd0173fcc969d7c7c
3. Ryu Funase, et al.: On-Orbit Verification of Fuel-Free Attitude Control System for Spinning Solar Sail Utilizing Solar Radiation Pressure, https://www.sciencedirect.com/science/article/pii/S0273117711001657?via%3Dihub

Scope Title: Next-Generation Solar Sail System Technologies for Enhanced and Enabling Sailing

Scope Description:

Aside from the two targeted scope technologies within this subtopic, NASA also recognizes there are several new and budding ideas that may prove to be significantly enhancing or enabling for next-generation (post Solar Cruiser) sailing. In this scope, ideas for advanced technologies in the core categories of advanced sail materials (especially diffractive and metamaterials), advanced sail deployment booms, and sail-embedded power-generation concepts (especially ultraviolet (UV) stable thin-film protective coatings) are solicited. Direct requirements nor key performance parameters in these categories are not being solicited; however, offerors must quantitatively compare their concepts to state-of-the-art sailing technologies and clearly show how the offered technology is expected to be significantly enhancing or enabling to the next generation of solar sails.

Expected TRL or TRL Range at completion of the Project: 2 to 5

Primary Technology Taxonomy:
Level 1: TX 01 Propulsion Systems
Level 2: TX 01.4 Advanced Propulsion

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype

Desired Deliverables Description:
The anticipated Phase I product of this solicitation would be a proof-of-concept demonstration of the technology with determination of the Key Performance Parameters by test and/or analyses leading to a higher fidelity prototype(s) and relevant environmental demonstrations in Phase II.

State of the Art and Critical Gaps:
Gaps within advanced sail material, advanced boom and deployers, as well as embedded power generation exist for larger (larger than solar cruiser) class sails—such as those proposed for the HISM (High Inclination Solar Mission) and SPI (Solar Polar Imager) missions. State-of-the-art sail materials used on NEAScout and Solar Cruiser are CP1 (colorless polyimide 1). Lighter materials with higher photon momentum transfer are highly enhancing. State-of-the-art booms are composite based and typically are a "TRAC" (Triangular Rollable and Collapsible). Improved mass and strength properties are both enhancing and enabling. State-of-the-art embedded power generation is based on LISA (Lightweight Integrated Solar Array) and LISA-T (Lightweight Integrated Solar Array and anTenna) concepts. UV robust coatings provided greater radiation protection without sacrificing mass and thickness, and flexibility would be both enhancing and enabling.

Relevance / Science Traceability:
Next-generation solar sailing will enable several priority science missions such as out of the ecliptic plane imaging of the Sun as well as fast transit to deep space for the interstellar probe.

References:

1. Johnson, L., Young, R., Montgomery, E., and Alhorn, D. "Status of Solar Sail Technology Within NASA," Advances in Space Research, Vol. 48, No. 11, 2011, pp. 1687-1694.
2. Johnson, L., Castillo-Rogez, J., and Dervan, J. "Near Earth Asteroid Scout: NASA's Solar Sail Mission to a NEA," 2017.
3. Johnson, C., Heaton, A., Curran, F., and Rich, D. "The Solar Cruiser Mission: Demonstrating Large Solar Sails for Deep Space Missions," Presentation at the 70th International Astronautical Congress, Washington, DC, 2019.
4. Johnson, L., McKenzie, D., and Newmark, J. "The Solar Cruiser Mission Concept—Enabling New Vistas for Heliophysics," American Astronomical Society Meeting Abstracts, Vol. 236, 2020, pp. 106-108.

Focus Area 6 Life Support and Habitation Systems

The Life Support and Habitation Systems Focus Area seeks key capabilities and technology needs encompassing a diverse set of engineering and scientific disciplines, all of which provide technology solutions that enable extended human presence in deep space and on planetary surfaces such as Moon and Mars, including Orion, ISS, Gateway, Artemis and Human Landing Systems. The focus is on systems and elements that directly support human missions and astronaut crews, such as Environmental Control and Life Support Systems (ECLSS), Extravehicular Activity (EVA) systems, Human Accommodations, including crew and cabin provisioning, hygiene and clothing systems, and Bioregenerative Life Support, including plant growth for food production.

For future crewed missions beyond low-Earth orbit (LEO) and into the solar system, regular resupply of consumables and emergency or quick-return options will not be feasible. New technologies must be compatible with attributes of the environments expected, including microgravity or partial gravity, varying atmospheric pressure and composition (both internal to the cabin and external to the vehicle), space radiation, and the presence of planetary dust. Technologies of interest are those that enable long-duration, safe, economical, and sustainable deep-space human exploration. Special emphasis is placed on developing technologies that will fill existing gaps as described in this solicitation, that reduce requirements for consumables and other resources, including mass, power, volume and crew time, and which will increase safety and reliability with respect to the state-of-the-art. Spacecraft may be untended by crew for long periods, therefore systems must be operable after these intervals of dormancy.

ECLSS encompass process technologies and monitoring functions necessary to provide and maintain a livable environment within the pressurized cabin of crewed spacecraft, including environmental monitoring, water recycling, waste management and atmosphere revitalization including particulate removal. There are two specific technical areas of interest for ECLSS submissions. Advancements in heaters and thermal swing components are needed for thermally desorbed carbon dioxide removal and compression beds, including considerations for structured monolithic sorbents created by additive manufacturing or slip casting of the sorbent itself. Secondly, proposals are sought to address challenges in carbon dioxide reduction systems, including separation, collection, removal and storage of carbon particulates, methods to recharge or recycle catalysts and solutions to prevent clogging of frits and filters in recycle gas streams. Also, of interest to ECLSS but included elsewhere in this solicitation, is lunar dust filtration and monitoring for spacecraft cabins.

For Human Accommodations, the focus in this solicitation includes advanced heating and refrigeration systems for stored food, personal hygiene including handwash, combination clothes washer and dryer systems and volumetrically efficient concepts for equipment, flexible work surfaces and stowage. In addition, textiles are sought for extreme surface environments and high oxygen atmospheres, applicable to crew clothing. Lastly, of interest to the focus area but included elsewhere, is the subtopic Plant Research Capabilities in Space, which is applicable to Bioregenerative Life Support.

Unique needs also exist for the Exploration Extra-vehicular Mobility Unit (xEMU), commonly called spacesuits. Textiles used for the xEMU Environmental Protection Garment (EPG), the outermost component of the xEMU, must resist extreme surface environments including planetary dust and also be suitable for oxygen-rich atmospheres. Applicable to the xEMU’s Portable Life Support System (PLSS), sorbent technologies are sought for a low volume, low power and low mass carbon dioxide and humidity control system. In addition, miniaturized gas sensor technologies are needed for measurement of oxygen, carbon dioxide and water vapor within the suit.

Please refer to the description and references of each subtopic for further detail to guide development of proposals within this technically diverse focus area.

T6.08 Textiles for Extreme Surface Environments and High Oxygen Atmospheres (STTR)

Lead Center: JSC
Participating Center(s): N/A

Scope Title: Textiles for Extreme Surface Environments and High Oxygen Atmospheres

Scope Description:
A spacesuit is essentially a one-person fully equipped spacecraft. It is complex and consists of more than 100 components. One of the primary purposes of the spacesuit is to protect the astronaut from the dangers in space outside the spacecraft. Therefore, it is more than a set of clothes. The current spacesuit used for the International Space Station (ISS) is known as the Extravehicular Mobility Unit (EMU). The EMU was designed for spacewalks on the Space Shuttle and was enhanced for use on the ISS. Extravehicular mobility means the astronaut can move around in space outside the space vehicle.

The astronauts use the spacesuit only when they are performing a spacewalk. When astronauts are inside the space vehicle, they wear regular clothes. When the astronauts prepare to perform a spacewalk, they remove their regular clothes and put on two-piece thermal underwear known as the "thermal comfort undergarment (TCU). The TCU is only used by the astronauts while they are in the spacesuit. After a spacewalk, the astronaut gets out of the spacesuit and takes off the TCU. The TCU is not part of this solicitation.

NASA has been working on a new spacesuit called the Exploration Extravehicular Mobility Unit (xEMU). The objective of the xEMU is to protect the astronauts from the harsh environment of space. This xEMU is designed for lunar surface exploration and operations in extreme environments. It incorporates more advanced technologies than the current EMU. The xEMU is designed to be the next-generation spacesuit to benefit several space programs, namely the International Space Station, Human Landing System (HLS), Artemis, Gateway, and Orion.

This STTR subtopic covers two different applications of textile technology. First, it addresses the primary need to develop new textiles for the xEMU Environmental Protection Garment (EPG). Second, it addresses the need for crew clothing when the astronauts are not inside their spacesuits.

The EPG is the outer component of the xEMU. The EPG is considered the first line of defense when an astronaut is performing a spacewalk. The function of the EPG is to protect the astronaut from extreme surface environments and flammability in oxygen-rich atmosphere. NASA is looking for innovative materials for the entire EPG. Likewise, NASA is looking for innovative textiles for crew clothing. Crew clothing is not part of the EPG and is never worn inside the spacesuit. Crew clothing includes t-shirts, pants, and sleepwear.

Both the EPG and the crew clothing shall be addressed in the proposal. Also, due to the complexity of the EPG and the urgency for its development for the Artemis program, priority shall be given to the development of the EPG. Additionally, the Technical Readiness Level (TRL) for the EPG is expected to be the highest level possible at the end of Phase II.

Part A: Development of the EPG
The requirements of the EPG are given below and followed by a description of the extreme surface environments and oxygen-rich atmosphere:

Requirements
The EPG is a multilayered component consisting of fabrics and thin films. Each layer of this component contributes to the protection of the xEMU from the extreme lunar environment while enabling xEMU functionality of its three subsystems: the Pressure Garment System (PGS), the Portable Life Support System

(PLSS), and the informatics system. The EPG is the spacesuit's first line of defense. It must be designed to have properties to perform in the harsh surface environment of the south pole of the Moon.

The desired properties and requirements of the EPG for the extreme environment of the lunar surface are:

1. Thermal:
   The EPG shall have an average:
   - Ratio of solar absorptivity to infrared emissivity (α/ε) of 0.21
   - Solar absorption of 0.18

2. Physical:
   The EPG solution may consist of many layers. Although the offeror shall address the entire EPG, the offeror shall place a priority on the outermost layer. The outermost layer shall be designed in a manner to limit dust accumulation and penetration. It shall have properties such that the regolith particles of microns and submicrons sizes cannot penetrate the EPG. In addition, the external surface of the outermost layer shall have low energy and a nanotexture that prevents entrapment of most regolith particles. The outermost layer may be a composite structure.

   Opportunities for mass reduction for the entire EPG shall be investigated. The reference for mass reduction is the International Space Station (ISS) EMU. Using the current fabric layers, the entire ISS EMU EPG weighs approximately 16 lb. The ISS EMU has a total density of approximately 31 oz/yd2.

   The composition of the EMU EPG includes:
   - Orthofabric with density 14.25 + 0.75 oz/yd2
   - Aluminized Mylar with density 1.12 oz/yd2 maximum per layer with a total of 7 layers
   - Neoprene-coated nylon with density 9.0 oz/yd2 maximum

3. Mechanical with respect to mobility:
   The EPG shall not significantly affect mobility of the suit. The EPG fabrics must be flexible with both low bending and low torsional stiffness to withstand exposure to the extreme temperatures of 260 °F (127 °C) to -292 °F (-180 °C). The outermost layer is directly exposed to these temperatures. The other layers of the xEMU are not subject to these extreme temperatures. The combination of the EPG layers shall not hinder the joint mobility of the xEMU. The EPG fabrics shall not outgas at vacuum.

Extreme Surface Environments

The description of the extreme environments is as follows:

1. Thermal
   The environment temperatures will be the temperature on the outside of the suit. The internal layers of the EPG are higher because of the suit heat leak provided by the astronaut, which warms the surrounding area.
   - Extreme heat (260 °F, 127 °C)
   - Extreme cold (-292 °F, -180 °C)

2. Regolith Terrain
   The lunar regolith is a blanket of abrasive dust and unconsolidated, loose, heterogeneous, superficial deposits covering solid rock. The EPG fabrics must have sufficient resistance to abrasion and tear to last for multiple uses.

   In the south pole region of the Moon, the regolith is:
   - Highly abrasive
     The EPG durability in the dust environment is a key requirement. The spacesuit must operate during prolonged exposure and operation in the dusty regolith environment.

Because of bending, kneeling, and falling on the lunar surface, the EPG will be in constant contact with the abrasive regolith.

- Electrostatic and Triboelectrostatic Charging
  The electrostatic and triboelectrostatic properties of the lunar dust particles are so averse to the outer layer of the EPG that they promote abrasion and wear necessitating the development of new EPG outer fabrics. The electrostatic charges are produced by the photoemission of electrons due to vacuum ultraviolet (VUV) sunlight irradiation. The regolith becomes slightly positively charged. In the shadow, these charges reverse. In addition, the triboelectrostatic charges are created by the friction of fabrics on the regolith. In both cases, there is a risk that these charged particles can be carried inside and contaminate the lunar lander.

3. Radiation and Plasma
   The Moon does not have an atmosphere. Therefore, it receives unattenuated galactic and solar radiation. This solar radiation does not cause radioactivity. The annual Galactic Cosmic Rays dose in milli-Sieverts (mSv) on the Moon is 380 mSv (solar minimum) and 110 mSv (solar maximum). The annual cosmic ionizing cosmic radiation on Earth is 2.4 mSv. The EPG layers and particularly the outer layer fabric must be durable over hundreds of hours of VUV radiation exposure without a reduction in functionality.

   Plasma is a concern due to the charged environment that may be in contact with the spacesuit. The plasma is explained in a PowerPoint document from Timothy J. Stubbs et al., "Characterizing the Near-Lunar Plasma Environment," Workshop on Science Associated with the Lunar Exploration Architecture, Tempe, AZ, February 26-March 2, 2007 (https://www.lpi.usra.edu/meetings/LEA/whitepapers/Stubbs_charging_NAC_whitepaper_v01.pdf).

Oxygen-Rich Atmosphere
The EPG must satisfy flammability requirements. The EPG outer layer shall not support combustion in the lunar lander's atmosphere. It is currently determined that atmosphere of the lunar lander in HLS will contain 34% ±2% oxygen at a pressure of 8.2 psia (56.5 kPa). This oxygen concentration may even be higher. Hence, all materials directly exposed to the lunar lander atmosphere are required to be flame retardant.

Past program technologies do not meet the requirements for the HLS and Artemis programs and their sustaining missions. Beta fabric, the glass fiber fabric used in the Apollo spacesuit, addressed only the high flammability risk in the Apollo Lunar Module (LM) atmosphere of 100% oxygen at 4.8 psi (33 kPa). The three extravehicular activities (EVAs) in the last Apollo mission, with an average combined duration of 22 hours, resulted in damage to the outer layer of the Apollo spacesuits, and the suits could not have endured more EVAs. The glass fiber developed for NASA was the first-ever textile microfiber (3.8 µm fiber diameter) that would not burn in a 100% oxygen atmosphere, but it did not have the mechanical properties to withstand abrasion from the lunar regolith.

Part B: Development of Crew Clothing Fabrics
The criteria for the development of new crew clothing fabrics are based on the HLS program requirement of flame retardance in 36% oxygen at 8.2 psia and the need to have clothes to wear when the astronauts are not exploring the surface of the Moon. The new fabric items must be flame retardant inside the lunar lander.

Requirements

1. Flame Retardance
   Options for developing flame-retardant clothing include inherently flame-retardant textile fibers and durable flame-retardant treatments. These options are described below:
   - Inherently flame-retardant textile fibers:

The 1.5 denier polybenzimidazole (PBI) fiber is the only inherently flame-retardant fiber commercially available to make yarns for apparel fabrics.

While there are several polymers that meet the flame retardant threshold of 36% oxygen at 14.7 psia, few have been used to produce textile fibers. Among those that are currently spun into fibers like polyimide, the fibers are mostly used to make yarns and fabrics for industrial applications.

Most existing textile fibers that do not support combustion in 36% oxygen-rich atmosphere have linear densities too high to produce yarns and fabrics that are comfortable for next-to-the-skin apparel fabrics. In other words, the diameter of these fibers is usually too large, and consequently, the fibers bending and torsional properties are not adequate to produce yarns suitable for knitted garments.

- Durable flame-retardant treatments:
  A durable flame-retardant treatment is a treatment that can withstand wear abrasion and 50 laundry cycles. A durable flame-retardant treatment may be applied to fibers, yarns, or fabric considered for crew clothing.

2. Comfort
   Comfort is a function of yarn hairiness, which promotes softness and warmth. Greater hairiness promotes flammability. Flame-retardant treatments reduce hairiness and the accompanying comfort. This competition between comfort from hairiness and the reduction of hairiness due to flame-retardant treatment would seem to favor the use of an inherently flame-retardant fiber over a flame-retardant treatment.

   A potential solution is a fabric with a flame-retardance outward-facing side, while the inward-facing side next to the skin may be more comfortable with the consequence of reduced flame retardance. This solution may be achieved by methods of fabric construction including woven, knitted, laminated, and nonwoven fabrics.

3. Volatile Emissions
   The fabrics shall be free of volatile materials that can be toxic to humans. Also, the fabrics shall not adversely affect the Environmental Control and Life Support System of the lunar lander.

4. Lint Reduction
   The fabrics shall produce a minimal amount of lint.

5. Odor Control
   The fabrics shall not produce malodor.

6. Resistance to the lunar Regolith
   The crew clothing fabrics shall be resistant to wear from the abrasive lunar regolith particles to last for the length of the Artemis mission.

   While mentioned previously as not part of this solicitation, the TCU can be a source of regolith contamination. The astronaut takes the TCU off after getting out of the spacesuit. If contaminated with regolith particles, the TCU can contribute to the contamination of materials inside the lunar lander. In addition, regolith dust can enter the lander from an airlock or directly from outside depending on the design of the lander. Because of this exposure, textiles for the crew clothing must be either inherently flame retardant or have “regolith-proof” flame-retardant finishes. These textiles must not be at risk of losing their flame retardance due to the abrasive nature of the regolith.

Expected TRL or TRL Range at completion of the Project: 2 to 6

Primary Technology Taxonomy:
Level 1: TX 06 Human Health, Life Support, and Habitation Systems
Level 2: TX 06.2 Extravehicular Activity Systems

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype

Desired Deliverables Description:
Phase I: Phase I offerors are expected to deliver written reports (Interim and Final) containing a plan or strategy that explains in detail their approach for solving the problems of the EPG and the crew clothing. Reports shall include rationale for approach, research, proof of concept, analysis, and any strategy leading to one or more prototypes.

Phase II: Phase II deliverables shall include prototypes or finished goods. The prototypes or finished goods shall be delivered to NASA Johnson Space Center with a “Material Inspection and Receiving Report” (Form DD250) OMB No. 0704-0248. Photographs of the delivered prototypes or finished goods shall accompany the DD250 form. Deliverables shall also include complete documentation such as technical data sheets with detailed description and composition of the material or product, with testing methods and testing data, design sketches or drawings, and full information on material and/or chemical sourcing. The Phase II deliverables shall also include a final report documenting all work accomplished for the Phase II effort and shall not duplicate the Phase II proposal.

Examples of the deliverables for the EPG and crew clothing may include:

- EPG: prototype textiles with coating, lamination, thin film, other new technology, composite structure, or fabrics integrated in a spacesuit.
- Crew clothing: novel fibers, yarns, and fabrics for everyday garment prototypes (e.g. T-shirt, pants, and sleepwear).

The proposers shall clearly state the Technology Readiness Level (TRL) levels at which they start their research and at which they expect to be at the end of Phase I and Phase II. For the EPG, the TRL level is expected to be the highest level possible at the end of Phase II. Reference for the TRL definitions are at the following link: (https://www.nasa.gov/pdf/458490main_TRL_Definitions.pdf).

State of the Art and Critical Gaps:
The gap is the lack of available commercial-off-the-shelf (COTS) textiles that satisfy spacesuit and crew clothing mitigation requirements for extreme surface environments and fire safety in a 36% oxygen atmosphere.

The second gap is the lack of knowledge of the effects of lunar dust on textile products with respect to their useful life in EVA applications. Extent of wear and tear and levels of contamination and retention of the dust in the textile structure are not known.

Relevance / Science Traceability:
This scope is included under the Space Technology Mission Directorate (STMD). The xEMU project is under the Human Exploration and Operations Mission Directorate (HEOMD).

This work will benefit several space programs, namely the ISS, Human Landing System (HLS), Artemis, Gateway, and Orion. Near term, the work on the EPG will directly benefit the xEMU project.

The textiles developed could be useful for other soft goods applications.

References

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4. J. J. Dillon, E. S. Cobb, "Research, Development and Application of Noncombustible Beta Fiber Structures," Final Report, 17 April 1967–31 December 1974. 24 pp, NASA-CR-144365 (https://ntrs.nasa.gov/api/citations/19750021113/downloads/19750021113.pdf).
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8. Andrew E. Potter, Jr., Benny R. Baker, "Static Electricity In The Apollo Spacecraft," December 1969. 23 pp, NASA-TN-D-5579 (https://ntrs.nasa.gov/api/citations/19700004167/downloads/19700004167.pdf).
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11. Lunar Reconnaissance Orbiter Camera (LROC :: QuickMap (asu.edu)).

Focus Area 8 In-Situ Resource Utilization

In-Situ Resource Utilization (ISRU) involves any hardware or operation that harnesses and utilizes 'in-situ' resources (natural and discarded) to create products and services for robotic and human exploration. Local resources include 'natural' resources found on extraterrestrial bodies such as water, solar wind implanted volatiles (hydrogen, helium, carbon, nitrogen, etc.), vast quantities of metals in mineral rocks and soils, and atmospheric constituents, as well as human-made resources such as trash and waste from human crew, and discarded hardware that has completed its primary purpose. The most useful products from ISRU are propellants, fuel cell reactants, life support commodities (such as water, oxygen, and buffer gases), and feedstock for manufacturing and construction. ISRU products and services can be used to i) reduce Earth launch mass or lander mass by not bringing everything from Earth, ii) reduce risks to the crew and/or mission by reducing logistics, increasing shielding, and providing increased self-sufficiency, and/or iii) reducing costs by either needing less launch vehicles to complete the mission or through the reuse of hardware and lander/space transportation vehicles. Since ISRU systems must operate wherever the resource of interest exists, technologies and hardware will need to be designed to operate in harsh environments, reduced gravity, and potential non-homogeneous resource physical, mineral, and ice/volatile characteristics. This year's solicitation will focus on critical technologies needed in the areas of Resource Acquisition and Consumable Production for the Moon and Mars. The ISRU focus area is seeking innovative technology for:

- Novel Silicate Reduction Methods
- Noncontact High Temperature Measurement

- Regolith Feed/Removal Systems and Mineral Measurement for Oxygen Removal
- Non-Water Volatile Capture
- Regolith/Ice Crushing
- Size-Sorting
- Beneficiation of Water Ice
- Mineral Beneficiation
- Metal Production

As appropriate, the specific needs and metrics of each of these specific technologies are described in the subtopic descriptions.

T7.05 Climate Enhancing Resource Utilization (STTR)

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

Scope Title: Sustainable Atmospheric Carbon Dioxide Extraction and Transformation

Scope Description:
Component and subsystem technologies are sought to demonstrate sustainable, energy-efficient extraction of carbon dioxide (CO_2) from a defined planetary or habitable atmosphere fully integrated with CO_2 transformation into one or more stable products such as manufacturing feed stock polymers or readily storable, noncryogenic propellants or fuels. This scope is intended to incentivize revolutionary, dual-use technologies that may lead to reduced dependence of sustainable space exploration activity on terrestrial supplies of carbon-containing resources and lead to products with commercial promise for repurposing terrestrial atmospheric CO_2. At the core of this scope is a requirement for integrated technology solutions that dramatically reduce mass, volume, and end-to-end energy consumption of highly integrated CO_2 collection and transformation.

Proposals must specifically and clearly describe: (1) physical and/or chemical processes to be implemented for CO_2 collection and transformation, including reference to the current state of the art; (2) specific engineering approaches to be used in dramatically reducing mass, volume, and end-to-end energy consumption per mass of product carbon content mass; (3) validated performance estimates of high-cycle utilization of any sorption, catalytic, or other unconsumed materials used in the CO_2 collection or transformation processes; (4) suitability or adaptability of the proposed CO_2 capture approach for operation in various ambient CO_2 mixture and partial pressure environments (i.e., ambient Mars atmosphere to ambient Earth atmosphere conditions); (5) substantiated estimates of the mass conversion efficiency of ingested carbon to product carbon; and (6) estimated total end-to-end energy consumption per unit mass of product carbon.

The scope specifically excludes: (1) evolutionary improvements in mature CO_2 collection technologies that do not provide large reductions in mass, volume, and end-to-end energy consumption; (2) CO_2 collection approaches that employ CO_2 absorbing materials that require frequent replenishment or replacement (e.g., greater than 50% reduction in absorption efficiency after 500 cycles); (3) technologies considered as life support systems including air revitalization, water processing, or waste processing; (4) biological or biology-based components or subsystems of any kind; and (5) CO_2 transformation products that are not readily stored at approximately Earth-ambient conditions such as cryogenic propellants.

Expected TRL or TRL Range at completion of the Project: 3 to 5

Primary Technology Taxonomy:
Level 1: TX 07 Exploration Destination Systems
Level 2: TX 07.1 In-Situ Resource Utilization

Desired Deliverables of Phase I and Phase II:

- Prototype
- Research
- Analysis

Desired Deliverables Description:
Phase I deliverable is defined as a detailed feasibility study that clearly defines the specific technical innovation and estimated performance of CO_2 collection and transformation into products, identifying critical development risks anticipated in a Phase II effort. Technology feasibility evaluation should address the scope proposal elements including: (1) process descriptions; (2) results of engineered mass, volume, and energy consumption efficiency designs; (3) cyclic performance of participating unconsumed process materials; (4) adaptability to different atmospheric CO_2 mixtures and partial pressures; (5) ingested atmosphere throughput and carbon conversion efficiency to product carbon, and (6) estimated total end-to-end energy consumption per unit mass of product carbon. Phase I feasibility deliverables should include laboratory test results that demonstrate the performance of unit processes, components, or subsystems against these metrics.

Phase II deliverables are to include matured feasibility analysis provided in Phase I, and matured laboratory prototype components or subsystems integrated into an end-to-end CO_2 collection and transformation prototype system, including design drawings. Component, subsystem, and integrated system performance test data is a specific deliverable and must include: (1) cyclic performance; (2) ingested atmosphere throughput and carbon conversion efficiency to product carbon; (3) evaluated properties of products; and (4) the results of engineered mass, volume, and energy consumption efficiency designs including measured end-to-end energy consumption per unit mass of product carbon. Analysis deliverables for Phase II should address a credible path toward maturation of the technology and approaches to scaling the technologies to larger processing capacities.

State of the Art and Critical Gaps:
This topic is intended to solicit innovative technologies with clear dual use: (1) adoption by NASA for infusion into long-term mission capabilities enabling mission scale in situ resource utilization (ISRU) use of the Martian atmosphere and (2) commercialization and the potential formation of a terrestrial industry to meet potentially significant future demand for terrestrial atmospheric CO_2 extraction and repurposing. Additionally, if or as a viable industry associated with terrestrial applications of these technologies emerges, commercial competition may continue to drive innovation and contribute over the long term to improved NASA mission capability. Early-stage innovations in this topic are anticipated from teams of small businesses and research institutions, which can demonstrate feasibility and readiness for accelerated maturation.

Well-developed and mature technologies for atmospheric CO_2 capture have been flown and operated on NASA spacecraft, based on phase change (freezing) of ambient gas; accepting the power requirements and efficiency levels of both the refrigeration and heating devices in a freeze/thaw-based collection cycle. NASA operational collection of CO_2 from habitable atmospheres is performed using flow-through beds of sorption materials driven to saturation followed by either desorption processes or discarding of the sorption material and the collected CO_2. Similarly, CO_2 processing based on electrochemical reduction of CO_2 into carbon monoxide (CO) has been flown demonstrating production of oxygen from atmospheric sources. However, the collected carbon is a disposable byproduct. Significantly, these systems are not developed nor optimized for recovery and repurposing of considerable process heat drawn from spacecraft power sources, nor for repurposing of the collected carbon. Recent literature suggests emerging laboratory research of both efficient CO_2 capture and repurposing processes is occurring and may be well positioned for development into components and subsystems suitable for longer-term infusion by NASA into ISRU systems and an emerging terrestrial industry.

Relevance / Science Traceability:
The quantification of resources on Mars suitable for the local production of a variety of mission consumables, manufactured products, and other mission support materials has become much better understood through recent in situ measurements and introductory technology demonstrations. Evolving mission scenarios for

expanded robotic and human exploration of Mars uniformly depend on the utilization of these resources to dramatically reduce the cost and risks associated with these exploration goals. In order to reduce the broad goal of utilizing the CO_2 of the Martian atmosphere as a source of both carbon and oxygen to practical, full-scale reality, substantial improvements in system mass, volume, and power requirements are needed. This solicitation is intended to incentivize these innovations in the service of future NASA missions.

Additionally, there is a growing recognition of the planetwide consequences of accumulating CO_2 in the terrestrial atmosphere. Technologies that advance NASA's Mars ISRU aspirations may be created with the necessary energy efficiencies to support scaling up to terrestrial industrial capacity large enough to begin to reduce or reverse atmospheric CO_2 accumulation.

References:

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T14.01 Advanced Concepts for Lunar and Martian Propellant Production, Storage, Transfer, and Usage (STTR)

Lead Center: GRC
Participating Center(s): JSC

Scope Title: Advanced Concepts for Lunar and Martian Propellant Production, Storage, Transfer, and Usage

Scope Description:
This subtopic seeks technologies related to cryogenic propellant (e.g., hydrogen, oxygen, and methane) production, storage, transfer, and usage to support NASA's in situ resource utilization (ISRU) goals. This includes a wide range of applications, scales, and environments consistent with future NASA missions to the Moon and Mars. Anticipated outcomes of Phase I proposals are expected to deliver proof of the proposed concept with some sort of basic testing or physical demonstration. Proposals shall include plans for a prototype and demonstration in a defined relevant environment (with relevant fluids) at the conclusion of Phase II. Solicited topics are as follows:

- Develop an in-situ hydrogen safety sensor to detect concentrations of hydrogen gas within high-pressure oxygen systems. Regenerative fuel cells (RFCs) and ISRU systems use water electrolysis to generate hydrogen and oxygen for either propellants or energy storage. For safety reasons, there is a need to monitor the quantity of hydrogen within saturated (noncondensing) oxygen process streams flowing up to 50 SLPM to ensure product gas purity. This is especially true for high-pressure systems that range from 250 to 2500 psia. Current technologies require the use of a slipstream to condition the sample gases for analysis. This slipstream represents a loss of reactants and imposes both power and mass penalties on systems deployed on the lunar surface. Existing sensor calibration intervals currently do not support the identified NASA maintenance intervals defined by lunar surface access by crewed missions (>30,000 hr, targeting >50,000 hr). As this application is critically limited by available power and mass, preference is given to solutions with lower parasitic power and mass as well as systems without a slipstream to lose reactants.
- Develop and implement computational methodology to enhance the evaluation of temperature and species gradients at the liquid/vapor interface in unsettled conditions. Techniques could include arbitrary Lagrangian-Eulerian (ALE) interface tracking methods with adaptive mesh morphing, interface reconstruction methods, immersed boundary approaches, or enhanced-capability level set and volume of fluid (VOF) scheme that decrease numerically generated spurious velocities and increase gradient evaluation accuracy. The uncertainty of such techniques in determining the interfacial gradients should be <5% and on par with accuracies of a sharp interface method applied to a nonmoving, rigid interface. Applications include cryogenic tank self-pressurization, pressure control via jet mixing, and filling and liquid transfer operations. It is highly desirable if the methodology can be implemented via user-defined functions/subroutines into commercial computational fluid dynamics (CFD) codes. The final deliverable should be the documentation showing the detailed formulation, implementation, and validation, and any stand-alone code or customized user-defined functions that have been developed for implementation into commercial codes.

Expected TRL or TRL Range at completion of the Project: 2 to 4

Primary Technology Taxonomy:
Level 1: TX 14 Thermal Management Systems
Level 2: TX 14.1 Cryogenic Systems

Desired Deliverables of Phase I and Phase II:

- Hardware
- Software
- Prototype

Desired Deliverables Description:
Phase I proposals should at a minimum deliver proof of the concept, including some sort of testing or physical demonstration, not just a paper study. Phase II proposals should provide component validation in a laboratory environment preferably with hardware (or model subroutines) deliverable to NASA.

Deliverables for the hydrogen sensing technologies for oxygen streams would be at least two operational sensor package test articles demonstrating the capability of the sensor to be tested at a NASA center in either a RFC system or an ISRU. These sensors must have a detection range of at least 0% to 4% hydrogen in oxygen with a minimum detection limit of 20 ppm. The process fluid temperatures will range from -40 to 110 °C due to environmental temperatures on the lunar surface. The Phase I prototypes must demonstrate operation at pressures greater than or equal to 250 psia while Phase II prototypes must demonstrate operation at pressures greater than or equal to 2,500 psia.

Deliverables for the modeling: Phase I should demonstrate the accuracy of the method for simulating self-pressurization under unsettled, low-gravity conditions. Phase II should demonstrate the accuracy of the method for simulating jet mixing and filling and transfer operations. The final deliverable should be the documentation showing the detailed formulation, implementation, and validation, and any stand-alone code or customized user-defined functions that have been developed for implementation into commercial codes.

State of the Art and Critical Gaps:
Cryogenic Fluid Management (CFM) is a cross-cutting technology suite that supports multiple forms of propulsion systems (nuclear and chemical), including storage, transfer, and gauging, as well as liquefaction of ISRU-produced propellants. The Space Technology Mission Directorate (STMD) has identified that CFM technologies are vital to NASA's exploration plans for multiple architectures, whether it is hydrogen/oxygen or methane/oxygen systems including chemical propulsion and nuclear thermal propulsion.

Current hydrogen sensing technologies have three key features inhibiting their use in NASA applications: low pressure capability, unacceptably low calibration stability, and a required slipstream to condition the sample gases for analysis. The low pressure prevents monitoring hydrogen in ISRU propellant streams or RFC energy storage systems. This slipstream represents a loss of reactants and imposes both power and mass penalties on systems deployed on the lunar surface. Based on the performance of hydrogen sensors used in the low-pressure International Space Station (ISS) Oxygen Generator Assembly (OGA) and in terrestrial hydrogen depots, existing sensor calibration intervals currently do not support the identified NASA maintenance intervals defined by lunar surface access by crewed missions.

Relevance / Science Traceability:
STMD strives to provide the technologies that are needed to enable exploration of the solar system, both manned and unmanned systems, and CFM is a key technology to enable exploration. Whether liquid oxygen/liquid hydrogen or liquid oxygen/liquid methane is chosen by Human Exploration and Operations Mission Directorate (HEOMD) as the main in-space propulsion element to transport humans, CFM will be required to store propellant for up to 5 years in various orbital environments. Transfer will also be required, whether to engines or other tanks (e.g., depot/aggregation), to enable the use of cryogenic propellants that have been stored. In conjunction with ISRU, cryogens will have to be produced, liquefied, and stored, the latter two of which are CFM functions for the surface of the Moon or Mars. ISRU and CFM liquefaction drastically reduces the amount of mass that has to be landed on the Moon or Mars.

Generating hydrogen from water electrolysis includes an extremely small but nonzero potential for hydrogen to contaminate the oxygen stream. Monitoring this process for medium pressure systems (e.g., ISRU) or high pressure systems (e.g., energy storage) adds another layer of protection for sustained operation on the surface of the Moon or Mars.

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4. Commercial Lunar Propellant Architecture: A Collaborative Study of Lunar Propellant Production, https://doi.org/10.1016/j.reach.2019.100026 (link is external).

Focus Area 9 Sensors, Detectors, and Instruments

NASA's Science Mission Directorate (SMD), https://science.nasa.gov/ encompasses research in the areas of Astrophysics, Earth Science, Heliophysics and Planetary Science. The National Academies of Science have provided NASA with recently updated Decadal surveys that are useful to identify technologies that are of interest to the above science divisions. Those documents are available at https://www.nationalacademies.org/

A major objective of SMD instrument development programs is to implement science measurement capabilities with smaller or more affordable aerospace platforms so development programs can meet multiple mission needs and therefore make the best use of limited resources. The rapid development of small, low-cost remote sensing and in-situ instruments capable of making measurements across the electromagnetic spectrum is essential to achieving this objective. For Earth Science needs, in particular, the subtopics reflect a focus on remote sensing (active and passive) and in situ instrument development for space-based, airborne, and uninhabited aerial vehicle (UAV) platforms. A strong focus is placed on reducing the size, weight, power, and cost of remote and in situ instruments to allow for deployment on more affordable and wider range of platforms. Astrophysics has a critical need for sensitive detector arrays with imaging, spectroscopy, and polarimetric capabilities, which can be demonstrated on ground, airborne, balloon, or suborbital rocket instruments. Heliophysics, which focuses on measurements of the sun and its interaction with the Earth and the other planets in the solar system, needs a significant reduction in the size, mass, power, and cost for instruments to fly on smaller spacecraft. Planetary Science has a critical need for miniaturized instruments with in-situ sensors that can be deployed on surface landers, rovers, and airborne platforms. For the 2022 program year, we are continuing to update the included subtopics. Please read each subtopic of interest carefully. We continue to emphasize Ocean Worlds and solicit development of in-situ instrument technologies and components to advance the maturity of science instruments focused on the detection of evidence of life, especially extant of life, in the Ocean Worlds. The microwave technologies continue as two subtopics, one focused on active microwave remote sensing and the second on passive systems such as radiometers and microwave spectrometers. NASA has additional interest in advancing quantum sensing technologies to enable wholly new quantum sensing and measurement techniques focused on the development and maturation towards space application and qualification of atomic systems that leverage their quantum properties. Furthermore, photonic integrated circuit technology is sought to enable size, weight, power, and cost reductions, as well as improved performance of science instruments, subsystems, and components which is particularly critical for enabling use of affordable small spacecraft platforms.

A key objective of this SBIR Focus Area is to develop and demonstrate instrument component and subsystem technologies that reduce the risk, cost, size, and development time of SMD observing instruments and to enable new measurements. Proposals are sought for development of components, subsystems and systems that can be used in planned missions or a current technology program. Research should be conducted to demonstrate feasibility during Phase I and show a path towards a Phase II prototype demonstration. The following subtopics are concomitant with these objectives and are organized by technology.

T8.06 Quantum Sensing and Measurement (STTR)

Lead Center: GSFC
Participating Center(s): GRC, JPL, LaRC

Scope Title: Quantum Sensing and Measurement

Scope Description:
This Quantum Sensing and Measurement subtopic calls for proposals using quantum systems to achieve unprecedented measurement sensitivity and performance, including quantum-enhanced methodologies that outperform their classical counterparts. Shepherded by advancements in our ability to detect and manipulate single quantum objects, the so-called Second Quantum Revolution is upon us. The emerging quantum sensing technologies promise unrivaled sensitivities and are potentially game changing in precision measurement fields. Significant gains include technology important for a range of NASA missions such as efficient photon detection, optical clocks, gravitational wave sensing, ranging, and interferometry. Proposals focused on atomic quantum sensor and clocks, and quantum communication should apply to those specific subtopics and are not covered in this Quantum Sensing and Measurement subtopic.

Specifically identified applications of interest include quantum sensing methodologies achieving the optimal collection light for photon-starved astronomical observations, quantum-enhanced ground-penetrating radar, and quantum-enhanced telescope interferometry.

- Superconducting Quantum Interference Device (SQUID) systems for enhanced multiplexing factor reading out of arrays of cryogenic energy-resolving single-photon detectors, including the supporting resonator circuits, amplifiers, and room temperature readout electronics.
- Quantum light sources capable of efficiently and reliably producing prescribed quantum states including entangled photons, squeezed states, photon number states, and broadband correlated light pulses. Such entangled sources are sought for the visible infrared (vis-IR) and in the microwave entangled photons sources for quantum ranging and ground-penetrating radar.
- On-demand single-photon sources with narrow spectral linewidth are needed for system calibration of single-photon counting detectors and energy-resolving single-photon detector arrays in the midwave infrared (MIR), near infrared (NIR), and visible. Such sources are sought for operation at cryogenic temperatures for calibration on the ground and aboard space instruments. This includes low size, weight, and power (SWaP) quantum radiometry systems capable of calibrating detectors' spectroscopic resolution and efficiency over the MIR, NIR, and/or visible.

Expected TRL or TRL Range at completion of the Project: 2 to 4

Primary Technology Taxonomy:
Level 1: TX 08 Sensors and Instruments
Level 2: TX 08.X Other Sensors and Instruments

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype

Desired Deliverables Description:
NASA is seeking innovative ideas and creative concepts for science sensor technologies using quantum sensing techniques. The proposals should include results from designs and models, proof-of-concept demonstrations, and prototypes showing the performance of the novel quantum sensor.

Phase I does not need to include a physical deliverable to the government but it is best if it includes a demonstration of feasibility through measurements. This can include extensive modeling, but a stronger proposal will have measured validation of models or designs that support the viability of the planned Phase II deliverable.

Phase II should include prototype delivery to the government. (It is understood that this is a research effort and the prototype is a best effort delivery where there is no penalty for missing performance goals.) The Phase II effort should be targeting a commercial product that could be sold to the government and/or industry.

State of the Art and Critical Gaps:
Quantum Entangled Photon Sources:

Sources for generation of quantum photon number states. Such sources would utilize high detection efficiency photon energy-resolving single-photon detectors (where the energy resolution is used to detect the photon number) developed at NASA for detection. Sources that fall in the wavelength range from 20 µm to 200 nm are of high interest. Photon number state generation anywhere within this spectral range is also highly desired including emerging photon-number quantum state methods providing advantages over existing techniques. (Stobińska, et al., Sci. Adv. 5 (2019)).

Quantum dot source produced entangled photons with a fidelity of 0.90, a pair generation rate of 0.59, a pair extraction efficiency of 0.62, and a photon indistinguishability of 0.90, simultaneously (881 nm light) at 10 MHz. (Wang, Phys. Rev. Lett. 122, 113602 (2019)). Further advances are sought.

Spectral brightness of 0.41 MHz/mW/nm for multimode and 0.025 MHz/mW/nm for single-mode coupling. (Jabir: Scientific Reports. 7, 12613 (2017)).

Higher brightness and multiple entanglement and heralded multiphoton entanglement and boson sampling sources. Sources that produce photon number states or Fock states are also sought for various applications including energy-resolving single-photon detector applications.

For energy-resolving single-photon detectors, current state-of-the-art multiplexing can achieve kilopixel detector arrays, which with advances in microwave SQUID multiplexing can be increased to megapixel arrays. (Morgan, Physics Today. 71, 8, 28 (2018)).

Energy-resolving detectors achieving 99% detection efficiency have been demonstrated in the NIR. Even higher quantum efficiency absorber structures are sought (either over narrow bands or broadband) compatible with transition-edge sensor (TES) detectors. Such ultra-high- (near-unity-) efficiency absorbing structures are sought in the ultraviolet, vis-IR, NIR, mid-infrared, far-infrared, and microwave.

Absolute detection efficiency measurements (without reference to calibration standards) using quantum light sources have achieved detection efficiency relative uncertainties of 0.1% level. Further reduction in detection efficiency uncertainty is sought to characterize ultra-high-efficiency absorber structures. Combining calibration method with the ability to tune over a range of different wavelengths is sought to characterize cryogenic single-photon detector's energy resolution and detection efficiency across the detection band of interest. For such applications, the natural linewidth of the source lines must be much less than the detector resolution (for NIR and higher photon energies, resolving powers $R=E/\Delta E_{FWHM}=\lambda/\Delta\lambda_{FWHM}$ much greater than 100 are required). Quantum sources operating at cryogenic temperatures are most suitable for cryogenic detector characterization and photon number resolving detection for wavelengths of order 1.6 µm and longer.

For quantum sensing applications that would involve a squeezed light source on an aerospace platform, investigation of low SWaP sources of squeezed light would be beneficial. From the literature, larger footprint sources of squeezed light have demonstrated 15 dB of squeezing (Vahlbruch, et al., Phys. Rev. Lett. 117, 11, 110801 (2016)). For a source smaller in footprint, there has been a recent demonstration of parametric down conversion in an optical parametric oscillator (OPO) resulting in 9.3 dB of squeezing (Arnbak, et al., Optics Express. 27, 26, 37877–37885 (2019)). Further improvement of the state-of-the-art light squeezing capability (i.e., >10 dB), while maintaining low SWaP parameters, is desired.

Relevance / Science Traceability:

Quantum technologies enable a new generation in sensitivities and performance and include low baseline interferometry and ultraprecise sensors with applications ranging from natural resource exploration and biomedical diagnostic to navigation.

Human Exploration and Operations Mission Directorate (HEOMD)—Astronaut health monitoring.

Science Mission Directorate (SMD)—Earth, planetary, and astrophysics including imaging spectrometers on a chip across the electromagnetic spectrum from x-ray through the infrared.

Space Technology Mission Directorate (STMD)—Game-changing technology for small spacecraft communication and navigation (optical communication, laser ranging, and gyroscopes).

Small Business Technology Transfer (STTR)—Rapid increased interest.

Space Technology Roadmap 6.2.2, 13.1.3, 13.3.7, all sensors 6.4.1, 7.1.3, 10.4.1, 13.1.3, 13.4.3, 14.3.3.

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4. European Union Quantum Flagship Program: https://qt.eu (link is external).
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T8.07 Photonic Integrated Circuits (STTR)

Lead Center: GSFC
Participating Center(s): GRC, LaRC

Scope Title: Photonic Integrated Circuits

Scope Description:
Photonic integrated circuits (PICs) generally integrate multiple lithographically defined photonic and electronic components and devices (e.g., lasers, detectors, waveguides/passive structures, modulators, electronic control, and optical interconnects) on a single platform with nanometer-scale feature sizes. PICs can enable size, weight, power, and cost reductions and improve the performance of science instruments, subsystems,

and components. PIC technologies are particularly critical for enabling small spacecraft platforms. Proposals are sought to develop PIC technologies including the design and fabrication of PICs that use nanometer-scale structures and optical metamaterials. On-chip generation, manipulation, and detection of light in a single-material system may not be practical or offer the best performance, so hybrid packaging of different material systems are also of interest. Often the full benefits of photonic integration are only realized when combined with integrated electronics. This subtopic solicits methods, technology, and systems for development and incorporation of active and passive circuit elements for PICs for:

- PICs for in situ and remote sensors—NASA application examples include but are not limited to lab-on-a-chip systems for landers, 3D mapping and spectroscopic lidar systems and components, and optical spectrometers. We are also interested in the integration of active and passive components on chip allowing for optical processing and manipulation of laser spectra (such as optical phase lock loops) with detector bandwidths >30 GHz. Monolithic integration is preferred when plausible, but it is understood that hybrid and heterogeneous integration is also useful.
- PICs for analog radiofrequency (RF) photonics applications—NASA applications require new methods to reduce the size, weight, and power of passive and active RF, microwave, submillimeter, and terahertz signal processing. Example applications include terahertz spectroscopy, microwave radiometry, and hyperspectral microwave sounding needing integrated high-speed electro-optic modulators, optical filters with tens of GHz free-spectral-range and few GHz resolution. Ka-band operation of RF photonic up/down frequency converters and filters need wideband tunability (>10 GHz) and <1 GHz instantaneous bandwidth.

Expected TRL or TRL Range at completion of the Project: 2 to 4

Primary Technology Taxonomy:
Level 1: TX 08 Sensors and Instruments
Level 2: TX 08.1 Remote Sensing Instruments/Sensors

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Hardware

Desired Deliverables Description:
Phase I does not need to include a physical deliverable to the government but it is best if it includes a demonstration of feasibility through measurements. This can include extensive modeling, but a stronger proposal will have measured validation of models or designs.

Phase II should include prototype delivery to the government. (It is understood that this is a research effort and the prototype is a best-effort delivery where there is no penalty for missing performance goals.) The Phase II effort should be targeting a commercial product that could be sold to the government and/or industry.

State of the Art and Critical Gaps:
There is a critical gap between discrete and bulk photonic components and waveguide multifunction PICs. The development of PICs permits size, weight, power, and cost reductions for spacecraft microprocessors, communication buses, processor buses, advanced data processing, and integrated optic science instrument optical systems, subsystems, and components. This is particularly critical for small spacecraft platforms.

Relevance / Science Traceability:
Human Exploration and Operations Mission Directorate (HEOMD)—Astronaut health monitoring.

Science Mission Directorate (SMD)—Earth, planetary, and astrophysics compact science instrument (e.g., optical and terahertz spectrometers and magnetometers on a chip, lidar systems and subsystems).

(See Earth Science and Planetary Science Decadal Surveys)

Space Technology Mission Directorate (STMD)—Game-changing technology for small spacecraft navigation (e.g., laser ranging and gyroscopes).

Small Business Technology Transfer (STTR)—Exponentially increasing interest in programs at universities and startups in integrated photonics.

Space Technology Roadmap 6.2.2, 13.1.3, 13.3.7, all sensors, 6.4.1, 7.1.3, 10.4.1, 13.1.3, 13.4.3, 14.3.3.

References:

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Focus Area 15 Materials Research, Advanced Manufacturing, Structures, and Assembly

As NASA embarks on its mission for human exploration of the Moon as a step towards the human mission to Mars, taking full advantage of the potential offered by new and existing technologies will be critical to enabling sustainable Lunar and Mars presence. The Materials Research, Advanced Manufacturing, Structures and Assembly focus area seeks to address challenges such as lowering the cost of exploration, enabling efficient, reliable operations in extreme environments, and accelerating the integration of advanced tools and technologies into next generation structural designs.

Improvement in all these areas is critical to future missions. Since this focus area covers a broad area of interests, specific topics and subtopics are chosen to enhance and/or fill gaps in the space and exploration technology development programs, as well as to complement other mission directorate materials, manufacturing, structures, and in-space assembly needs.

T12.07 Design Tools for Advanced Tailorable Composites (STTR)

Lead Center: LaRC
Participating Center(s): MSFC

Scope Title: Design Tools for Advanced Tailorable Composites

Scope Description:
Affordable space exploration beyond the lower Earth orbit will require innovative lightweight structural concepts. Use of advanced tailorable composites or hybrid material systems can be one of the means of lightweighting exploration vehicles, space habitats, and other space hardware or to enable challenging performance characteristics such as near-zero thermal dimensional sensitivity of telescope structures while retaining required strength and stiffness. Lightweighting and/or reducing thermal sensitivity stemming from application of novel material systems oftentimes fails to be fully exploited due to the lack of engineering tools enabling structural and thermal-structural tailoring to yield optimal designs. Consequently, highly tailorable material systems are commonly used to produce quasi-isotropic ("black aluminum") or otherwise off-optimal designs.

By recognizing that achieving certain performance requirements might entail using not just layups of similar reinforcing and matrix materials but also the option of integrating dissimilar reinforcement and/or matrix materials resulting in a hybrid material system. This solicitation seeks to advance the design capabilities not only for layered composites but also for hybrid systems. To exploit the full potential of novel structural concepts, applicable composite and hybrid material systems can leverage a broad variety of materials, including but not limited to metallic alloys, short and/or continuous fiber reinforcements, and a variety of matrices (thermoset, thermoplastic, ceramics, and others).

A design tool development for composite and/or a hybrid material system and its demonstration on a relevant structure is sought. The design tool shall be developed leveraging the broadly adopted and accessible engineering codes, including but not limited to MSC.Patran/Nastran, Abaqus, Hypersizer, Hyperworks, LSOPT, etc. Development in a form of "wrapper" or "plug-in" codes is strongly preferred over re-developing functionalities that readily exist and can be incorporated within the design tool. Intuitive user-friendly code interfaces for the design definition setup are also highly desirable.

The ability to predict performance based on tailorable composite or a hybrid material system integrated in the most optimal way shall be demonstrated on a study case representative of a space exploration hardware, including but not limited to:

- Pressurized structures, e.g.,
    - Crew modules and habitats (including features such as hatches, access, and windows cutouts).
    - Cryogenic tanks.
- Dry and unpressurized structures, e.g.,
    - Thermally stable telescope arrays.
    - Truss structures, such as lander cages or landing gear struts.
    - Other smaller/discrete structural components or portions thereof, such as joints and mechanisms (e.g., brackets, hinges, clevises).

Examples of relevant applications and specific metrics sought include current vehicle architectures being considered for the return to the Moon missions. They are targeted to fit within a 15-ft-diameter shroud, thus tank and habitat maximum dimensions are likely on the order of this 15-ft-diameter constraint. For tanks, nominal operating pressures in the range of 40 to 65 psi are considered common. The internal pressures for habitats can be guided by the International Space Station's internal pressure of 14.7 psi. For thermally stable telescope array and similar applications, passive dimensional thermal stability is sought rather than a solution assisted by an active thermal control. A design based on the minimum 40 Msi elastic modulus in the principal direction and the coefficient of thermal expansion (CTE) of order of 0.01×10^{-6} in./(in. ^{o}F) over a range of 10 ^{o}F is likely required. Tailored/optimized designs shall be manufacturable considering presently available fabrication techniques.

Expected TRL or TRL Range at completion of the Project: 5 to 6

Primary Technology Taxonomy:
Level 1: TX 12 Materials, Structures, Mechanical Systems, and Manufacturing
Level 2: TX 12.2 Structures

Desired Deliverables of Phase I and Phase II:

- Analysis
- Software
- Research

Desired Deliverables Description:
Phase I of the award shall deliver a proposed implementation of the design tool with a functioning code, however its capabilities can be truncated relative to the overall proposed development. The truncated code shall include enough capabilities to be able to produce a simplified demonstration case that would also constitute a part of the Phase I deliverable.

Phase II deliverable shall include a releasable version of the design tool with the complete proposed functionality and a refined demonstration study case. For both Phase I and II developments, an open code architecture is of value such that the end users can gain insight into the implementation and possibly alter or add functionalities. From a practical standpoint, use of Python in conjunction with Abaqus implementation or PCL in conjunction with MSC.Patran/Nastran implementation might be considered examples of "open architectures." Use of an existing design optimization tools, e.g., LSOPT, is also allowed and encouraged.

State of the Art and Critical Gaps:
Present composite designs are typically limited to straight fiber arrangements and lamination stacking sequences resulting in quasi-isotropic material properties. No commercially available design tools exist to produce advanced highly tailorable designs with optimized load paths or minimized effective coefficient of thermal expansion.

Relevance / Science Traceability:
Examples of potential uses include: Space Technology Mission Directorate, Artemis/HLS programs, developers of air-launched systems (e.g., Generation Orbit Launch Services; Science Mission Directorate (SMD) and projects concerned with telescope structure development; Aeronautics Research Mission Directorate) next-generation airframe technology beyond "tube and wing" configurations (e.g., hybrid/blended wing body).

References:

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3. Antunes, N., Dardis, J., Grandine, T., Farmer, B., Hahn, G., Design Optimization of Short Fiber Composite Parts, AIAA-2020-0163, AIAA SciTech Forum, Orlando, FL, 2020.
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Focus Area 16 Ground & Launch Processing

Ground processing technology development prepares the agency to test, process, launch, and recover the next generation of rockets and spacecraft in support of NASA's exploration objectives by developing the necessary ground systems, infrastructure and operational approaches for terrestrial and off-planet surface systems. This topic seeks innovative concepts and solutions for both addressing long-term ground processing and test complex operational challenges and driving down the cost of government and commercial access to space. Technology infusion and optimization of existing and future operational programs, while concurrently maintaining continued operations, are paramount for cost effectiveness, safety assurance, and supportability.

A key aspect of NASA's approach to long term sustainability and affordability is to make test, processing and launch infrastructure available to commercial and other government entities, thereby distributing the fixed cost burden among multiple users and reducing the cost of access to space for the United States.

Unlike previous work focusing on a single kind of launch vehicle such as the Saturn V rocket or the Space Shuttle, NASA is preparing common infrastructure to support several different kinds of spacecraft and rockets that are in development. Products and systems devised at a NASA center could be used at other launch sites on earth and eventually on other planets or moons.

Specific emphasis to substantially reduce the costs and improve safety/reliability of NASA's test and launch operations includes development of ground test and launch environment technology components, system level ground test systems for advanced propulsion, autonomous control technologies for fault detection, isolation, and recovery, including autonomous propellant management, and advanced instrumentation technologies including Intelligent wireless sensor systems.

T13.01 Intelligent Sensor Systems (STTR)

Lead Center: SSC
Participating Center(s): N/A

Scope Title: Advanced Instrumentation for Rocket Propulsion Testing

Scope Description:
Rocket propulsion system development is enabled by rigorous ground testing to mitigate the propulsion system risks inherent in spaceflight. Test articles and facilities are highly instrumented to enable a comprehensive analysis of propulsion system performance. Advanced instrumentation has the potential for substantial reduction in time and cost of propulsion systems development, with substantially reduced operational costs and evolutionary improvements in ground, launch, and flight system operational robustness.

Advanced instrumentation would provide a wireless, highly flexible instrumentation solution capable of measurement of heat flux, temperature, pressure, strain, and/or near-field acoustics. Temperature and pressure measurements must be acquired from within the facility mechanical systems or the rocket engine itself. These advanced instruments should function as a modular node in a sensor network, capable of performing some processing, gathering sensory information, and communicating with other connected nodes in the network. The collected sensor network must be capable of integration with data from conventional data acquisition systems adhering to strict calibration and timing standards to support static propulsion system testing standards. Synchronization with Inter-Range Instrumentation Group—Time Code Format B (IRIG-B) and National Institute of Standards and Technology (NIST) traceability is critical to propulsion test data analysis.

Rocket propulsion test facilities also provide excellent testbeds for testing and using the innovative technologies for possible application beyond the static propulsion testing environment. These sensors would be capable of addressing multiple mission requirements for remote monitoring such as vehicle health monitoring in flight systems, autonomous vehicle operation, or instrumenting inaccessible measurement locations, all while eliminating cabling and auxiliary power. It is envisioned this advanced instrumentation would support sensing and control applications beyond those of propulsion testing. For example, inclusion of expert system or artificial intelligence technologies might provide great benefits for autonomous operations, health monitoring, or self-maintaining systems.

This subtopic seeks to develop advanced wireless instrumentation capable of performing some processing, gathering sensory information, and communicating with other connected nodes in the network. Sensor systems must provide the following functionality:

- Wireless acquisition and conversion to engineering units for quantifying heat flux, temperature, pressure, strain, and/or near-field acoustics such that it contributes to rocket engine system performance analysis within established standards for error and uncertainty.
- Self-contained to collect information and relay measurements through various means by a sensor-web approach to provide a self-healing, autoconfiguring method of collecting data from multiple sensors, and relaying for integration with other acquired datasets.
- Function reliably in extreme environments, including rapidly changing ranges of environmental conditions, such as those experienced in space. These ranges may be from extremely cold temperatures, such as cryogenic temperatures, to extremely high temperatures, such as those experienced near a rocket engine plume.
- Capable of in-place calibrations with NIST traceability.
- Collected data must be time-stamped to facilitate analysis with other collected datasets.
- Transfer data in real time to other systems for monitoring and analysis.
- Interface to flight-qualified sensor systems, which could be used for multivehicle use.
- Determine the quality of the measurement and instrument state of health.

This subtopic is specifically not interested in structural health monitoring applications; specifically, Fiber-Bragg-related sensors, which have been under development for a few decades. Those type of proposals will be considered outside of the scope for this subtopic.

Expected TRL or TRL Range at completion of the Project: 3 to 6

Primary Technology Taxonomy:
Level 1: TX 13 Ground, Test, and Surface Systems
Level 2: TX 13.1 Infrastructure Optimization

Desired Deliverables of Phase I and Phase II:

- Prototype
- Hardware
- Software

Desired Deliverables Description:
For all above technologies, research should be conducted to demonstrate technical feasibility with a final report at Phase I and show a path towards Phase II hardware/software demonstration with delivery of a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

State of the Art and Critical Gaps:
Highly modular, remote sensors are of interest to many NASA tests and missions. Real-time data from sensor networks reduces risk and provides data for future design improvements. Wireless sensors offer a highly flexible solution for scientists and engineers to collect data remotely. They can be used for thermal, structural, and acoustic measurement of systems and subsystems and provide emergency system halt instructions in the case of leaks, fire, or structural failure. Other examples of potential NASA applications include (1) measuring temperature, strain, voltage, and current from power storage and generation systems, (2) measuring pressure, strain, and temperature in pumps and pressure vessels, and (3) measuring strain in test structures and ground support equipment and vehicles, including high-risk deployables.

There are many other applications that would benefit from increased real-time sensing in remote hard-to-test locations. For example, sensor networks on a vehicle body can give measurement of temperature, pressure, strain, and acoustics. This data is used in real time to determine safety margins and test anomalies. The data is also used post-test to correlate analytical models and optimize vehicle and test design. Because these sensors are small and low mass, they can be used for ground test and for flight. Sensor module miniaturization will further reduce size, mass, and cost.

No existing wireless sensor network option meets NASA's current needs for flexibility, size, mass, and resilience to extreme environments.

Relevance / Science Traceability:
This subtopic is relevant to the development of liquid propulsion systems development and verification testing in support of the Human Exploration and Mission Operations Directorate. It supports all test programs at Stennis Space Center (SSC) and other propulsion system development centers, and potential advocates are the Rocket Propulsion Test (RPT) Program Office and all rocket propulsion test programs at SSC.

References:

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2. J. Schmalzel; F. Figueroa; J. Morris; S. Mandayam; R. Polikar, "An architecture for intelligent systems based on smart sensors," IEEE Transactions on Instrumentation and Measurement (Volume: 54, Issue: 4, Aug. 2005).
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4. David J. Coote, Kevin P. Power, Harold P. Gerrish, Glen Doughty, "Review of Nuclear Thermal Propulsion Ground Test Options," 51st AIAA/SAE/ASEE Joint Propulsion Conference, AIAA Propulsion and Energy Forum (AIAA 2015-3773).
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9. Propulsion Test Data Acquisition and Control Systems (DACS), https://www.nasa.gov/centers/wstf/pdf/397001main_Prop_test_data_acq_cntl_sys_DACS_doc.pdf

Focus Area 18 Air Vehicle Technology

This focus area includes tools and technologies that contribute to both the Advanced Air Vehicles Program (AAVP) and the Transformative Aeronautics Concepts Program (TACP) encompassing technologies in all six Strategic Thrusts within the NASA Aeronautics Mission Directorate (ARMD). AAVP develops knowledge, technologies, tools, and innovative concepts to enable safe new aircraft that will fly faster, cleaner, and quieter and use fuel far more efficiently than in the past. AAVP advanced, integrated technologies and capabilities improve vehicle performance and intrinsic safety by reducing fuel usage, noise, and emissions. Fuel efficiency and environmental factors will play an increasingly significant role as the aviation market grows in capacity.

Partnering with industry, academia, and other government agencies, AAVP pursues mutually beneficial collaborations to leverage opportunities for effective technology transition. TACP encourages revolutionary concepts, creates the environment for researchers to experiment with new ideas, performs ground and small-scale flight tests, and drives rapid turnover into potential future concepts to enable aviation transformation. Research is organized to aggressively engage both the traditional aeronautics community and non-traditional partners. Although TACP focuses on sharply focused studies, the program provides flexibility for innovators to assess new-technology feasibility and provide the knowledge base for radical aeronautics advances.

T15.04 Full-Scale (2+ Passenger) Electric Vertical Takeoff and Landing (eVTOL) Scaling, Performance, Aerodynamics, and Acoustics Investigations (STTR)

Lead Center: AFRC
Participating Center(s): ARC, GRC, LaRC

Scope Title: Full-Scale (2+ Passenger) Electric Vertical Takeoff and Landing (eVTOL) Scaling, Performance, Aerodynamics, and Acoustics Investigations

Scope Description:
NASA's Aeronautics Research Mission Directorate (ARMD) laid out a Strategic Implementation Plan for aeronautical research aimed at the next 25 years and beyond. The documentation includes a set of Strategic Thrusts—research areas that NASA will invest in and guide. It encompasses a broad range of technologies to meet future needs of the aviation community, the nation, and the world for safe, efficient, flexible, and environmentally sustainable air transportation. Furthermore, the convergence of various technologies will also enable highly integrated electric air vehicles to be operated in domestic or international airspace. This subtopic supports ARMD’s Strategic Thrusts #1 (Safe, Efficient Growth in Global Operations), #3 (Ultra-Efficient Commercial Vehicles), and #4 (Safe, Quiet, and Affordable Vertical Lift Air Vehicles).

Proposals are sought in the following areas: (1) design and execution of experiments to gather research-quality data to validate aerodynamic and acoustic modeling of full-scale, multirotor eVTOL aircraft, with an emphasis on rotor-rotor interactions and (2) development and validation of scaling methods for extending and applying the results of instrumented subscale model testing to full-scale applications. This solicitation does not seek proposals for designs or experiments that do not address full-scale eVTOL applications. Full-scale is defined as a payload capacity equivalent to two or more passengers, including any combination of pilots, passengers, or ballast.

Proposals should address the following if applicable:

(1) Clearly define the data that will be provided and how it will help NASA and the community accelerate the design cycle of full-scale eVTOL aircraft. Also define what data will be collected and data that will be considered proprietary. Data includes vehicle specifications, models, results, flight test data, and any other information relative to the work proposed.

(2) If the proposal cannot address the full topic, please state a reasoning/justification.

(3) Clearly propose a path to commercialization and include detail with regards to the expected products, data, stakeholders, and potential customers.

Expected TRL or TRL Range at completion of the Project: 2 to 6

Primary Technology Taxonomy:
Level 1: TX 15 Flight Vehicle Systems
Level 2: TX 15.1 Aerosciences

Desired Deliverables of Phase I and Phase II:

- Software
- Hardware
- Analysis
- Research
- Prototype

Desired Deliverables Description:
Expected deliverables of Phase I awards may include but are not limited to:

- Initial experiment test plans for gathering experimental results related to the aerodynamic and/or acoustic characteristics of a multirotor eVTOL aircraft, with an emphasis on interactions between rotors and between the rotors and the vehicle structure for either:
    - A full-scale flight vehicle.
    - A subscale vehicle with fully developed methods for scaling the results to full scale.
- Expected results for the flight experiment using appropriate design and analysis tools.
- Design (CAD, OpenVSP, etc.) and performance models for the vehicle used to generate the expected results.
- Preliminary design of the instrumentation and data recording systems to be used for the experiment.
- Final report.

Expected deliverables of Phase II awards may include but are not limited to:

- Experimental results that capture aerodynamic and/or acoustic characteristics of a multirotor eVTOL aircraft, with an emphasis on interactions between rotors and between the rotors and the vehicle structure for either:
    - A full-scale flight vehicle.
    - A subscale vehicle with results extrapolated to full scale.
- Design (e.g., CAD, OpenVSP, etc.) and performance models for the experimental vehicle.
- Experimental data along with associated as-run test plans and procedures.
- Details on the instrumentation and data logging systems used to gather experimental data.
- Comparisons between predicted and measured results.
- Final report.

State of the Art and Critical Gaps:
Integration of Distributed Electric Propulsion (DEP) (4+ rotors) systems into Advanced Air Mobility eVTOL aircraft involves multidisciplinary design, analysis, and optimization (MDAO) of several disciplines in aircraft technologies. These disciplines include aerodynamics, propulsion, structures, acoustics, and/or control in traditional aeronautics-related subjects. Addressing ARMD's Strategic Thrust #1 (Safe, Efficient Growth in Global Operations), #3 (Ultra-Efficient Commercial Vehicles), and #4 (Safe, Quiet, and Affordable Vertical Lift Air Vehicles) innovative approaches in designing and analyzing highly integrated DEP eVTOL aircraft are needed to reduce the energy use, noise, emissions, and safety concerns. Due to the rapid advances in DEP-enabling technologies, current state-of-the-art design and analysis tools lack sufficient validation against full-scale eVTOL flight vehicles. This is especially true in the areas of aerodynamics and acoustics.

Relevance / Science Traceability:
This subtopic supports ARMD's Strategic Thrusts #1 (Safe, Efficient Growth in Global Operations), #3 (Ultra-Efficient Commercial Vehicles), and #4 (Safe, Quiet, and Affordable Vertical Lift Air Vehicles). Specifically, the following ARMD program and projects are highly relevant.

NASA/ARMD/Advanced Air Vehicles Program (AAVP):

- Revolutionary Vertical Lift Technology (RVLT) Project
- Advanced Air Transport Technology (AATT) Project
- Convergent Aeronautics Solutions (CAS) Project

- Transformational Tools and Technologies (TTT) Project
- University Innovation (UI) Project
- Advanced Air Mobility National Campaign

References:

1. ARMD/Advanced Air Transport Technology (AATT) Project: https://www.nasa.gov/aeroresearch/programs/aavp/aatt
2. ARMD/Revolutionary Vertical Lift Technology (RVLT) Project: https://www.nasa.gov/aeroresearch/programs/aavp/rvlt
3. ARMD/Convergent Aeronautics Solutions (CAS) Project: https://www.nasa.gov/aeroresearch/programs/tacp/cas
4. ARMD/Transformational Tools and Technologies (TTT) Project: https://www.nasa.gov/aeroresearch/programs/tacp/ttt
5. ARMD/University Innovation (UI) Project: https://www.nasa.gov/aeroresearch/programs/tacp/ui
6. ARMD Strategic Implementation Plan: https://www.nasa.gov/aeroresearch/strategy
7. ARMD Advanced Air Mobility National Campaign: https://www.nasa.gov/uamgc

Focus Area 23 Digital Transformation for Aerospace

Digital Transformation is the strategic transformation of an organization's products, processes, and capabilities, driven and enabled by rapidly advancing and converging digital technologies, to dramatically enhance the organization's performance and efficiency. These advancing digital technologies include software, cloud computing, data management and analytics, artificial intelligence, mobile access, Internet of Things (IoT), and others. Their convergence is producing major transformations across industries - media and entertainment, retail, advertising, publishing, health care, travel, transportation, etc. Through digital transformation, organizations seek to gain or retain their competitive edge by becoming more aware of and responsive to both customer and employee interests, more agile in testing and implementing new approaches, and more innovative and prescient in pioneering the next wave of products and services.

Central to the success of digital transformation is the pervasive (and often automated) collection and use of data about everything that impacts success--the organization's infrastructure, processes, activities, competencies, products and services, customers, partners, industry, and so on. Organizations can mine this massive, complex, and often unstructured data to develop accurate insights into how to improve organizational performance and efficiency. An organization may also use this data to build models of systems to refine operations, or to train machine learning algorithms to automate processes, provide recommendations, or enhance customer experiences. The digital technologies listed above are essential to generate, collect, transform, mine, analyze, and utilize this data across the enterprise. NASA is undertaking a digital transformation journey to enhance mission success and impact. NASA is engaging digital transformation to:

- Accelerate innovation and knowledge growth
- Support data-informed decisions
- Achieve more complex missions
- Enable pervasive collaboration
- Enhance cost-effectiveness
- Build a digital-savvy workforce

Through this focus area, NASA is seeking to explore and develop technologies that are essential for the Agency's successful digital transformation. Specific innovations being sought in this solicitation are:

- Model-based enterprise, which seeks to create digital models or twins of NASA's enterprise, to enable decision-making with increased insight and velocity primarily for supporting agency operations and evolving infrastructure needs.

- Hyper-realistic Extended Reality (XR) real time visualization technologies for Lunar and subsequent Mars Extravehicular Activity (EVA) surface operations and training with extensibility to similar agency needs.

Details about these applications of digital transformation technologies are in the respective subtopic descriptions.

T11.05 Model-Based Enterprise (STTR)

Lead Center: ARC
Participating Center(s): HQ, LaRC, MSFC, SSC

Scope Title: Model-Based Enterprise, Digitally Interacting Comprehensive Frameworks and Models, and Automated Decision Making for Agency Operations

Scope Description:
Model-based enterprise targets the use of models in any function, from engineering to safety to finance to facilities and more (i.e., Model-Based "Anything" or MBx), to enable high-complexity decision making embodying agile processes to achieve efficiency, accuracy, confidence, and adaptability in support of NASA's mission, programmatic development, and institutional activities.

Consider an example of how Model-Based Systems Engineering (MBSE) is increasing in importance to future projects and programs as demonstrated by the strategic thrust towards "Model-Based Anything" of the Digital Transformation Initiative. At the same time, the nature of work at NASA is increasingly distributed with a workforce that may continue partial telework even after pandemic-related restrictions are relaxed.

As previously indicated, the Agency will need to focus on efforts associated with the new changes in the "Future of Work" at NASA (reference provided in the section below). NASA will likely have fewer people working in buildings post-pandemic, and such buildings may be used differently than at present because many people will be working offsite and less frequently working in NASA facilities—except for special activities and needs. We will need to restructure our present older facilities for this type of change and/or plan to design differently for any new facilities, and we will need models for that.

NASA is seeking specific innovative, transformational, model-based solutions in the area of "Digital Twin" Institutional Management of Health/Automated Decision Support of Agency Facilities, which represents an opportunity to make revolutionary changes in how our Agency conducts business by investing in nascent technologies. The Agency's newly minted Digital Transformation Office is interested in how to help reposition and accelerate the modernization of digital systems that support modern approaches to managing the Agency's aging infrastructure. Recent initiatives in smart city technologies focus on condition-based/preventive maintenance, smart buildings, and smart lighting, which will address pressing Agency facility needs.

The STTR vehicle offers the small business community an opportunity to have a hand in this process towards repositioning and accelerating the modernization of digital systems supporting the Agency's aging infrastructure to:

- Save energy costs due to water and electricity usage that is poorly measured and managed.
- Enable the deployment of nascent technological trends in data-driven decision making and support tools based upon statistical methods to help streamline and improve the efficiency of facility operations and maintenance activities.
- Determine how well technologies using techniques from the previous bullet can be broadly deployed across NASA.
- Enabling new agency-centric insight and management capabilities (building upon center models) to meet evolving future-of-work and other challenges in a more proactive and seamless manner.

At the conclusion of a Phase II effort, we anticipate that offerors should deliver a means to develop a model that is capable of context switching among various categorical factors established according to various levels of granularity including but not limited to the following: independent facility needs, facility inventory lifecycle balancing needs, workforce needs, etc.

For example, such a model should use past years' data to predict the condition of certain facility systems, and which ones should be invested in first for repairs to improve the return on investment or improve the overall condition and reliability of the facility. A deferred maintenance assessment is conducted at NASA every year or on a 2 to 3-year cycle, where the inventory of buildings at every center is considered, for 27 systems total. A comparison of the current condition of those systems to previous years for each of those building systems is conducted. At the moment, there is a (sometimes categorical, sometimes numerical) mission dependency index (MDI) that comprises six factors (ref. 7), which is used to decide the highest priority for investments.

By the end of Phase II, offerors should have developed a model capable of identifying which of these 27 systems to invest in to increase the overall MDI. For example, given a specific building and the relative condition of its 27 systems, the model should make a recommendation on which systems to focus on for the highest return on investment (ROI) and fastest payback, as not all systems will feasibly be invested in for concurrent improvements.

The model should also be capable of the following:

1. Identifying an optimal sequence of investments for which systems and which projects should be undertaken first.
2. Be scalable and be capable of prioritizing project(s) by looking at 27 systems to identify the best investments based on a large number of buildings (e.g., 100 or more).
3. Capable of identifying macro-level systemic issues throughout the entire facility inventory from independent predictions made at the local level.

Several years of data (potentially up to 10 years) can be supplied to support the development of these enhanced features of such a model as well.

However, it should be noted that it is easier to provide data for **specific** facility-level improvements rather than for facility **inventory** optimization due to the diverse and nontraditional set of facility functions that NASA as an Agency is challenged with due to unique mission needs and requirements. Data to support this type of macro-level analysis is not readily available, e.g., on the quality of the spaces.

However, at the local level, there are a limited number of high-performance modern facilities in the Agency that may offer very granular levels of detail to inform the development of a model that could effectively be used to address post-pandemic facility **layout** optimization needs, e.g., due to social distancing requirements, etc.

Expected TRL or TRL Range at completion of the Project: 4 to 6

Primary Technology Taxonomy:
Level 1: TX 11 Software, Modeling, Simulation, and Information Processing
Level 2: TX 11.X Other Software, Modeling, Simulation, and Information Processing

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Hardware
- Software

Desired Deliverables Description:
Phase I Deliverables – Reports identifying use cases, proposed tool views/capabilities, identification of NASA or industry leveraging and/or integration opportunities, test data from proof-of-concept studies, and designs for Phase II.

Phase II Deliverables – Delivery of models/tools/platform prototypes that demonstrate capabilities or performance over the range of NASA target areas identified in use cases. Working integrated software framework capable of direct compatibility with existing programmatic tools.

State of the Art and Critical Gaps:
Outside of NASA, industry is rapidly advancing Model-Based Systems Engineering (MBSE) tools and scaling them to larger, more complex development activities. Industry sees scaling as a natural extension of their ongoing digitization efforts. These scaling and extension efforts will result in reusable, validated libraries containing models, model fragments, patterns, contextualized data, etc. They will enable the ability to build upon, transform, and synthesize new concepts and missions, which has great attraction to both industry and government alike. Real-time collaboration and refinement of these validated libraries into either “single source” or “authoritative sources” of truth provide further appeal as usable knowledge can be pulled together much more quickly from a far wider breadth of available knowledge than was ever available before.

One example of industry applying MB/MBe/MBSE is through Digital Thread™, a communication framework that helps facilitate an integrated view and connected data flow of the product's data throughout its lifecycle. In other words, it helps deliver the right information at the right time and at the right place. Creating an “identical” copy (sometimes referred to as a "digital twin") is another use, a digital replica of potential and actual physical assets, processes, people, places, systems, and devices that can be used for various purposes. These twins are used to conduct virtual cost/technical trade studies, virtual testing, virtual qualification, etc., that are made possible through an integrated model-based network. Given the rise of MBSE in industry, NASA will need to keep pace in order to continue to communicate with industry, manage and monitor supply chain activities, and continue to provide leadership in spaceflight development.

Within NASA, our organization is faced with increasingly complex problems that require better and timelier integration and synthesis of both models and larger sets of data, not only in the systems engineering or MBSE realm, but in the broader MB Institution, MB Mission Management, and MB Enterprise Architecture. NASA is challenged to sift through and pull out the particular pieces of information needed for specific functions, as well as to ensure requirements are traced into designs, tested, and delivered; thus, confirming that the Agency gets what it has paid for. On a broader cross-agency scale, we need to ensure that needed information is available to support critical decisions in a timely and cost-effective manner. All these challenges are addressed through the benefits of model-based approaches. Practices such as reusability, common sources of data, and validated libraries of authoritative information become the norm, not the exception, using an integrated, model-based environment. This model-based environment will contribute to a diverse, distributed business model encompassing multicenter and government-industry partnerships as the normal way of doing business.

Relevance / Science Traceability:
MBx solutions can benefit all NASA Mission Directorates and functional organizations. NASA activities could be a dramatically more efficient and lower risk through MBx support of more automated creation, execution, and completion verification of important agreements, such as international, supply chain, or data use.

References:

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2. Facilities and Real Estate Division (FRED): https://www.nasa.gov/offices/FRED
3. Object Management Group (OMG): https://www.omg.org/
4. Open Model-Based Engineering Environment (OpenMBEE): https://www.openmbee.org/

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6. The Future of Work: https://blogs.nasa.gov/futureofwork/
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T11.06 Extended Reality (Augmented Reality, Virtual Reality, Mixed Reality, and Hybrid Reality) (STTR)

Lead Center: JSC
Participating Center(s): GSFC, KSC

Scope Title: Extended Reality (XR) Extravehicular Activity (EVA) Surface Operations and Training Technologies

Scope Description:
Future NASA lunar missions will last much longer, be more complex, and face more challenges and hazards than were faced during the Apollo missions. These new missions will require that astronauts have the very best training and real-time operations support tools possible because a single error during task execution can have dire consequences in the hazardous lunar environment.

Training for lunar surface EVA during the Apollo era required the use of physical models in labs, large hangars, or outdoor facilities. These support modalities had inherent detractors such as the background environments that included observers, trainers, cameras, and other objects. These detractors reduced the immersiveness and overall efficacy of the system. Studies show that the more “real” a training environment is, the better the training is received. This is because realism improves “muscle memory,” which is critically important, especially in hazardous environments. XR systems can be made that mitigate the distractors posed by observers, trainers, background visuals, etc., which was not possible in Apollo-era environments. The virtual environments that can be created are so “lifelike” that it can be extremely difficult to determine when someone is looking at a photograph of a real environment or a screen captured from a digitally created scene. XR systems also allow for training to take place that is typically too dangerous (e.g., evacuation scenarios that include fire, smoke, or other dangerous chemicals), too costly (buildup of an entire habitat environment with all their subsystems), not physically possible (e.g., incorporation of large-scale environments in a simulated lunar/Mars environment), and a system that is easily and much more cost effective to reconfigure for different mission scenarios (i.e., it is easier, quicker, and less expensive to modify digital content than to create or modify physical mockups or other physical components).

The objective of this subtopic is to develop, and mature XR technologies related to EVA activities being used for lunar and subsequent Mars surface operations. NASA’s current plans are to have boots on the surface of the Moon in late 2024. The initial lunar missions will be short in duration and provide limited objectives related to science and exploration and instead focus on the checkout of core vehicle systems. Current XR capabilities will provide support for these missions, but the scope of this subtopic will focus on the technologies that can support subsequent missions where the mission duration is longer and where science, exploration, and lunar infrastructure development are higher in priority.

The three key technology areas of interest for this subtopic include:

- A comprehensive hyperrealistic XR real-time visualization system that includes multiresolution terrain, where any location astronauts carry out activities would have highly detailed resolution terrain (centimeter or lower resolution), and areas where astronauts will not carry out activities, will have adequate resolution to provide the appropriate contextual situational awareness. Also, the system should have photorealistic and interactive representative geological features (e.g., rocks, soil, cliff faces, lava tubes, etc.) incorporated, photorealistic avatars of astronauts wearing representative space suits that are properly rigged for motion capture/animation, and the assets needed to carry out the missions in the environment (e.g. habitats, landers, rovers, instruments, tools, etc.). Furthermore, the system should allow observers to join the digital environment virtually from a remote location and be able to "tie" their viewpoint to the astronaut's viewpoint or to any location in the scene. The appropriate physics should be adhered to by all the content in the environment.
- High-precision, reliable tracking—This includes multiple-room-based tracking that can provide the geolocation (and object registration) of the physical objects being used. The system must be able to track physical objects that may be part of a larger system (e.g., instruments on a rack) and thus have the ability to overcome limited line-of-sight issues with the external space. Also, tracking of the hands/fingers accurately and reliably is important.
- The system should allow for a real-time two-person redirected walking capability that allows two individuals to walk around in a very large virtual reality (VR) digitally created terrain environment, while physically present in a small conference-room-sized environment. The system should also allow the astronauts to walk around the environment without colliding.

Although the context of the technologies listed are focused on their use for lunar and subsequent Mars surface EVA activities, these technologies are crosscutting in nature and have applications in many other areas across NASA.

Expected TRL or TRL Range at completion of the Project: 3 to 6

Primary Technology Taxonomy:
Level 1: TX 11 Software, Modeling, Simulation, and Information Processing
Level 2: TX 11.3 Simulation

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Hardware
- Software

Desired Deliverables Description:
Phase I awards will be expected to develop theoretical frameworks, algorithms, and demonstrate feasibility (TRL 3) of the overall system (both software and hardware). Phase II awards will be expected to demonstrate the capabilities with the development of a prototype system that includes all the necessary hardware and software elements (TRL 6).

As appropriate for the phase of the award, Phases I and II should include all the algorithms and research results clearly depicting metrics and performance of the developed technology in comparison to state of the art (SOA). Software implementation of the developed solution along with the simulation platform must be included as a deliverable.

State of the Art and Critical Gaps:
Video game programmers and computer modeling artists are currently leading the industry in SOA for hyperrealistics, real-time VR environment development. Applying these concepts, along with human-computer interface methods to areas outside of the video game industry is known as "gamification." New gamification concepts are increasing the realism, immersion, and ways that users can interact with the XR systems. Companies like NVIDIA, Microsoft, Apple, Facebook, and others are developing XR capabilities that are pushing the boundaries on what is possible in XR across the spectrum, but small companies are also making significant contributions to many areas and finding innovative solutions for XR needs and gaps. Although work has been expended in industry to address several XR challenges, there is quite a bit of work left to develop consistent, reliable, and robust solutions that address specific gaps related to the XR high-interest areas for this subtopic that include:

- Redirected walking (RW)—RW has been implemented successfully for large physical environments for one individual in the scene. Research papers and concepts have been published that show how one could approach the development of a redirectly walking system for smaller spaces. Furthermore, there is published research related for the development of a system that can have two individuals in the scene while wearing a VR head-mounted display (HMD) and adjusting the visuals so that the individuals do not run into each other. Successfully implementation of the research and concepts is required.
- Real-time hyperrealistic rendering of large virtual environments that includes a high level of detail terrains (appropriate details for surface operations) and object models (instruments, tools, facilities, etc.).
- Highly accurate torso, finger, hand, and object tracking for multiple rooms, which includes tracking of objects that may have limited visibility with the exterior environment.
- Novel human-computer interface methods.

Relevance / Science Traceability:
XR technologies can facilitate many missions, including those related to human space exploration. The technology can be used during the planning, training, and operations support phase. The Human Exploration and Operations Mission Directorate (HEOMD), Space Technology Mission Directorate (STMD), and Science Mission Directorate (SMD), Artemis, and Gateway programs could benefit from this technology for various missions. Furthermore, the crosscutting nature of XR technologies allows it to support all of NASA's Directorates.

- Human Exploration and Operations: https://www.nasa.gov/directorates/heo/index.html
- Space Technology Mission Directorate: https://www.nasa.gov/directorates/spacetech/home/index.html
- NASA Science: Share the Science: https://science.nasa.gov/
- Artemis: https://www.nasa.gov/specials/artemis/
- NASA's Gateway: https://www.nasa.gov/gateway

References:

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2. NASA Tests Mixed Reality, Scientific Know-How, and Mission Operations for Exploration: https://www.nasa.gov/feature/ames/analog-missions-mixed-reality
3. The Past, Present and Future of XR for Space Exploration: http://www.modsimworld.org/papers/2019/MODSIM_2019_paper_43.pdf
4. See Photos of How Astronauts Trained for the Apollo Moon Missions: https://www.history.com/news/moon-landing-apollo-11-training-photos
5. How To Effectively Use XR Training In High-Risk Industries: 4 Examples: https://roundtablelearning.com/how-to-effectively-use-xr-training-in-high-risk-industries/

6. Training for space: Astronaut training and mission preparation: https://www.nasa.gov/centers/johnson/pdf/160410main_space_training_fact_sheet.pdf
7. Towards Virtual Reality Infinite Walking: Dynamic Saccadic Redirection: https://research.nvidia.com/publication/2018-08_Towards-Virtual-Reality
8. Virtual and Augmented Reality: 15 Years of Research on Redirected Walking in Immersive Virtual Environments: https://www.cs.purdue.edu/cgvlab/courses/490590VR/notes/VRLocomotion/15YearsOfRedirectedWalking.pdf
9. An Immersive Multi-User Virtual Reality for Emergency Simulation Training: Usability Study: https://www.immersivelearning.news/tag/multi-user/

Appendices

Appendix A: Technology Readiness Level (TRL) Descriptions

The Technology Readiness Level (TRL) describes the stage of maturity in the development process from observation of basic principles through final product operation. The exit criteria for each level document that principles, concepts, applications, or performance have been satisfactorily demonstrated in the appropriate environment required for that level. A relevant environment is a subset of the operational environment that is expected to have a dominant impact on operational performance. Thus, reduced gravity may be only one of the operational environments in which the technology must be demonstrated or validated in order to advance to the next TRL.

TRL	Definition	Hardware Description	Software Description	Exit Criteria
1	Basic principles observed and reported.	Scientific knowledge generated underpinning hardware technology concepts/applications.	Scientific knowledge generated underpinning basic properties of software architecture and mathematical formulation.	Peer reviewed publication of research underlying the proposed concept/application.
2	Technology concept and/or application formulated.	Invention begins, practical application is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture.	Practical application is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture. Basic properties of algorithms, representations and concepts defined. Basic principles coded. Experiments performed with synthetic data.	Documented description of the application/concept that addresses feasibility and benefit.
3	Analytical and experimental critical function and/or characteristic proof of concept.	Analytical studies place the technology in an appropriate context and laboratory demonstrations, modeling and simulation validate analytical prediction.	Development of limited functionality to validate critical properties and predictions using non-integrated software components.	Documented analytical/experimental results validating predictions of key parameters.
4	Component and/or breadboard validation in laboratory environment.	A low fidelity system/component breadboard is built and operated to demonstrate basic functionality and critical test environments, and associated performance predictions are defined relative to the final operating environment.	Key, functionally critical, software components are integrated, and functionally validated, to establish interoperability and begin architecture development. Relevant Environments defined and performance in this environment predicted.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of relevant environment.
5	Component and/or breadboard	A medium fidelity system/component brassboard is built and	End-to-end software elements implemented and interfaced with existing	Documented test performance demonstrating

	validation in relevant environment.	operated to demonstrate overall performance in a simulated operational environment with realistic support elements that demonstrates overall performance in critical areas. Performance predictions are made for subsequent development phases.	systems/simulations conforming to target environment. End-to-end software system, tested in relevant environment, meeting predicted performance. Operational environment performance predicted. Prototype implementations developed.	agreement with analytical predictions. Documented definition of scaling requirements.
6	System/sub-system model or prototype demonstration in a relevant environment.	A high fidelity system/component prototype that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate operations under critical environmental conditions.	Prototype implementations of the software demonstrated on full-scale realistic problems. Partially integrate with existing hardware/software systems. Limited documentation available. Engineering feasibility fully demonstrated.	Documented test performance demonstrating agreement with analytical predictions.
7	System prototype demonstration in an operational environment.	A high fidelity engineering unit that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate performance in the actual operational environment and platform (ground, airborne, or space).	Prototype software exists having all key functionality available for demonstration and test. Well integrated with operational hardware/software systems demonstrating operational feasibility. Most software bugs removed. Limited documentation available.	Documented test performance demonstrating agreement with analytical predictions.
8	Actual system completed and "flight qualified" through test and demonstration.	The final product in its final configuration is successfully demonstrated through test and analysis for its intended operational environment and platform (ground, airborne, or space).	All software has been thoroughly debugged and fully integrated with all operational hardware and software systems. All user documentation, training documentation, and maintenance documentation completed. All functionality successfully demonstrated in simulated operational scenarios. Verification and Validation (V&V) completed.	Documented test performance verifying analytical predictions.
9	Actual system flight proven through successful mission operations.	The final product is successfully operated in an actual mission.	All software has been thoroughly debugged and fully integrated with all operational hardware/software systems. All documentation has been completed. Sustaining software engineering support is in place. System has been successfully operated in the operational environment.	Documented mission operational results.

Definitions

Brassboard: A medium-fidelity functional unit that typically tries to make use of as much operational hardware/software as possible and begins to address scaling issues associated with the operational system. It does not have the engineering pedigree in all aspects but is structured to be able to operate in simulated operational environments in order to assess performance of critical functions.

Breadboard: A low-fidelity unit that demonstrates function only, without respect to form or fit in the case of hardware, or platform in the case of software. It often uses commercial and/or ad hoc components and is not intended to provide definitive information regarding operational performance.

Engineering Unit: A high-fidelity unit that demonstrates critical aspects of the engineering processes involved in the development of the operational unit. Engineering test units are intended to closely resemble the final product (hardware/software) to the maximum extent possible and are built and tested so as to establish confidence that the design will function in the expected environments. In some cases, the engineering unit will become the final product, assuming proper traceability has been exercised over the components and hardware handling.

Laboratory Environment: An environment that does not address in any manner the environment to be encountered by the system, subsystem, or component (hardware or software) during its intended operation. Tests in a laboratory environment are solely for the purpose of demonstrating the underlying principles of technical performance (functions), without respect to the impact of environment.

Mission Configuration: The final architecture/system design of the product that will be used in the operational environment. If the product is a subsystem/component, then it is embedded in the actual system in the actual configuration used in operation.

Operational Environment: The environment in which the final product will be operated. In the case of spaceflight hardware/software, it is space. In the case of ground-based or airborne systems that are not directed toward spaceflight, it will be the environments defined by the scope of operations. For software, the environment will be defined by the operational platform.

Proof of Concept: Analytical and experimental demonstration of hardware/software concepts that may or may not be incorporated into subsequent development and/or operational units.

Prototype Unit: The prototype unit demonstrates form, fit, and function at a scale deemed to be representative of the final product operating in its operational environment. A subscale test article provides fidelity sufficient to permit validation of analytical models capable of predicting the behavior of full-scale systems in an operational environment

Relevant Environment: Not all systems, subsystems, and/or components need to be operated in the operational environment in order to satisfactorily address performance margin requirements. Consequently, the relevant environment is the specific subset of the operational environment that is required to demonstrate critical "at risk" aspects of the final product performance in an operational environment. It is an environment that focuses specifically on "stressing" the technology advance in question.

Appendix B: STTR and the Technology Taxonomy

NASA's technology development activities expand the frontiers of knowledge and capabilities in aeronautics, science, and space, creating opportunities, markets, and products for U.S. industry and academia. Technologies that support NASA's missions may also support science and exploration missions conducted by the commercial space industry and other Government agencies. In addition, NASA technology development results in applications for the general population, including devices that improve health, medicine, transportation, public safety, and consumer goods.

The 2020 NASA Technology Taxonomy is an evolution of the technology roadmaps developed in 2015. The 2020 NASA Technology Taxonomy provides a structure for articulating the technology development disciplines needed to enable future space missions and support commercial air travel. The 2020 revision is composed of 17 distinct technical-discipline-based taxonomies (TX) that provide a breakdown structure for each technology area. The taxonomy uses a three-level hierarchy for grouping and organizing technology types. Level 1 represents the technology area that is the title of that area. Level 2 is a list of the subareas the taxonomy is a foundational element of NASA's technology management process. NASA's mission directorates reference the taxonomy to solicit proposals and to inform decisions on NASA's technology policy, prioritization, and strategic investments.

The 2020 NASA Technology Taxonomy can be found at:
(https://www.nasa.gov/sites/default/files/atoms/files/2020_nasa_technology_taxonomy_lowres.pdf).

The research and technology subtopics for the STTR program are identified annually by Agency's Center Chief Technologists (CCTs). The CCTs identify high-priority research and technology needs for respective programs and projects.

The table on the following pages relates the current STTR subtopics to the Technology Taxonomy.

2020 TX Mapping Level 1	2020 TX Mapping Level 2	STTR Subtopic Number	Subtopic Title
TX04 - Robotics Systems	TX04.6 - Robotics Integration	T4.01	Information Technologies for Intelligent and Adaptive Space Robotics
TX05 - Communications, Navigation, and Orbital Debris Tracking and Characterization Systems	TX05.5 - Revolutionary Communications Technologies	T5.04	Quantum Communications
		T5.05	Advanced Solar Sailing Technologies
TX06 - Human Health, Life Support, and Habitation Systems	TX06.2 - Extravehicular Activity Systems	T6.08	Textiles for Extreme Surface Environments and High Oxygen Atmospheres
TX07 - Exploration Destination Systems	TX07.1 - In-Situ Resource Utilization	T7.05	Climate Enhancing Resource Utilization
	TX07.2 - Mission Infrastructure, Sustainability, and Supportability	T7.04	Lunar Surface Site Preparation
TX08 - Sensors and Instruments	TX08.1 - Remote Sensing Instruments/Sensors	T8.07	Photonic Integrated Circuits
	TX08.X - Other Sensors and Instruments	T8.06	Quantum Sensing and Measurement
TX10 - Autonomous Systems	TX10.1 - Situational and Self Awareness	T10.05	Integrated Data Uncertainty Management and Representation for Trustworthy and Trusted Autonomy in Space
	TX10.3 - Collaboration and Interaction	T10.03	Coordination and Control of Swarms of Space Vehicles
		T10.04	Autonomous Systems and Operations for the Lunar Orbital Platform-Gateway
TX11 - Software, Modeling, Simulation, and Information Processing	TX11.3 - Simulation	T11.06	Extended Reality (Augmented Reality, Virtual Reality, Mixed Reality, and Hybrid Reality)
	TX11.X - Other Software, Modeling, Simulation, and Information Processing	T11.05	Model-Based Enterprise
TX12 - Materials, Structures, Mechanical Systems, and Manufacturing	TX12.2 - Structures	T12.07	Design Tools for Advanced Tailorable Composites
TX13 - Ground, Test, and Surface Systems	TX13.1 - Infrastructure Optimization	T13.01	Intelligent Sensor Systems
TX 14 Thermal Management Systems	TX 14.1 Cryogenic Systems	T14.01	Advanced Concepts for Lunar and Martian Propellant Production, Storage, Transfer, and Usage
TX15 - Flight Vehicle Systems	TX15.1 - Aerosciences	T15.04	Full-Scale (2+ Passenger) Electric Vertical Takeoff and Landing (eVTOL) Scaling, Performance, Aerodynamics, and Acoustics Investigations

Appendix C: Potential Transition and Infusion Opportunities

NASA has several programs and initiatives that help to drive the Agency's overall mission and goals. Many of the subtopics within the STTR program touch on these mission and goals and are possible areas for STTR funded firms to consider for future technology transition and infusion opportunities. Some examples of where NASA is making investments to meet these goals are:

Climate - NASA is increasing investments in climate research due to the dangers to humanity posed by climate change, including the economic and national security impacts of this threat. These investments increase our ability to better understand our own planet and how it works as an integrated system. This will require an array of instruments, platforms, and missions to deliver the highest priority data to create a 3D view of our Earth, from atmosphere to bedrock. It will also require innovation in clean energy technology, particularly technologies that enable sustainable aviation.

Moon to Mars - NASA will lead an innovative and sustainable program of exploration with commercial and international partners to send humans farther into space and bring back to Earth new knowledge and opportunities.

In addition to those listed above, NASA is making investments in the areas of Commercial Lunar Payload Services (CLPS) and working with several American companies to deliver science and technology to the lunar surface through the CLPS initiative. NASA's Flight Opportunities rapidly demonstrates promising technologies for space exploration, discovery, and the expansion of space commerce through suborbital testing with industry flight providers. The program matures capabilities needed for NASA missions and commercial applications while strategically investing in the growth of the U.S. commercial spaceflight industry. And lastly, conducting experiments on the International Space Station (ISS) is a unique opportunity to eliminate gravity as a variable, provide exposure to vacuum and radiation, and have a clear view of the Earth and space.

Below is a listing of all the STTR subtopics by focus area and a designation if there are potential transition and infusion opportunities that exist within each subtopic. Offerors should think of this as a guide while understanding that NASA is not placing any priority on subtopics or awards that fall under these specific opportunities. Offerors that submit a proposal under a subtopic that is aligned with these opportunities do not increase their chance for an award.

Subtopic #	Subtopic Title	Climate	Moon to Mars	CLPS	Flight Opps	ISS
Focus Area 1 In-Space Propulsion Technologies						
T5.05	Advanced Solar Sailing Technologies				Yes	
Focus Area 3 Autonomous Systems for Space Exploration						
T10.05	Integrated Data Uncertainty Management and Representation for Trustworthy and Trusted Autonomy in Space	Yes	Yes	Yes		Yes
T10.03	Coordination and Control of Swarms of Space Vehicles		Yes	Yes	Yes	Yes
T10.04	Autonomous Systems and Operations for the Lunar Orbital Platform-Gateway		Yes	Yes	Yes	Yes
Focus Area 4 Robotic Systems for Space Exploration						

Subtopic #	Subtopic Title	Climate	Moon to Mars	CLPS	Flight Opps	ISS
T4.01	Information Technologies for Intelligent and Adaptive Space Robotics		Yes	Yes	Yes	Yes
T7.04	Lunar Surface Site Preparation		Yes	Yes	Yes	
Focus Area 5 Communications and Navigation						
T5.04	Quantum Communications		Yes	Yes	Yes	Yes
Focus Area 6 Life Support and Habitation Systems						
T6.08	Textiles for Extreme Surface Environments and High Oxygen Atmospheres		Yes	Yes	Yes	Yes
Focus Area 8 In-Situ Resource Utilization						
T14.01	Advanced Concepts for Lunar and Martian Propellant Production, Storage, Transfer, and Usage		Yes	Yes	Yes	Yes
T7.05	Climate Enhancing Resource Utilization	Yes	Yes			Yes
Focus Area 9 Sensors, Detectors, and Instruments						
T8.06	Quantum Sensing and Measurement		Yes		Yes	Yes
T8.07	Photonic Integrated Circuits		Yes	Yes	Yes	Yes
Focus Area 15 Materials Research, Advanced Manufacturing, Structures, and Assembly						
T12.07	Design Tools for Advanced Tailorable Composites		Yes	Yes	Yes	Yes
Focus Area 16 Ground & Launch Processing						
T13.01	Intelligent Sensor Systems		Yes	Yes	Yes	Yes
Focus Area 18 Air Vehicle Technology						
T15.04	Full-Scale (2+ Passenger) Electric Vertical Takeoff and Landing (eVTOL) Scaling, Performance, Aerodynamics, and Acoustics Investigations	Yes				
Focus Area 23 Digital Transformation for Aerospace						
T11.05	Model-Based Enterprise		Yes			Yes
T11.06	Extended Reality (Augmented Reality, Virtual Reality, Mixed Reality, and Hybrid Reality)		Yes	Yes	Yes	Yes

Appendix D: List of NASA STTR Phase I Clauses, Regulations and Certifications

Introduction

Offerors who plan to submit a completed proposal package to this solicitation will be required to meet specific rules and regulations as part of the submission and if awarded a contract. Offerors should ensure that they are understand these rules and requirements before submitting a completed proposal package to NASA.

Below are the all the clauses, regulations and certifications that apply to Phase I submissions and contracts. Each clause, regulation and certification contain a hyperlink to the webpages from the NASA FAR Supplement, SBIR/STTR Policy Directive, and www.acquisition.gov where you can read about the requirements.

On December 7, 2021, the United States District Court for the Southern District of Georgia Augusta Division (hereinafter "the Court") ordered a nationwide injunction enjoining the Government from implementing Executive Order 14042 in all covered contracts. As a result, NASA will take no action to enforce the clause implementing requirements of Executive Order 14042, absent further written notice from the agency, where the place of performance identified in the contract is in a U.S. state or outlying area subject to a court order prohibiting the application of requirements pursuant to the Executive Order (hereinafter, "Excluded State or Outlying Area"). A current list of such Excluded States and Outlying Areas is maintained at https://www.saferfederalworkforce.gov/contractors/

Federal Acquisition Regulations (FAR) Clauses for Phase I

52.203-19 PROHIBITION ON REQUIRING CERTAIN INTERNAL CONFIDENTIALITY AGREEMENTS OR STATEMENTS.

52.204-6 UNIQUE ENTITY IDENTIFIER.

52.204-7 SYSTEM FOR AWARD MANAGEMENT.

52.204-8 ANNUAL REPRESENTATIONS AND CERTIFICATIONS (DEVIATION 20-02A)

52.204-10 REPORTING EXECUTIVE COMPENSATION AND FIRST-TIER SUBCONTRACT AWARDS.

52.204-13 SYSTEM FOR AWARD MANAGEMENT MAINTENANCE.

52.204-16 COMMERCIAL AND GOVERNMENT ENTITY CODE REPORTING.

52.204-18 COMMERCIAL AND GOVERNMENT ENTITY CODE MAINTENANCE.

52.204-19 INCORPORATION BY REFERENCE OF REPRESENTATIONS AND CERTIFICATIONS.

52.204-22 ALTERNATIVE LINE ITEM PROPOSAL.

52.204-23 PROHIBITION ON CONTRACTING FOR HARDWARE, SOFTWARE, AND SERVICES DEVELOPED OR PROVIDED BY KASPERSKY LAB AND OTHER COVERED ENTITIES.

52.204-24 REPRESENTATION REGARDING CERTAIN TELECOMMUNICATIONS AND VIDEO SURVEILLANCE SERVICES OR EQUIPMENT

52.204-25 PROHIBITION ON CONTRACTING FOR CERTAIN TELECOMMUNICATIONS AND VIDEO SURVEILANCE SERVICES OR EQUIPMENT.

52.204-26 COVERED TELECOMMUNICATIONS EQUIPMENT OR SERVICES - REPRESENTATION.

52.209-6 PROTECTING THE GOVERNMENT'S INTEREST WHEN SUBCONTRACTING WITH CONTRACTORS DEBARRED, SUSPENDED, OR PROPOSED FOR DEBARMENT.

52.215-1 INSTRUCTIONS TO OFFERORS—COMPETITIVE ACQUISITION.

52.215-8 ORDER OF PRECEDENCE—UNIFORM CONTRACT FORMAT.

52.216-1 TYPE OF CONTRACT.

52.219-6 NOTICE OF TOTAL SMALL BUSINESS SET-ASIDE

52.219-28 POST-AWARD SMALL BUSINESS PROGRAM REREPRESENTATION.

52.222-3 CONVICT LABOR.

52.222-21 PROHIBITION OF SEGREGATED FACILITIES.

52.222-26 EQUAL OPPORTUNITY.

52.222-36 EQUAL OPPORTUNITY FOR WORKERS WITH DISABILITIES.

52.222-50 COMBATING TRAFFICKING IN PERSONS.

52.223-6 DRUG-FREE WORKPLACE.

52.223-18 ENCOURAGING CONTRACTOR POLICIES TO BAN TEXT MESSAGING WHILE DRIVING.

52.223-99 ENSURING ADEQUATE COVID-19 SAFETY PROTOCOLS FOR FEDERAL CONTRACTORS (DEVIATION 21-03)

52.225-13 RESTRICTIONS ON CERTAIN FOREIGN PURCHASES.

52.227-1 AUTHORIZATION AND CONSENT.

52.227-11 PATENT RIGHTS—OWNERSHIP BY THE CONTRACTOR.

52.227-20 RIGHTS IN DATA—SBIR PROGRAM.

52.232-2 PAYMENTS UNDER FIXED-PRICE RESEARCH AND DEVELOPMENT CONTRACTS.

52.232-9 LIMITATION ON WITHHOLDING OF PAYMENTS.

52.232-12 ADVANCE PAYMENTS.

52.232-23 ASSIGNMENT OF CLAIMS.

52.232-25 PROMPT PAYMENT.

52.232-33 PAYMENT BY ELECTRONIC FUNDS TRANSFER—SYSTEM FOR AWARD MANAGEMENT.

52.232-39 UNENFORCEABILITY OF UNAUTHORIZED OBLIGATIONS.

52.232-40 PROVIDING ACCELERATED PAYMENTS TO SMALL BUSINESS SUBCONTRACTORS. (DEVIATION 20-03A)

52.233-1 DISPUTES.

52.233-3 PROTEST AFTER AWARD.

52.233-4 APPLICABLE LAW FOR BREACH OF CONTRACT CLAIM.

52.242-15 STOP-WORK ORDER.

52.243-1 CHANGES—FIXED PRICE.

52.246-7 INSPECTION OF RESEARCH AND DEVELOPMENT—FIXED PRICE.

52.246-16 RESPONSIBILITY FOR SUPPLIES.

52.244-6 SUBCONTRACTS FOR COMMERCIAL ITEMS. (DEVIATION 20-03A)

52.249-1 TERMINATION FOR CONVENIENCE OF THE GOVERNMENT (FIXED-PRICE) (SHORT FORM).

52.252-1 SOLICITATION PROVISIONS INCORPORATED BY REFERENCE.

52.252-5 AUTHORIZED DEVIATIONS IN PROVISIONS.

52.253-1 COMPUTER GENERATED FORMS.

52.252-2 CLAUSES INCORPORATED BY REFERENCE.

52.252-6 AUTHORIZED DEVIATIONS IN CLAUSES.

NASA Clauses

Phase I

1852.216-78 FIRM FIXED PRICE.

1852.203-71 REQUIREMENT TO INFORM EMPLOYEES OF WHISTLEBLOWER RIGHTS

1852.204-76 SECURITY REQUIREMENTS FOR UNCLASSIFIED INFORMATION TECHNOLOGY RESOURCES. (DEVIATION 21-01)

1852.215-84 OMBUDSMAN.

1852.219-80 LIMITATION ON SUBCONTRACTING – SBIR PHASE I PROGRAMT. (OCT 2006)

1852.219-83 LIMITATION OF THE PRINCIPAL INVESTIGATOR – SBIR PROGRAM. (OCT 2006)

1852.225-70 EXPORT LICENSES

1852.225-71 RESTRICTION ON FUNDING ACTIVITY WITH CHINA

1852.225-72 RESTRICTION ON FUNDING ACTIVITY WITH CHINA – REPRESENTATION. (DEVIATION 12-01A)

1852.215-81 PROPOSAL PAGE LIMITATIONS.

Additional Regulations

SBA Certifications required for Phase I