National Aeronautics and Space Administration

Small Business

Technology Transfer (STTR)

Phase I

Fiscal Year 2024 Solicitation

Completed Proposal Package Due Date and Time:
March 11, 2024 - 5:00 p.m. ET

Contents

Executive Summary

This solicitation sets the requirements for you, the offeror, to submit a proposal to NASA for Small Business Technology Transfer (STTR) Program Phase I projects in fiscal year (FY) 2024. Chapters 1-8 contain the objectives, deadlines, funding information, eligibility criteria, and instructions to submit a proposal package**.** Chapter 9 contains research and technology topics, categorized by focus areas and subtopics.

The NASA STTR program supports small businesses to create innovative, disruptive technologies that benefit society and may be used in NASA programs and missions, other government agencies, and/or sold in commercial markets. Different from most investors, the NASA STTR Program provides equity-free funding for early or "seed" stage research and development.

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.

Important considerations:

Ensure you have the following registrations complete and up to date. If you are not registered, NASA recommends you start immediately.

- SAM.gov registration at https://sam.gov/. You must have a unique Entity Identifier (UEI)
- Registration with the STTR Firm Registry at https://www.sbir.gov/registration

You must use the Proposal Submissions and Award Management System (ProSAMS) to submit a proposal package. ProSAMS requires firm registration and login and provides a secure connection. To access ProSAMS, go to https://prosams.nasa.gov/.

Agencies must assess the security risks presented by offerors with financial ties or obligations to certain foreign countries. STTR programs may not make awards to businesses with certain connections to foreign entities. See sections 1.1.1 Due Diligence Program to Assess Security Risks and 2.3.1 Disclosures of Foreign Affiliation or Relationships to Foreign Countries for additional details.

1. Program Description

1.1 Legislative Authority and Background

Congress created the Small Business Technology Transfer (STTR) program to support scientific excellence and technological innovation through the investment of federal research funds. The purpose of this investment is to build a strong national economy, strengthen the role of small business in meeting federal research and development needs, increase the commercial application of research results, and foster and encourage participation by socially and economically disadvantaged and women-owned small businesses.

The Small Business Administration (SBA) provides policy through the combined Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs. The SBIR and STTR Extension Act of 2022 amended the Small Business Act *(15 U.S.C. 63*8) to extend the SBIR and STTR programs until September 30, 2025.

1.1.1 Due Diligence Program to Assess Security Risks

The SBIR and STTR Extension Act of 2022 requires NASA, in coordination with the SBA, to establish and implement a due diligence program to assess security risks presented by offerors seeking a federally funded award. As noted above, the NASA SBIR/STTR Programs follow the policies and practices of the SBA SBIR/STTR Policy Directive. Revisions to the Policy Directive are in effect as of May 3, 2023, and can be viewed through the Federal Register Notice. This revision is incorporated into this solicitation, including Appendix III, "Disclosures of Foreign Affiliations or Relationships to Foreign Countries" as reflected in the Disclosures of Foreign Affiliations or Relationships to Foreign Countries form (see section 2.3.1).

In accordance with Section 4 of the SBIR and STTR Extension Act of 2022, NASA will review all proposals submitted in response to this solicitation to assess security risks presented by offerors seeking an SBIR or STTR award. NASA will use information provided by the offeror in response to the Disclosures of Foreign Affiliations or Relationships to Foreign Countries form and the proposal to conduct a risk-based due diligence review on the cybersecurity practices, patent analysis, employee analysis, and foreign ownership of a small business concern, including the financial ties and obligations (which shall include surety, equity, and debt obligations) of the offeror and its employees to a foreign country, foreign person, or foreign entity.

1.2 Purpose and Priorities

This solicitation sets the requirements for you, the offeror, in collaboration with a research institution (RI) to submit a proposal to NASA Small Business Technology Transfer (STTR) Program Phase I projects in fiscal year (FY) 2024. **NASA will release its FY 2024 Phase I STTR solicitation on January 9, 2024. You must submit completed proposal packages by Monday, March 11, 2024, 5:00 p.m. Eastern.**

The Space Technology Mission Directorate (STMD) directs implementation of the NASA SBIR and STTR programs. The NASA SBIR/STTR Program Management Office (PMO), hosted at the NASA

Ames Research Center, operates the programs together with NASA mission directorates and centers. The NASA Shared Services Center (NSSC) manages SBIR and STTR procurements.

Each year NASA's Center Chief Technologists (CCTs) identify the research problems and technology needs that the STTR program will solitict. 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 Technology Taxonomy, see chapter 9.

1.3 Three-Phase Program

NASA STTR projects advance through three phases and are described in detail on the NASA SBIR/STTR website: https://sbir.nasa.gov/.

Phase I

Phase I projects should demonstrate technical feasibility of the proposed innovation and the potential for use in a NASA program or mission and/or the commercial market. The NASA STTR Program does not make awards solely directed toward system studies, market research, routine engineering, development of existing product(s), proven concepts, or modifications of existing products without substantive innovation.

Maximum value and period of performance (POP) for Phase I:

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

Phase II

Phase II proposals continue the research and development started in Phase I to bring the innovation closer to use in a NASA program or mission and/or the commercial market. Phase II requires a more detailed proposal of the technical effort and commercialization strategy. Only Phase I awardees are eligible to submit a Phase II proposal at the conclusion of the Phase I contract. NASA will publish a separate solicitation for Phase II proposals.

Phase II Contracts	STTR
Maximum Contract Value	$850,000
Maximum Period of Performance	24 months

Post-Phase II Opportunities for Continued Technology Development

Phase I and II awards may not be sufficient in either dollars or time to prepare the project for government or commercial use. Therefore, NASA supports small businesses beyond Phase I and II awards with several Post Phase II initiatives. Please refer to the NASA SBIR/STTR website for eligibility, application deadlines, matching requirements and further information.

Phase III

STTR awardees are eligible to receive sole-source Phase III contracts any time after award of their Phase I contracts. In Phase III, customers outside the SBIR and STTR programs—including NASA programs, other government agencies, or the private sector—fund the further development or use of innovative technologies, products, and services resulting from either a Phase I or Phase II award. Please refer to the NASA SBIR/STTR website for Phase III information.

1.4 Availability of Funds

NASA does not commit to fund any proposal or to make a specific number of awards. NASA may elect to make several or no awards in any specific research subtopic. NASA will determine the number of awards based on the level of appropriated funding provided to the program in FY 2024.

NASA will not accept more than 10 proposal packages from any one offeror. NASA does not plan to award more than two (2) STTR contracts to any offeror. See sections 3.1 and chapter 4.

1.5 Eligibility Requirements

1.5.1 Small Business Concern (SBC)

You must submit a certification stating that the SBC meet the size, ownership, and other requirements of the STTR program at the time of proposal package submission, award, and at any other time set forth in SBA's regulations at 13 CFR §§ 121.701-121.705. NASA encourages socially and economically disadvantaged and women-owned SBCs to propose.

1.5.2 SBC Size

You, combined with affiliates, must not have more than 500 employees.

1.5.3 STTR Restrictions on Level of Small Business Participation

You must be the primary performer of the proposed research effort. To be awarded an STTR Phase I contract, you must perform at least 40% of the effort, and a single research institution must perform at least 30% of the effort.

1.5.4 Place of Performance and American-made Products and Equipment

Congress intends that the Awardee of a Funding Agreement under the SBIR/STTR program should, when purchasing any equipment or a product with funds provided through the Funding Agreement, purchase only American-made equipment and products, to the extent possible, in keeping with the overall purposes of this program.

If a rare and unique circumstance exists (for example, if a supply, material, equipment, product, subcontractor/ consultant, or project requirement is not available in the United States), NASA requires you to provide justification by completing the Foreign Vendor Form. This form must be submitted within the Proposal Budget Form, see section 3.1.3.4. NASA will consider a deviation request during contract negotiation and either approve or decline before award.

If a foreign vendor is proposed, the Phase I contract may be delayed or not awarded.
NASA will not approve purchases from or work with countries that appear on the Designated Country list. For reference, please see https://www.nasa.gov/oiir/export-control.

1.5.5 Principal Investigator (PI) Employment Requirement

Requirements	STTR
Primary Employment	Principal investigator must be primarily employed with the SBC or the research institution (RI)
Employment Certification	For Phase I, the principal investigator must be primarily employed with the SBC or the research institution. Primary employment means that more than one-half of the PI employment time is spent in the employ of the SBC or research institution, based on a 40-hour workweek. NASA considers a 19.9-hour or more workweek elsewhere to conflict with this rule.
Co-PIs	Not allowed
Deviation Request	NASA will review any deviation requests during negotiation and either approve or decline before award.
Misrepresentation of Qualifications	If you mispresent qualifications, NASA will decline the proposal package or terminate the contract.
Substitution of PIs	To substitute PIs, you must request approval from NASA after award

1.5.6 Restrictions on Venture-Capital-Owned Businesses

Small businesses owned in majority part by multiple venture capital operating companies, hedge funds, or private equity firms are not eligible to submit a proposal to this 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 as defined in 1.5.1. Include in the proposal package a copy or summary of the joint venture or partnership agreement that includes, at a minimum, a statement of how the workload will be distributed, managed, and charged. See definitions for Joint Ventures along with examples at 13 CFR 121.103(h).

1.5.8 Required Benchmark Transition Rate

More experienced firms (SBCs with 21 or more Phase I awards) must meet performance benchmark requirements to continue participating in SBIR and STTR programs. The purpose of these benchmarks is to ensure that Phase I offerors that have won multiple prior SBIR and STTR awards are progressing towards commercialization. SBA will notify companies failing the benchmarks as well as the relevant officials at participating agencies like NASA.

Please refer to https://www.sbir.gov/performance-benchmarks for more information.

1.6 NASA Technology Available (TAV) for STTR Use

You may use technology developed by NASA, or Technology Available (TAV), on SBIR projects. NASA has over 1,400 patents available for licensing, including many patents related to sensors and materials, and over 1,000 available software applications/tools in the Portfolio and Software Catalog via the NASA Technology Transfer Portal, http://technology.nasa.gov.

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 an offeror 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 you intend 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. Awardees will request the SUA from the appropriate NASA Center Software Release Authority (SRA) after contract award.

1.6.2 Use of NASA Patent

If you intend to use a NASA patent, you must apply for a nonexclusive, royalty-free evaluation license prior to submitting a proposal. After you have identified a patent to license in the NASA patent portfolio (http://technology.nasa.gov), click the link on the patent webpage ("Apply Now to License this Technology") to NASA's Automated Licensing System (ATLAS) to finalize your license with the appropriate field center technology transfer office. You must provide the completed evaluation license application with the proposal following the directions in section 3.1.3.7.

The evaluation license will automatically terminate at the end of the STTR contract. License applications are treated in accordance with federal patent licensing regulations 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.

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. This is a time-consuming process and therefore, NASA does not recommend it for Phase I projects.

1.7 I-Corps™

NASA partners with the National Science Foundation (NSF) to give Phase I awardees the opportunity to participate in the NSF Innovation Corps (I-Corps™) program. I-Corps enables you to conduct customer discovery to learn your customers' needs, to obtain a better understanding of your company's value proposition, and to develop an outline of a business plan for moving forward. This training is designed to lower the market risk inherent in bringing a product or innovation to market, thereby improving the chances for a viable business. For more information on the NASA I-Corps program, visit the NASA SBIR/STTR website.

If you are selected for Phase I contract negotiations, you will be provided the opportunity to opt into and participate in the NASA SBIR/STTR I-Corps program as indicated in section 3.1.3.9.

The amount of funding is up to $25,000 to support participation in the full I-Corps program for STTR awardees. I-Corps awards will be made separately with a modification to the Phase I contract.

1.8 Technical and Business Assistance (TABA)

Under the Small Business Act, you may request a Technical and Business Assistance (TABA) supplement up to $6,500 above the award amount of the Phase I contract. At Phase II, you may request a TABA supplement up to $50,000. If your project is selected for award and the TABA supplement is authorized by NASA, you must use the TABA supplement to contract with one or more vendors to receive services to assist in:

- Making better technical decisions concerning this SBIR project
- Solving technical problems that arise during the conduct of this SBIR project
- Minimizing technical risks associated with this SBIR project
- Commercializing new products and processes resulting from this SBIR project

TABA may include, for example:

- Access to a network of non-NASA scientists and engineers
- Assistance with product sales
- Intellectual property (IP) protections
- Market research
- Market validation
- Development of regulatory and manufacturing plans
- Access to technical and business literature available through online databases

TABA vendors may include private commercialization assistance or business development service providers, public-private partnerships, other entrepreneurial support organizations (ESOs), and attorneys or other IP or licensing professionals. TABA funds may not be used to fund activities conducted internally by the small business awardee.

For information on how to request a TABA supplement at Phase I, please see section 3.1.3.8, Request for Use of Technical and Business Assistance Funds. NASA does not guarantee approval of requests for a TABA supplement. Awardees who receive a TABA supplement must deliver a description of services obtained, and results at completion of their Phase I contract. For reference, see https://www.sbir.gov/node/2088581.

1.9 Small Business Administration (SBA) Applicant Resources

The SBA works with several local partners of various organizational types to train and support potential SBIR/STTR applicants around the country from proposal assistance to SAM registration, and commercialization support to industry connections. To find local assistance visit: https://www.sbir.gov/local-assistance.
To find out more information on the specific types of SBA federal resources available, visit: https://www.sbir.gov/resources.

1.10 Fraud, Waste and Abuse and False Statements

Fraud is "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."

NASA reserves the right to decline any proposal packages that include plagiarism and false claims. Further, 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 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: https://oig.nasa.gov/cyberhotline.html

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

1.11 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 proposal packages, or any other aspect of the SBIR procurement. The clause at NASA Federal Acquisition Regulation (FAR) Supplement (NFS) 1852.215-84 ("Ombudsman") is incorporated into this solicitation.

The cognizant ombudsman is:

Marvin Horne, Procurement Ombudsman
Office of Procurement
NASA Headquarters
Washington, DC 20546-0001
Telephone: 202-358-4483
Email: nhq-dl-op-comp-advocate-vendor-engagement@mail.nasa.gov

In accordance with NFS 1852.215-84, the ombudsman does not participate in any way with the evaluation of proposal packages, the source selection process, or the adjudication of formal contract disputes.

Therefore, before consulting with the ombudsman, you must first address your concerns, issues, disagreements, and/or recommendations to the Contracting Officer for resolution. The process set forth in this solicitation provision (and described at NFS 1852.215-84) does not change your right to file a bid protest or the period in which to timely file a protest.

1.12 General Information

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

To ensure fairness, NASA will not answer questions about the intent and/or content of research subtopics in this solicitation during the open solicitation period.

If you have questions requesting clarification of proposal package instructions and administrative matters, refer to the NASA SBIR/STTR website or contact the NASA SBIR/STTR Helpdesk. **The Helpdesk will not guarantee a timely answer to questions received after March 4, 2024, at 5:00 p.m. ET.**

1. NASA SBIR/STTR Website: http://sbir.nasa.gov
2. Helpdesk:
   a. Email: agency-sbir@mail.nasa.gov
   b. You must provide the name and telephone number of the person to contact, the organization name and address, and the specific questions or requests.

1.13 Definitions

NASA strongly encourages you to review the list of definitions 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.

2. Registrations, Certifications, and Other Information

2.1 Small Business Administration (SBA) Company Registry

You must register with SBA's Company Registry and update your commercialization status. See https://www.sbir.gov/registration. You must provide your unique SBC Control ID (assigned by SBA upon completion of the Company Registry registration) and upload a PDF copy of the SBA Company Registry registration with the Firm Certification From.

2.2 System for Award Management (SAM) Registration

SAM, maintained by the GSA's Federal Acquisition Service, is the primary repository for contractor information required to conduct business with NASA. To be registered in SAM, all mandatory information, including the Unique Entity Identifier (UEI) and a Commercial and Government Entity (CAGE) code, must be validated in SAM. You may obtain information on SAM registration and annual confirmation requirements at https://sam.gov/content/home or by calling 866-606-8220.

You must start the registration process with SAM prior to submitting a proposal package. To be eligible for SBIR awards, you must have an active SAM registration under North American Industry Classification System (NAICS) code 541713 or 541715 at the time of proposal selection.

If you do not have an active SAM registration at the time of proposal selection, you will be ineligible for award. If you have started the registration process but did not complete the registration by the time of proposal selection, you will be ineligible for award.

If you are not registered, you should consider applying for registration immediately upon receipt of this solicitation. Typically, SAM registration and updates to SAM registration take several weeks. NASA recommends to list Purpose of Registration as "All Awards" on your SAM Registration.

2.3 Certifications

You must complete the Firm and Proposal Certifications by answering "Yes" or "No" to certifications as applicable in the Proposal Submissions and Award Management System (ProSAMS). Carefully read each of the certification statements. The Federal Government relies on the information to determine whether you are eligible for a SBIR program award. ProSAMS requires firm registration and login. To access ProSAMS, go to https://prosams.nasa.gov.

NASA uses a similar certification to ensure continued compliance with specific program requirements at time of award and at the time of final payment. 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 invoice certifications and as a condition for payment, a life cycle certification shall be completed in ProSAMS. The life cycle certification 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 you may not meet certain eligibility requirements for award, they may request you provide clarification or supporting documentation. If the Contracting Officer still believes you are not eligible, you must file a size protest with the SBA, who will determine eligibility.

2.3.1 Disclosures of Foreign Affiliation or Relationships to Foreign Countries

You must complete the "Disclosures of Foreign Affiliations or Relationships to Foreign Countries" form as part of your proposal submission. Even if you do not have any foreign relationships, you must complete this form to represent that such relationships do not exist. If you do not submit this form, NASA will decline your proposal during the administrative screening process, and it will not be evaluated. Foreign involvement or investment does not independently disqualify you but failing to disclose such affiliations or relationships may result in denial of an award.

The disclosures require the following information:

- (A) the identity of all owners and covered individuals of the small business concern who are a party to any foreign talent recruitment program of any foreign country of concern, including the People's Republic of China;
- (B) the existence of any joint venture or subsidiary of the small business concern that is based in, funded by, or has a foreign affiliation with any foreign country of concern, including the People's Republic of China;
- (C) any current or pending contractual or financial obligation or other agreement specific to a business arrangement, or joint venture-like arrangement with an enterprise owned by a foreign state or any foreign entity;
- (D) whether the small business concern is wholly owned in the People's Republic of China or another foreign country of concern;
- (E) the percentage, if any, of venture capital or institutional investment by an entity that has a general partner or individual holding a leadership role in such entity who has a foreign affiliation with any foreign country of concern, including the People's Republic of China;
- (F) any technology licensing or intellectual property sales to a foreign country of concern, including the People's Republic of China, during the five-year period preceding submission of the proposal; and
- (G) any foreign entity, offshore entity, or entity outside the United States related to the small business concern.

After reviewing the above listed disclosures, and if determined appropriate by NASA, the program may ask you to provide true copies of any contractual or financial obligation or other agreement specific to a business arrangement or joint venture-like arrangement with an enterprise owned by a foreign state or any foreign entity in effect during the five-year period before proposal submission.

During award, you must regularly report to NASA any changes to a required disclosure.

2.4 Federal Acquisition Regulation (FAR) Certifications and NASA Certifications and Clauses

SAM contains required certifications that you may access at https://www.acquisition.gov/browsefar as part of the required registration (see FAR 4.1102). You must complete these certifications to be eligible for award. You must provide representations and certifications electronically via the website and update the representations and certifications as necessary, and at least annually, to keep them current, accurate, and complete. NASA will not enter any contract if you do not comply with these requirements.

In addition, you will need to be aware of the clauses that will be included in the contract if selected for a contract. For a complete list of FAR and NASA clauses see Appendix C.

2.5 Software Development Standards

If you are proposing projects involving the development of software, you may be required to comply with NASA Procedural Requirements (NPR) 7150.2D, NASA Software Engineering Requirements, available online at https://nodis3.gsfc.nasa.gov/npg_img/N_PR_7150_002D_/N_PR_7150_002D__Preface.pdf.

2.6 Human and/or Animal Subject

NASA requires a protocol approved by a NASA review board if proposed work includes human or animal subjects. **Due to the complexity of the approval process, NASA does not allow use of human and/or animal subjects for Phase I projects.** For additional information, contact the NASA SBIR/STTR Program Office at agency-sbir@mail.nasa.gov. Reference 14 CFR 1230 and 1232.

2.7 Flight Safety Standards

If you are proposing projects involving the delivery of a spacecraft, you must comply with NASA Procedural Requirements (NPR) 8079.1, NASA Spacecraft Conjunction Analysis and Collision Avoidance for Space Environment Protection, available online at https://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=8079&s=1.

2.8 HSPD-12

If your project is selected for award and requires access to federally controlled facilities or access to a federal information system (a*s defined in FAR 2.101(b)(2)*) for 6 consecutive months or more, you must apply for and receive appropriate Personal Identify Verification (PIV) credentials.

FAR clause 52.204-9, Personal Identity Verification of Contractor Personnel, states in part that the contractor must ensure that individuals needing such access provide the personal background and biographical information requested by NASA. See https://nvlpubs.nist.gov/nistpubs/FIPS/NIST.FIPS.201-3.pdf.

3. Proposal Preparation Instructions and Requirements

3.1 Requirements to Submit a Phase I Proposal Package

3.1.1 General Requirements

NASA will be using ProSAMS for the submission of these proposal packages. This solicitation guides firms through the steps for submitting a complete proposal package. All submissions will be completed through the secure ProSAMS URL and most communication between NASA and the firm is through email. To access ProSAMS, go to https://prosams.nasa.gov.

Proposal packages contain a Technical Proposal as described in section 3.1.3.5 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 chapter 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 missions and/or programs, commercial markets, and other potential markets and customers.

Be thoughtful in selecting a subtopic to ensure the proposal is responsive to the subtopic. **NASA will not move a proposal between subtopics or programs.**

Classified Information
NASA will decline any proposal package that contains classified information.

3.1.2 Format Requirements

NASA administratively screens all elements of a proposal package for compliance with format requirements. At its discretion, NASA may decline any proposal package or disregard specific proposal content that exceeds the stated limits when adjusted to comply with format requirements.

Required Page Limits and Suggested Page Lengths
A Phase I technical proposal—all 10 parts including all graphics and table of contents—must not exceed a total of 19 standard letter size (8.5- by 11-inch or 21.6- by 27.9-cm) pages.

NASA will not accept technical proposal uploads with any page(s) over the 19-page limit. The additional forms required for proposal package submission do not count against the 19-page limit.

As a guideline to help you address each part of the technical proposal within the 19-page limit, NASA suggests a page length for each of the 10 parts.

Technical Proposal Part	Suggested Number of Pages
Part 1: Table of Contents	0.5 pages

Part 2: Identification and Significance of Innovation	5 pages
Part 3: Technical Objectives	1 page
Part 4: Work Plan	5 pages
Part 5: Related R/R&D	1 page
Part 6: Key Personnel and Bibliography of Directly Related Work	2.5 pages
Part 7: The Market Opportunity	1 page
Part 8: Facilities/Equipment	1 page
Part 9: Subcontractors and Consultants	1 page
Part 10: Related, Essentially Equivalent, and Duplicate Proposals and Award	1 page

Margins
Use 1.0-inch (2.5 cm) margins.

Type Size
Use type size 10 point or larger for text or tables, except as legends on reduced drawings.

Header/Footer Requirements
Include the SBC name, proposal number, and project title in the header on each page of the proposal. Include the page number and proprietary legend (see section 3.4), if applicable in the footer on each page of the proposal. You may use margins for header/footer information.

Project Title
The proposal project title must be concise and descriptive of the proposed effort. Do not use the NASA research subtopic title, acronyms, or words like "development of" or "study of."

3.1.3 Proposal Package

Each proposal package must 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, subcontractors/consultants, and Foreign Vendor Form, if applicable)
5. Technical Proposal
6. Briefing Chart (must not contain proprietary data)
7. NASA Evaluation License Application, only if NASA Technology Available (TAV) is being proposed
8. Technical and Business Assistance (TABA) request (optional)
9. I-Corps Interest Form
10. SBC-Level Forms (completed once for all proposals submitted to a single solicitation)
    a. Firm Information
    b. Firm Certifications
    c. Audit Information
    d. Disclosures of Foreign Affiliations or Relationships to Foreign Countries Audit Information
    e. Prior Awards Addendum

    f. Commercial Metrics Report (CMR)
11. Electronic Endorsement by the designated small business representative and principal investigator (PI), is completed before the deadline

For many of the required forms, offerors can view sample forms located in the NASA SBIR/STTR Resources website: https://submissions.gsfc.nasa.gov/submissions/learning-support/firm-templates.

What Not to Include
NASA will not consider the following items during evaluation:

- Letters of interest, support, or funding commitment
- Technical papers
- Product samples
- Videos
- Slides
- PowerPoint slide decks
- Other ancillary items

However, all submitted content other than the required forms designated in 1-11 above will count against the proposal page limit.

3.1.3.1 Proposal Contact Information Form

You must provide complete information for each contact person and submit the form as required. **Contact Information is public information and may be disclosed.**

3.1.3.2 Proposal Certifications Form

You must provide complete information for each question in the form and certify its accuracy as required.

3.1.3.3 Proposal Summary Form

You must provide complete information for each section of the form as required. **The Proposal Summary, including the technical abstract, is public information and may be disclosed.**

3.1.3.4 Proposal Budget Form

You must complete the Proposal Budget form following the instructions provided. See 5.5 Profit for Fee and 5.6 Cost Sharing. The total requested funding for the Phase I effort must not exceed $150,000 or $156,500 (if requesting $6,500 for Technical and Business Assistance (TABA), see section 1.8 and 3.1.3.8 for more information on the TABA opportunity).

All proposed cost is supported with documentation, such as a quote, previous purchase order, published price lists, etc. **NASA is not responsible for any monies you expend for proposal preparation and submission.**

In addition, you must submit the following information in the Proposal Budget form, as applicable:

- **Use of a Foreign Vendor.** If you are requesting to purchase products and equipment from a foreign vendor, you must complete the Foreign Vendor Form (see section 1.5.4 for more information).

- **Use of Government Resources.** If you plan to use government resources (such as, services, equipment, facilities, laboratories, etc.), as described in Part 8 of the technical proposal instructions, you must provide the following:
    1. Statement, signed by the appropriate Federal department or agency official, verifying that the resources are available during the proposed period of performance, authorizing their use, and if applicable, including the associated cost.
    2. Signed letter on your company letterhead explaining why your STTR research project requires the use of government resources. Include data that verifies the absence of non-federal facilities or personnel capable of supporting the research effort, and, if applicable, the associated cost estimate.

  Due to the complexity and length of time for the approval process, NASA strongly discourages you from requesting the use of government resources during the performance of a Phase I. Approval for the use of government resources for a Phase I technical proposal requires a strong justification at the time of submission and will require approval by the Contracting Officer during negotiations if selected for award.
- **Use of Subcontractors and Consultants.** You may establish business arrangements with other entities or individuals to perform some of the proposed R/R&D effort, within the limits in section 1.5 and below. Subcontractors' and consultants' work must also be performed in the United States (see section 1.5.4 for more information).

  If you propose using subcontractors or consultants, you must submit the following:
    1. List of consultants by name with the number of hours and hourly costs identified for each consultant.
    2. Subcontractor budget that aligns with your Proposal Budget form and includes direct labor, other direct costs, and profit, as well as indirect rate agreements.
    3. A letter of commitment for each subcontractor and/or consultant, dated and signed by the appropriate person with contact information.
        a. If a university is proposed as a subcontractor, the signed letter must be on the university letterhead from the Office of Sponsored Programs.
        b. If an independent consultant is proposed, the signed letter must not be on university letterhead.

  The proposed subcontracted business arrangements, including consultants, must not exceed 30 percent of the research and/or analytical work. To calculate this percentage, divide the total cost of the proposed subcontracting effort including applicable indirect rates such as overhead and G&A by the total price proposed less profit.

  Percentage of subcontracting effort = (Subcontractor cost + G&A) / (Total price – Profit)

  Example: Total price including profit $150,000
  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 = 20.7%**

***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.

Occasionally, deviations from this requirement may occur, and must be approved in writing by the Contracting Officer after consultation with the NASA STTR PMO.

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 a limited budget, NASA strongly discourages travel during the Phase I contract. If the purpose of the meeting cannot be accomplished via videoconference or teleconference, you must justify the trip in the proposal budget form. The Contracting Officer and Technical Monitor will review travel requests to determine if they are necessary to complete the proposed effort.

3.1.3.5 Technical Proposal

The technical proposal must contain all 10 parts in order, number, and title as listed below. NASA will decline any proposal package that does not have all 10 parts and it will not be evaluated. If a part is not applicable to your proposed effort, you must include the part and mark it "Not applicable." Do not include any budget data in the technical proposal.

Part 1: Table of Contents (Suggested page limit – 0.5 page and counts toward the 19-page limit)
Begin the technical proposal with a brief table of contents indicating the page numbers of each of the parts of the technical proposal).

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 chapter 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 chapter 9.

If you plan to use NASA TAV including Intellectual Property (IP), you must describe planned developments with the IP. Add the NASA Evaluation License Application as an attachment in the Proposal Certifications form (see section 1.6).

Part 4: Work Plan (Suggested page limit – 5 pages)
Include a detailed plan to meet the Phase I technical objectives. The plan must include:

- Detailed task descriptions, that is, what will be done, where it will be done, and the methods you will use to do it
- Schedules
- Resource allocations
- Estimated task hours for each key personnel that match hours reported in the Proposal Budget Form
- Planned accomplishments (including project milestones)
- If the offeror is a joint venture or limited partnership, a statement of how the workload will be distributed, managed, and charged

Part 5: Related R/R&D (Suggested page limit – 1 page)
Describe significant existing R/R&D that is directly related to the technical proposal including any conducted by the PI or by the company. Describe how it relates to the proposed effort and any planned coordination with outside sources. You must demonstrate awareness of key recent R/R&D conducted by others in the specific subject area. Include any pertinent references or publications.

Part 6: Key Personnel and Bibliography of Directly Related Work (Suggested page limit – 2.5 pages)
Identify all 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, you may summarize the most relevant experience or publications.

The PI is key to the success of the effort. The following applies:

- **Functions:** The PI plans and directs the project, leading it technically and making substantial personal contributions during its implementation. The PI also serves as the primary contact with NASA on the project and ensures that work proceeds according to contract agreements. Competent management of PI functions is essential to project success. You must 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:** You must clearly present the qualifications and capabilities of the proposed PI and the basis for PI selection. NASA has the sole right to accept or decline a PI based on factors such as education, experience, demonstrated ability and competence, and any other evidence related to the specific assignment.
- **Eligibility:** You must establish and confirm the eligibility of the PI and indicate if existing projects and other proposals recently submitted or planned commit the time of the PI concurrently with this proposed project. NASA will decline your proposal if you try to circumvent the restriction on PIs working more than half time for an academic or a nonprofit organization by substituting an ineligible PI.

Part 7: The Market Opportunity (Suggested page limit – 1 page)
Describe the potential commercialization approach for the innovation by addressing the following:

- The potential economic benefits associated with your innovation.
- The potential customers and basic go-to-market strategy.
- The potential risks in bringing your innovation to market.

The STTR program is mandated to move funded innovations into federal and private sector commercial markets. Companies that address market opportunities early are better positioned to apply for and receive follow-on STTR contracts, and to commercialize their innovations. **NASA encourages you to use TABA and I-Corps, to help you address market opportunities. See sections 3.1.3.8 for how to request TABA and 3.1.3.9 for opting into I-Corps.**

Part 8: Facilities/Equipment (Suggested page limit – 1 page)
Describe the types, location, and availability of equipment necessary to carry out the work proposed. You must justify any proposed equipment purchase. **When purchasing equipment or a product under the STTR contract, you should purchase only American-made products or equipment.**

Although use of government-furnished laboratory equipment, facilities, or services (collectively, "government resources") is strongly discouraged in Phase I proposals, describe in this part why the use of such government resources is necessary and not reasonably available from the private sector if applicable. See sections 3.1.3.4 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.

If you plan to use a federal laboratory/facility during a follow-on Phase II contract, please state this intent in your Phase I proposal.

Part 9: Subcontractors and Consultants (Suggested page limit – 1 page)

Describe all subcontracting or other business arrangements, including who they are with and for what expertise, functions, services, and number of hours. You must ensure that all organizations and individuals are available for the time periods proposed. The narrative description of subcontractors and consultants in the technical proposal should support the proposed approach and documentation in the Proposal Budget form, section 3.1.3.4.

Part 10: Related, Essentially Equivalent, and Duplicate Proposals and Awards (Suggested page limit – 1 page)
WARNING: It is illegal to enter into multiple funding agreements for essentially equivalent work. While you may submit similar or identical proposals to multiple solicitations, it is risky. You must notify the agencies in advance and resolve the matter prior to award.

If you choose to submit identical proposals or proposals containing a significant amount of essentially equivalent work under other federal program solicitations, you must include a statement in each proposal containing:

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.

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).

3.1.3.6 Briefing Chart

The 1-page briefing chart is required to assist in the ranking of technical proposals prior to selection. Summarize on the provided electronic form:

- Identification and Significance of Innovation
- Technical Objectives and Proposed Deliverables
- NASA Applications
- Non-NASA Applications
- Graphic

The briefing chart is public information and may be disclosed. Do not include proprietary information or International Traffic in Arms Regulation (ITAR)-restricted data. For more information on ITAR see https://www.sbir.gov/tutorials/itar/.

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

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

3.1.3.8 Request for Technical and Business Assistance (TABA) Supplement at Phase I

NASA encourages you to request the TABA supplement of up to $6,500 at Phase I. You will choose your own TABA vendor. NASA cannot direct you to any specific TABA vendor or website. See Section 1.8.

NASA encourages you to use the limited amount of $6,500 Phase I TABA funds for:

1. Development of a Phase II TABA Needs Assessment – If you plan to request a TABA supplement at Phase II, you should secure a TABA vendor at Phase I 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 you would need if the project was selected for a future Phase II award. Phase II TABA supplements may be up to $50,000.
2. Development of a Phase II Commercialization and Business Plan – If you are planning to submit a future proposal for Phase II funding, you will be required to submit a commercialization and business plan that meets the requirements of that future Phase II solicitation. NASA encourages you to use a Phase I TABA supplement to secure a TABA vendor to help develop the commercialization and business plan. The goal of the commercialization and business plan is to allow NASA to evaluate your ability to commercialize the innovation and provide a level of confidence regarding your future and financial viability.

If you request the Phase I TABA supplement, you must do so in the proposal package submission. You are not required to request TABA at Phase I. TABA at Phase II eligibility is not dependent on Phase I TABA participation.

TABA Vendor Information - The TABA request must provide the following information for each vendor according to the directions found in the Budget forms in ProSAMS:

- Contact information of the vendor (name, address, phone number, website)
- Description of vendor(s) expertise and knowledge of providing the desired technical and business assistance services
- Itemized list of services and costs the TABA vendor will provide (vendor quote)
- Description of 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.

All TABA vendors must be legal businesses 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 as incomplete and will not review the TABA request or provide TABA approval under the award.

The TABA supplement is in addition to the Phase I contract award value, is not subject to any profit or fee by the requesting offeror 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. NASA will not consider requests for TABA funding outside of the Phase I period of performance or after a proposal package submission.

3.1.3.9 I-Corps Interest Form

You will complete a short I-Corps interest form as part of your proposal package submission. NASA uses this form to determine the level of interest from Phase I offerors to participate in the NASA I-Corps program. See section 1.7.

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 STTR PMO during contract negotiations describing the process to provide a 5-page proposal to participate in the I-Corps program. NASA will provide directions for completing the proposal including due dates, training dates, and available funding by email.
NASA 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.

3.1.3.10 SBC Level Forms

You must complete all SBC level forms electronically within ProSAMS. The SBC level forms do not count toward the 19-page limit for the technical proposal. To access ProSAMS, go to https://prosams.nasa.gov.

A. Firm Information

You must complete the SBC identifying information once to be applicable across all proposals submitted to this solicitation.

B. Firm Certifications

You must complete the Firm Certifications section of by answering “Yes” or “No” as applicable. An example of the certifications can be found in the NASA SBIR/STTR Resources website: http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html.

C. Audit Information

Although you are not required to have an approved accounting system, it is easier for NASA to determine that your rates are fair and reasonable if you have an approved accounting system. To assist NASA, you must complete the questions in the Audit Information form regarding your 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 you must also complete. If you have 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 uses this Audit Information to assist with negotiations if the proposal package is selected for award. The Contracting Officer will advise you what is required to determine reasonable cost and/or rates in the event the Audit Information is not adequate.

D. Disclosures of Foreign Affiliations or Relationships to Foreign Countries

Each offeror is required to complete the Disclosures of Foreign Affiliations or Relationships to Foreign Countries form as required in ProSAMS. See section 2.3.1 for additional information on these disclosures. You must answer “Yes” or “No” as applicable and provide the requested information related to each “yes” response. Please note that even if you do not have any foreign relationships, you must complete the "Disclosures of Foreign Affiliations or Relationships to Foreign Countries form" to represent that such relationships do not exist. Failure to complete and include this form will result in the declination of your application during the administrative screening.

E. Prior Awards Addendum

If you have 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 you have received any SBIR or STTR Phase II awards, even if fewer than 15 in the last 5 years, NASA still recommends that you complete this form as the information will be useful to you when completing the Commercialization Metrics Report (CMR).

F. Commercialization Metrics Report (CMR)

NASA uses a commercialization report /data-gathering process to track the overall commercialization success of its SBIR and STTR programs. You must complete the Commercialization Metrics Report or update an existing report if applicable, via https://www.sbir.gov/ (the report is available in the "My Dashboard" section of your company's sbir.gov profile) as part of the proposal package submissions process. 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 you have 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 report will also ask you to provide financial, sales, and ownership information, as well as any commercialization success you have had because of SBIR or STTR awards. You must update this information annually during proposal package submission via ProSAMS

CMR input is kept confidential and will not be made public except in broad aggregate, with no company-specific attribution. Do not submit password protected documents.

3.2 Multiple Proposal Submissions

Each proposal must be based on a unique innovation, limited in scope to just one subtopic, and submitted only under that one subtopic within each program. You may not submit more than 10 proposals to the STTR program. You may submit more than one unique proposal to the same subtopic; however, you must not submit the same (or substantially equivalent) proposal to more than one subtopic. If you submit substantially equivalent proposals to several subtopics, NASA may decline all such proposals.

3.3 Understanding the Patent Landscape

You 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.

3.4 Proprietary Information in the Proposal Submission

Limit proprietary information to only that information that is essential to your proposal.

Information contained in unsuccessful proposals remains your property. 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 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 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 you wish to protect:

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

3.5 Release of Certain Proposal Information

In submitting a proposal, you agree 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 your property, and NASA will protect it from public disclosure to the extent permitted by law, including requests submitted under the Freedom of Information Act (FOIA).

4. Method of Selection and Evaluation Criteria

4.1 Phase I Process and Evaluation Criteria

NASA conducts a multi-stage review process of all proposal packages:

1. Administrative review for compliance with Chapters 3 and 6 of the solicitation
2. Initial screening for responsiveness to the subtopic
3. Technical evaluation on a competitive basis (as an "other competitive procedure" in accordance with FAR 6.102(d)(2) and FAR 35.016), using the criteria and procedures set forth within this solicitation
4. Price evaluation
5. Scoring and weighting to determine rating
6. Prioritization
7. Selection
8. Determination of cost/price reasonableness and responsibility

Do not assume that evaluators are acquainted with your company, key individuals, or with any experiments or other information. NASA will judge each proposal on its own merit and will not conduct any tradeoff analyses between or among competed proposals.

4.1.1 Administrative Review

NASA will review all proposal packages received by the published deadline to determine if the proposal package meets the requirements found in chapters 3 and 6. NASA may decline and not evaluate a proposal package that is not compliant with the requirements in chapters 3 and 6. NASA will notify you of its decision to eliminate the proposal package from consideration and the reason(s) for the decision.

4.1.2 Technical Responsiveness

NASA will screen proposal packages that pass the administrative review to determine technical responsiveness to the subtopic of this solicitation. Proposal packages that are not responsive to the subtopic will be declined and not evaluated. NASA will notify you of its decision to eliminate the proposal package from consideration and the reason(s) for the decision. **Ensure your technical proposal is responsive to the subtopic. NASA will NOT evaluate a technical proposal under a subtopic other than the one you select.**

4.1.3 Technical Evaluation Criteria

NASA will evaluate proposal packages that comply with administrative requirements and are technically responsive to the subtopic of this solicitation. Subject matter experts will determine the most promising technical and scientific approaches, based on the following criteria:

Factor 1: Scientific/Technical Merit and Feasibility

NASA will evaluate the proposed effort 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.
- 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 investigator/project manager, 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 equipment 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 3.1.3.4 and part 8 of the technical proposal), will be evaluated for reasonableness.

Factor 3: Effectiveness of the Proposed Work Plan
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
This evaluation factor will consider whether the offeror's proposal has demonstrated a knowledge of the potential economic benefits of the innovation, potential customers including NASA mission programs, other government agency programs, and/or non-government markets and strategies to reach them, as well as risks associated with this approach. If known, offerors may 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).

4.1.4 Price Evaluation

Utilizing the procedures set forth in FAR 15.404-1, NASA will evaluate the budget proposal form to determine whether the 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

NASA will score factors 1, 2, and 3 numerically. Factor 1 is worth 50 points. 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. NASA will assign factor 4 an adjectival rating (Excellent, Very Good, Good, Fair, or Poor).

The most highly rated proposals are eligible for prioritization. To determine the most highly rated 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). 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, and/or geographic distribution when making recommendations.

4.4 Selection

The SSO makes the final decisions to determine the proposals that will enter contract negotiations. The SSO may consider the additional programmatic balance factors identified in Section 4.3 along with the technical merit and commercial potential.

After the SSO selection has been finalized, NASA will post the list of proposals selected for negotiation on the NASA SBIR/STTR website. All SBCs selected by the SSO will receive a formal notification letter. NASA will evaluate each proposal selected for negotiation for cost/price reasonableness. After completion of evaluation for cost/price reasonableness and a determination of responsibility, the Contracting Officer will negotiate and award an appropriate contract to be signed by both parties before work begins.

4.5 I-Corps Evaluation Process

For awardees that submit an I-Corps proposal pursuant to sections 1.7 and 3.1.3.9, NASA will provide a programmatic assessment 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 demonstrates that there is potential for commercialization in both NASA and commercial markets.

Based on the assessment of the above criteria the NASA SBIR/STTR PMO will provide a recommendation to the SSO of I-Corps proposals to receive funding. The SSO will make the final selections. NASA anticipates selecting approximately 4 STTR SBCs 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 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 evaluation of the TABA request to determine if the request meets the requirements found in sections 1.8 and 3.1.3.8 and informs the Contracting Officer of the final determination to allow TABA funding under the contract. NASA will notify you of the approval or denial of TABA funding prior to TABA award.

During this review, NASA will consider:

- If the awardee proposes to 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 contact information.
- The vendor(s) expertise and knowledge in providing the desired technical and business assistance services
- Costs in the vendor quote(s) and whether they are reflected in the budget forms
- Proposed plans to submit a deliverable summarizing the outcome of the TABA services with expected supporting information.
- Any evidence of Fraud, Waste and Abuse.

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 proposal package. In deciding to obtain an outside evaluation, NASA will 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. Outside evaluators will certify that the information (data) contained in the proposal package is for evaluation purposes and will not be further disclosed.

4.7.2 Non-NASA Access to Confidential Business Information

In the conduct of proposal package processing and potential contract administration, NASA may need to provide access to the 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, NASA will send a notification to the designated small business representative identified in the proposal package according to the processes described below.

Due to the competitive nature of the program and limited funding, recommendations to fund or not fund a proposal package are final. NASA will not reconsider selection decisions or provide additional information regarding the final decision. Offerors are encouraged to use the written feedback to understand the outcome and review of their 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 proposal package.

1. At the time of the public selection announcement, NASA will send an email to the designated small business representative indicating the outcome of the 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 agency-sbir@mail.nasa.gov. **Due to the sensitivity of this feedback, NASA will only provide feedback to the designated small business representative and not to any other parties.**

5. Considerations

5.1 Requirements for Negotiations

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 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 proposal package, notify the Contracting Officer immediately.
2. Your SBC is registered with System for Award Management (SAM) (section 2.2).
3. Your SBC 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 C). 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 SBC HAS NOT proposed a co-principal investigator.
5. Your SBC will provide timely responses to all communications from the NSSC Contracting Officer. **Failure to respond in a timely manner to the NSSC Contracting Officer may result in the award being cancelled.**
6. All proposed cost is supported with documentation, such as a quote, previous purchase order, published price lists, etc.

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

5.1.1 Requirements for Contracting

Awardees are required to make certain legal commitments through acceptance of numerous clauses in their Phase I contracts. This list is not a complete list of clauses to be included in Phase I contracts and is not the specific wording of such clauses. Copies of complete terms and conditions are available by following the links in appendix C.

(1) Standards of Work. Work performed under the contract must conform to high professional standards.
(2) Inspection. Work performed under the contract 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 contract.
(4) Default. The Federal Government may terminate the contract if the contractor fails to perform the work contracted.
(5) Termination for Convenience. The contract 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 contract 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 applicant 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 applicant 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 contract.
(12) Covenant Against Contingent Fees. No person or agency has been employed to solicit or secure the contract 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 contract 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 contract.
(15) American Made Equipment and Products. When purchasing equipment or a product under the SBIR/STTR contract, purchase only American-made items whenever possible.

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 Evaluated	Number of STTR Phase I Awards	Percentage of STTR Phase I Awards
2023	126	50	39.6%
2022	131	53	40.4%
2021	192	56	29.1%

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 SBIR Phase I award with the following items:

- SF26—Contract Cover Sheet
- Contract Terms and Conditions—to include reference to the 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
- Confirmation of Negotiation
- Phase I Frequently Asked Questions (FAQs)

5.2.3 Type of Contract

NASA STTR Phase I awards are firm fixed price contracts.

5.2.4 Model Contracts

Examples of the NASA STTR contracts can be found in the NASA SBIR/STTR Resources website: http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html. 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 website: http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html. For more information, see NASA FAR Supplement clause 1852.204-76.

All contracts 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 (chapter 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.

You must provide to NASA all technical reports and other deliverables required by the contract. These reports must document progress made on the project and activities required for completion. Periodic certification for payment is required as stated in the contract. You must submit a final report 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 the 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 you receive the TABA supplement, your Phase I contract requires TABA deliverables that summarize the outcome of the TABA services. NASA bases reimbursement for TABA on delivery of a TABA final report at the end of the contract period of performance.

5.4 Payment Schedule

The exact payment terms are included in the contract. Invoices are submitted electronically through the Department of Treasury's Invoice Processing Platform (IPP). If you are approved to receive the TABA supplement under a Phase I award, you will be reimbursed for TABA expenses. You must submit TABA vendor invoices for reimbursement per the payment schedule in section 3.1.3.8. NASA will not reimburse any amounts incurred over the TABA funding amount that NASA approved prior to award.

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 proposal packages under this program solicitation; however, cost sharing is not required. Cost sharing will not be an evaluation factor in consideration of your proposal package and 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 Funding Agreements

The STTR program provides specific rights for data developed under SBIR 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 must 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 SBA SBIR/STTR Policy Directive provided in section 1.1 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 SBIR 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

Awardees must certify with every invoice that they have not previously been paid nor are 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 you submit certain organizational, management, personnel, and financial information to establish contractor responsibility. 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. Proposal packages requiring waivers must include an explanation of why the waiver is appropriate. NASA will provide your 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 3.1.3.4 of the solicitation. **NASA facilities qualify as federal laboratories.**

Support Agreements for Use of Government Resources

All offerors selected for award who require and receive approval from the STTR Program Executive for the use of any federal facility must, 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 website (http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html) and must be executed before a contractor can use NASA resources. NASA expects selected offerors to finalize and execute their NASA SBIR 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) for the performance of work under SBIR contracts. Generally, any contractor will furnish its own resources to perform the proposed work on the contract.

In all cases, the contractor is responsible for any costs associated with services, equipment, or facilities provided by NASA or another Federal department or agency, and such costs will not increase the price of this contract.

5.14 Agency Recovery Authority and Ongoing Reporting

In accordance with Section 5 of the SBIR and STTR Extension Act of 2022, the NASA will –

1) require a small business concern receiving an award under its STTR program to repay all amounts received from the Federal agency under the award if—

(A) the small business concern makes a material misstatement that the Federal agency determines poses a risk to national security; or

(B) there is a change in ownership, change to entity structure, or other substantial change in circumstances of the small business concern that the Federal agency determines poses a risk to national security; and

2) require a small business concern receiving an award under its SBIR program to regularly report to the Federal agency and the SBA throughout the duration of the award on—

(A) any change to a disclosure required under subparagraphs (A) through (G) of section 2.3.1 above.

(B) any material misstatement made under section 5.14 paragraph (A) above; and

(C) any change described in section 5.14 paragraph (B) above.

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. you must follow the steps found below.

6.1.1 Electronic Submission Requirements via the ProSAMS

NASA uses ProSAMS for the submission of these proposal packages. ProSAMS requires firm registration and login. To access ProSAMS, go to https://prosams.nasa.gov/.

NASA recommends that an authorized small business representative be the person to register the firm and complete the required firm level forms. They will be the only person allowed to edit the firm level forms.

For successful submission of a complete proposal package, you must complete all required and applicable forms, and upload the required documents per the submission requirements indicated in ProSAMS.

6.1.2 Deadline for Phase I Proposal Package

NASA must receive your proposal package for Phase I no later than 5:00 p.m. ET on Monday, March 11, 2024, via ProSAMS.

You are responsible for ensuring that all files constituting the proposal package are uploaded and endorsed prior to the deadline. **If a proposal package is not received by the 5:00 p.m. ET deadline, NASA will determine the proposal package to be incomplete and will not evaluate it.** Start the submission process early to allow sufficient time to upload the complete proposal package. If you wait to submit a proposal package near the deadline, you are at risk of not completing the required uploads and endorsements by the required deadline and NASA may decline the proposal package.

6.1.3 Proposal Package Submission

Upload all components of a proposal package using the Proposal Submissions module in ProSAMS. The designated business representative and principal investigator must endorse the proposal package. All transactions via ProSAMS are encrypted for security purposes.

Do not submit security/password-protected PDF files, as reviewers may not be able to open and read these files. NASA will decline proposal packages containing security/password-protected PDF files and they will not be evaluated.

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

You may upload a 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. Embedded animation or video, as well as reference technical papers for "further reading," will not be considered for evaluation. **NASA may decline a proposal package that is missing the final endorsements.**

6.1.4 Acknowledgment of a Proposal Package Receipt

NASA will acknowledge receipt of an electronically submitted proposal package by sending an email to the designated Business Official's email address as provided on the proposal package cover sheet. **If you do not receive a proposal package acknowledgment after submission, immediately contact the NASA SBIR/STTR Program Support Office at agency-sbir@mail.nasa.gov.**

6.1.5 Withdrawal of Proposal Packages

Prior to the close of submissions, you may withdraw proposal packages. To withdraw a proposal package after the deadline, the designated small business representative must send written notification via email to agency-sbir@mail.nasa.gov.

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), must be served on the Contracting Officer (addressed as follows) by obtaining written and dated acknowledgment of receipt from:

Kenneth Albright
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 must be received in the office designated above within one day of filing a protest with the GAO.

7 Proposal, Scientific and Technical 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: https://www.nasa.gov/budgets-plans-and-reports/
NASA Organizational Structure: http://www.nasa.gov/centers/hq/organization/index.html
NASA SBIR/STTR Programs: http://sbir.nasa.gov

Information regarding NASA's technology needs can be obtained at the following websites:

Office of the Chief Technologist	
2020 NASA Technology Taxonomy	https://www.nasa.gov/otps/2020-nasa-technology-taxonomy/

NASA Mission Directorates	
Aeronautics Research Mission Directorate (ARMD)	http://www.aeronautics.nasa.gov
Exploration Systems Development Mission Directorate (ESDMD)	https://www.nasa.gov/directorates/exploration-systems-development
Space Operations Mission Directorate (SOMD)	https://www.nasa.gov/directorates/space-operations-mission-directorate
Science Mission Directorate (SMD)	http://nasascience.nasa.gov
Space Technology Mission Directorate (STMD)	https://www.nasa.gov/space-technology-mission-directorate/

NASA Centers	
Ames Research Center (ARC)	https://www.nasa.gov/ames/
Armstrong Flight Research Center (AFRC)	https://www.nasa.gov/armstrong/
Glenn Research Center (GRC)	https://www.nasa.gov/glenn/
Goddard Space Flight Center (GSFC)	https://www.nasa.gov/goddard/
Jet Propulsion Laboratory (JPL)	https://www.jpl.nasa.gov/
Johnson Space Center (JSC)	https://www.nasa.gov/johnson/
Kennedy Space Center (KSC)	https://www.nasa.gov/kennedy/
Langley Research Center (LaRC)	https://www.nasa.gov/langley/
Marshall Space Flight Center (MSFC)	https://www.nasa.gov/marshall/
Stennis Space Center (SSC)	https://www.nasa.gov/stennis/
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 use to learn about the program and to get help for developing a proposal package to a Federal SBIR/STTR program. Offerors 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 https://www.sbir.gov/about 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, email or write:

National Technical Information Service
5301 Shawnee Road
Alexandria, VA 22312
URL: http://www.ntis.gov
E-mail: NTRLHelpDesk@ntis.gov

8. Submission Forms

Previews of all forms and certifications are available via the NASA SBIR/STTR Resources website, 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 package, use the following checklist:

- ☐ The technical proposal and innovation are submitted for one subtopic only.
- ☐ The entire proposal package is submitted consistent with the requirements outlined in chapter 3.
    - ☐ Proposal Contact Information
    - ☐ Proposal Certifications
    - ☐ Proposal Summary
    - ☐ Proposal Budget
        - ☐ Including letters of commitment for government resources and subcontractors/ consultants (if applicable)
        - ☐ Foreign Vendor form (if applicable)
    - ☐ Technical Proposal including all 10 parts in order as stated in section 3.1.3.5.
    - ☐ Briefing Chart
    - ☐ NASA Evaluation License Application, only if TAV is being proposed
    - ☐ I-Corps Interest Form
    - ☐ Technical and Business Assistance (TABA) Request, if applicable
    - ☐ SBC-Level Forms completed once for all proposal packages submitted to a single solicitation
        - ☐ SBC Certifications
        - ☐ Audit Information
        - ☐ Prior Awards Addendum
        - ☐ Commercialization Metrics Report (CMR)
        - ☐ Disclosure of Foreign Affiliations
- ☐ The technical proposal does not exceed a total of 19 standard 8.5- by 11-inch pages with one-inch margins and follows the format requirements (section 3.1.2).
- ☐ All required letters/documentation are included.
    - ☐ A letter of commitment from the appropriate government official if the research effort requires use of government resources (sections 3.1.3.4 and 5.13).
    - ☐ Letters of commitment from subcontractors/consultants.
    - ☐ If the SBC is an eligible joint venture or a limited partnership, a copy or comprehensive summary of the joint venture agreement or partnership agreement is included.
    - ☐ NASA Evaluation License Application if proposing the use of NASA technology (TAV).
    - ☐ Supporting documentation of budgeted costs.
- ☐ Proposed funding for the technical effort does not exceed $150,000 (section 1.3), and if requesting TABA, the cost for TABA does not exceed $6,500 (sections 1.8 and 3.1.3.8).

- ☐ Proposed project duration does not exceed six (6) months (section 1.3).
- ☐ Confirm you received an acknowledgement of submission email before 5:00 p.m. ET on March 11, 2024 (section 6.1.4).

9. Research Subtopics for STTR

Introduction

The SBIR subtopics are organized by NASA's Technology Taxonomy and thus identify subtopics where your research and development capabilities may be a good match. The 2020 NASA Technology Taxonomy reflects a shift to a structure that aligns technology areas based on technical disciplines.

In addition, there are some STTR subtopics that may be closely aligned with the NASA SBIR program. Consider both programs when planning to apply. To find the current NASA SBIR and STTR solicitations, visit the NASA SBIR/STTR website.

NASA uses the same subtopic numbering convention for the STTR program each year:

<u>For STTR Subtopics:</u>

T – Small Business Technology Transfer (STTR)

Think of the subtopic lead/participating centers as potential customers for your STTR technical proposals. Multiple centers may have interests across the subtopics within a Technology Taxonomy area.

Related subtopic pointers are identified in some subtopic headers to assist you with identifying other subtopics that seek related technologies for different customers or applications. As stated in chapter 3, NASA will not accept the same (or substantially equivalent) proposal packages to more than one subtopic. It is your responsibility to select which subtopic to propose to.

Contents

TX01: Propulsion Systems

This area covers technologies for chemical and non-chemical propulsion systems or their related ancillary systems for propulsion, space launch propulsion, or in-space propulsion applications.

T1.15 Alternative Design Approaches for High Heat Flux Detonation Engines (STTR)

Related Subtopic Pointers: A1.02, A1.03, A1.04, A1.09, Z10.05, Z5.06, Z8.09
Lead Center: MSFC
Participating Center(s): GRC

Subtopic Introduction:

While there are clear market demands and commercial interest for rapid infusion of Rotating Detonation Rocket Engines (RDREs), there is very limited literature available on thermal-structural environments and also uncooled rocket engine approaches using higher temperature materials to inform the range of rocket engine design approaches. Gaps in traditional approaches are known, with clear evidence the traditional Bartz approximation is not adequate for RDRE systems. Additional modeling, experimental testing, and validation are required to reduce design iterations to optimize performance and operability.

Scope Title: Alternative Materials Impacting Design

Scope Description:

Detonation engines have achieved significant recent milestones for mission-relevant duration testing, but current designs are highly dependent on active cooling with copper alloys. This limits the impact of the thermal-structural environment but also reduces overall performance by increasing propellant temperature at injection, which decreases detonative pressure rise and increases parasitic deflagration. Cooled systems also add complexity and weight. Higher temperature materials will simplify designs by eliminating active cooling and will additionally allow for higher performance. Candidate materials and design solutions will result in fundamentally different designs and enable higher performance innovative system concepts. Furthermore, these materials can operate in more severe thermal-structural environments and will not require active cooling for simplified operational flight solutions. In order to demonstrate one or more successful uncooled RDRE designs, it is expected that the development team will conduct thermal-structural design and analysis to identify theoretically attractive designs, perform subscale testing to validate the designs, and conduct full-scale testing to demonstrate the designs.

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

Primary Technology Taxonomy:

- Level 1: TX 01 Propulsion Systems
- Level 2: TX 01.1 Chemical Space Propulsion

Secondary Technology Taxonomy:

- Level 1: TX 12 Materials, Structures, Mechanical Systems, and Manufacturing
- Level 2: TX 12.1 Materials

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Hardware

Desired Deliverables Description:

Phase I: Deliver theoretical designs with supporting calculations and fabrication of simple demonstration hardware.
Phase II: Final hardware designs, lab-scale testing results, and results of testing of the RDRE(s) in a relevant environment.

State of the Art and Critical Gaps:

The majority of RDRE designs implement inner and outer bodies that are copper alloys and require active cooling for extended duration testing (longer than 3-5 sec). This not only limits the impact of the thermal-structural environment but also reduces overall performance by increasing propellant temperature at injection, which decreases detonative pressure rise and increases parasitic deflagration. Cooled systems also add complexity and weight. Advanced refractory materials have been demonstrated for solid rocket motors in aggressive highly aluminized, high-pressure solid rocket motors. These materials require innovative design solutions and compatible materials.

Relevance / Science Traceability:

This investment is highly relevant to fundamental design, fabrication, and optimization of high heat flux and high-frequency cyclic combustion devices.
The downstream applications are targeting lander propulsion systems (lunar and martian), small launch concepts, and large in-space propulsion maneuvers.

References:

1. Teasley, T. W., Fedotowsky, T. M., Gradl, P. R., Austin, B. L., Heister, S. D., “Current State of NASA Continuously Rotating Cycle Engine Development,” AIAA 2023-1873, AIAA SCITECH 2023 Forum, January 23-27, 2023.
2. Thakre, P. and Yang, V., “Chemical Erosion of Refractory-Metal Nozzle Inserts in Solid-Propellant Rocket Motor,” Journal of Propulsion and Power, Vol. 25. No. 1, 2009.

Scope Title: Defining Thermal-Structural Environments

Scope Description:

The scope of this effort includes obtaining heat transfer data by calorimetry or other methods for various fuels/oxidizers of interest and developing a time-efficient means of calculating thermal-structural loads to be utilized for accurately evaluating existing and new materials/designs. Of particular interest are approaches that obtain time-resolved as well as time-averaged measurements. The scope should include literature search, heat transfer measurements, enabling diagnostic tools/capabilities to measure in this aggressive environment, and dynamic thermal-structural modeling to guide and validate the proposed innovative approach. This effort is necessary to characterize and understand detonation behavior and apply it to enable high-fidelity simulations of transient heat transfer and stress analysis to predict the performance of innovative and new materials and designs. Also of interest, is enabling window technology to support efforts with improved diagnostics capability.

For clarification, it is entirely insufficient and noncompliant to simply take more calorimetry data for different RDREs. While the approach is left for the proposer to identify, controlled experiments coupled to thermal/fluid models are anticipated for an improvement to the traditional Bartz equation for high-frequency cyclic combustor/nozzle flows.

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

Primary Technology Taxonomy:

- Level 1: TX 01 Propulsion Systems
- Level 2: TX 01.1 Chemical Space Propulsion

Secondary Technology Taxonomy:

- Level 1: TX 12 Materials, Structures, Mechanical Systems, and Manufacturing
- Level 2: TX 12.1 Materials

Tertiary Technology Taxonomy:

- Level 1: TX 13 Ground, Test, and Surface Systems
- Level 2: TX 13.2 Test and Qualification

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Hardware
- Software

Desired Deliverables Description:

Phase I: Improved empirical expressions and analytical models for thermal-structural loads for limited fuels/oxidizers as a function of hot wall temperature and feasibility studies on thermal shock tolerant windows.
Phase II: Expand for additional fuels/oxidizers and for increased parameter ranges and continue development of window technology

State of the Art and Critical Gaps:

The community has limited ability to quantify and qualify theoretical values for thermal-structural loads (time and spatial variations of heat flux and pressure) in the detonation chamber necessary for high-fidelity finite element simulations (transient heat transfer and structural analyses). Current computational fluid dynamic (CFD) methodologies are difficult to implement and burdened with solution times that can be on the order of months. It is of interest to gather calorimetry data for various fuels/oxidizers of interest and develop a time-efficient means to calculate thermal-structural loads to be utilized for accurately evaluating existing and new materials/designs. Additionally, enabling technology to improve diagnostics is also of great interest, e.g., improving the thermal shock resistance of windows for lasers. This will also support the technology development goals by enabling improved diagnostics capability.

Relevance / Science Traceability:

This investment is highly relevant to fundamental design, fabrication, and optimization of high heat flux and high-frequency cyclic combustion devices.
The downstream applications are targeting lander propulsion systems (lunar and martian), small launch concepts, and large in-space propulsion maneuvers.

References:

1. Randall, S., et al, "Numerical and Experimental Study of Heat Transfer in a Rotating Detonation Engine," AIAA 2015-0880, January 2015.
2. Braun, J., et al, "Numerical Assessment of the Convective Heat Transfer in Rotating Detonation Combustors Using a Reduced-Order Model," Journal of Applied Science, 2018, 8(6), p. 893.

TX03: Aerospace Power and Energy Storage

This area covers the different components of a power system—power generation, energy storage, and power management and distribution—that require technological improvements to enable or enhance NASA missions.

T3.04 Advanced Low-Temperature Secondary Batteries (STTR)

Related Subtopic Pointers: S13.06, Z1.05, Z1.09
Lead Center: GRC
Participating Center(s): JPL

Subtopic Introduction:

The objective of this topic is to provide reliable, high-performing secondary battery technologies for sustained operation and survivability in low-temperature lunar conditions. The harsh, low-temperature environment of the lunar surface presents unique challenges for providing reliable surface power [1]. Advanced cells with lower temperature capability reduce the need for ancillary thermal management, which would reduce system mass and volume, enable longer mission durations, and enhance our capabilities throughout a sustained human presence on the lunar surface. These same technologies will also benefit both NASA's Moon to Mars initiative and planetary science missions to the outer solar system.

Scope Title: Advanced Low-Temperature Secondary Batteries

Scope Description:

This solicitation topic specifically seeks proposals to address the following development area:

- Cell-level technologies including chemistry, materials, and packaging improvements that allow for improved performance and cycling at a C/20 rate at -80 °C and below.

Component developments must be demonstrated at a full-cell level and projections must be included for cell performance in a hard-cased, 2 amp-hr cell size. In addition, battery-level approaches for furthering low-temperature operation are desirable. Proposals offering to develop only a single enabling component (e.g., electrolyte, anode, and cathode) are not requested and will be deemed noncompliant. Products achieving the following performance metrics are desired:

- Cell charge and discharge demonstrated in environments at -80 °C or below at a C/20 rate.
- >300 Wh/kg at the cell level at C/5 discharge rate (measured at 20 °C with a minimum of 100 charge/discharge cycles).

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

Primary Technology Taxonomy:

- Level 1: TX 03 Aerospace Power and Energy Storage
- Level 2: TX 03.2 Energy Storage

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype

Desired Deliverables Description:

Research should be conducted to demonstrate technical feasibility in a final report for Phase I and show a path toward a Phase II, and when possible, deliver a demonstration unit for NASA testing at the completion of the Phase II contract. Phase II emphasis should be placed on developing and demonstrating the technology under as many relevant test conditions as feasible within Phase II resources. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into science-worthy systems.

- Phase I: Test Reports and Technology Development Plan.
- Phase II: Prototype hardware with test reports and an updated Technology Development Plan.

State of the Art and Critical Gaps:

Existing battery technologies, if employed on the lunar surface or other cold environments, would require significant thermal management [1,2]. By extending the lower effective operating temperature range of the battery cells, the need for thermal management will be reduced. State-of-the-art secondary cells are limited to 100-150 Wh/kg at -30 °C. Previous and ongoing Space Technology Research Grants (STRG)-funded research [3,4] have highlighted some of the low-TRL approaches to enable low-temperature battery operations and lunar hibernation survivability in these ranges.

Relevance / Science Traceability:

These batteries are applicable over a broad range of exploration and science missions. Low-temperature batteries are needed to enable science and exploration missions aligned with Artemis, including supporting science missions such as Commercial Lunar Payload Services and Lunar Quest. These batteries may also serve for potential NASA decadal missions to ocean worlds (Europa, Enceladus, and Titan) and the icy giants (Neptune and Uranus). Low-temperature batteries developed under this subtopic would enhance these missions and could be enabling, particularly for missions that are highly mass, or volume limited.

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2. Jaugeumont, J., et al., A Comprehensive Review of Lithium-Ion Batteries Used in Hybrid and Electric Vehicles at Cold Temperatures, Applied Energy 164, 99-114, 2016.
3. 2018 Early Career Faculty Selections for STRG | NASA
4. Early Career Faculty 2022 | NASA

T7.05 Climate Enhancing Resource Utilization (STTR)

Related Subtopic Pointers: S13.06, Z1.05, Z1.09
Lead Center: GRC
Participating Center(s): JSC

Subtopic Introduction:

This subtopic is intended to encourage and attract innovations at a prototype system level to address both the integrated extraction and repurposing of atmospheric carbon and/or the production of non-fossil-based fuels that when used, displace the production of greenhouse gases. The subtopic is intended to establish a direct, synergistic link between NASA's evolving in-situ resource utilization (ISRU) capability requirements to produce power and propulsion consumables from lunar and martian carbon- or hydrogen-containing resources and terrestrial imperatives to address climate concerns through reductions in atmospheric carbon dioxide (CO_2) concentrations. The subtopic focuses on system-level approaches and seeks innovative approaches to components and subsystems that provide significant reductions in end-to-end system size, weight, energy consumption, and cost; and also addresses the performance of integrated systems in the challenging environments of the Moon and Mars, including reduced gravity and temperature extremes. Current scopes of the subtopic involve integrated extraction and transformation of atmospheric CO_2 into stable end-use products and integrated systems for the production of hydrogen from water, not fossil-based, sources.

The subtopic description makes clear note of the significant research and development that is ongoing in these areas in academic and entrepreneurial environments but intends to specifically seek true innovation in both unit process and integrated systems that result in the desired reductions in end-to-end size, weight, energy consumption, environmental compatibility, and cost.

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 that are fully integrated through this effort with CO_2 transformation into one or more ambient stable products such as (but not limited to) manufacturing feedstock 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 also 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 all of the following: (1) physical and/or chemical processes to be implemented for both 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 or utilized 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

Secondary Technology Taxonomy:

- Level 1: TX 03 Aerospace Power and Energy Storage
- Level 2: TX 03.2 Energy Storage

Desired Deliverables of Phase I and Phase II:

- Prototype
- Research
- Analysis
- Hardware

Desired Deliverables Description:

The minimum desired **Phase I deliverable** is 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 subtopic 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. The 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 are increasing demonstrations of the planet-wide 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.

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Scope Title: Sustainable Production of Hydrogen for Transportation and Energy Storage Applications

Scope Description:

Component and subsystem technologies are sought to demonstrate sustainable, energy-efficient production of hydrogen from water and organic materials other than extracted fossil fuel sources. Dual-use technologies are sought that may reduce dependence of sustainable space exploration activity on terrestrial supplies of hydrogen-containing resources, provide a source of advanced aviation and surface transportation fuels, provide advanced energy storage capabilities for aerospace or terrestrial power systems, or may be integrated into production of derivative products including structural materials, manufacturing feedstock, or other condensed-phase products. Dual use of hydrogen production capability extends to a focus for NASA applications on substantial reductions in size, weight, and energy consumption and improved utilization efficiencies, and applying those efficiencies to terrestrial implementations with opportunities for scale up to commercial hydrogen production. This scope is therefore intended to strongly emphasize significant overall efficiencies in size, weight, and energy consumption and utilization. The scope is intended to encourage alternative chemical, electrochemical, photocatalytic, and other alternative production pathways that may offer significant efficiencies in system size, weight, and energy consumption. This scope includes improvements in existing water electrolysis technologies only to the extent that large efficiency improvements are an outcome of the proposed effort.

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

Primary Technology Taxonomy:

- Level 1: TX 03 Aerospace Power and Energy Storage
- Level 2: TX 03.2 Energy Storage

Secondary 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:

- Analysis
- Prototype
- Research
- Hardware

Desired Deliverables Description:

Phase I Deliverable is defined as a detailed feasibility study that clearly defines the specific technical innovations in hydrogen production. Technology feasibility evaluation should include persuasive rationale showing process conversion effectiveness, approaches to minimization of specific mass and volume (i.e., per mass and volume of hydrogen produced), and substantial innovation in the utilization and minimization of total specific energy consumption. 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 and laboratory prototype components or subsystems integrated into an end-to-end hydrogen production system at a laboratory scale of maturity, and performance testing data that address metrics including process conversion effectiveness, specific mass and/or volume, energy utilization, and product properties. Analysis deliverables for Phase II should address a credible path toward maturation of the delivered technology and approaches to scaling the technologies to larger processing capacities. Phase II hardware delivery may possibly be deferred or waived to enable well-secured follow-on technology maturation support.

State of the Art and Critical Gaps:

This subtopic is intended to solicit innovative technologies with clear dual use including: (1) adoption by NASA for infusion into long-term mission capabilities enabling quasi-industrial scale ISRU and energy storage use of indigenous water resources and (2) commercialization and the potential formation of a terrestrial industry to encourage then meet potentially significant future demand for hydrogen for energy storage, advanced aviation and surface transportation fuels, and as feedstock for manufactured products. Additionally, if or as a viable industry associated with terrestrial applications of these technologies emerge, a commercial competition may continue to innovate and contribute over the longer 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.

Relevance / Science Traceability:

The application of compact, energy-efficient hydrogen production technologies will occur in future power and energy storage and ISRU implementations on the Moon and on Mars, which are currently constrained by the use of conventional water electrolysis approaches. Technology stemming from alternative hydrogen production pathways or large efficiency improvements in existing methods that successfully addresses size, mass, and energy consumption constraints for spaceflight applications will enable the utilization of those efficiencies as the basis for scaling up to commercial production for terrestrial applications at far larger production volumes than needed for spaceflight applications. This solicitation is intended to incentivize these innovations in the service of future NASA missions.

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TX05: Communications, Navigation, and Orbital Debris Tracking and Characterization Systems

This area covers technologies for transferring commands, spacecraft telemetry, mission data, and voice for human exploration missions, while maintaining accurate timing and providing navigation support. Orbital debris can be tracked and characterized by some of the same systems used for spacecraft communications and navigation, as well as by other specialized systems.

T8.06 Quantum Sensing/Measurement and Communication (STTR)

Related Subtopic Pointers: A2.01, H9.03, H9.08
Lead Center: GSFC
Participating Center(s): GRC, JPL, LaRC

Subtopic Introduction:
Quantum Sensing and Measurement 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 sensors and clocks and quantum communication should apply to those specific subtopics and are not covered in this Quantum Sensing and Measurement subtopic.

Quantum communications seeks proposals that develop technologies to support quantum communications between satellites and ground stations. Key aspects of these components are high performance, the ability to support free-space quantum communication between moving nodes, as well as low size, weight, and power (SWaP).

Scope Title: Quantum Sensing and Measurement

Scope Description:

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, NOON states, Holland-Burnett 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 SWaP quantum radiometry systems capable of calibrating detectors' spectroscopic resolution and efficiency over the MIR, NIR, and/or visible.

Quantum Sensing and Measurement includes: Quantum Metrology and Radiometry (absolute radiometry without massive blackbody cryogenic radiometer or synchrotron), Quantum Sources (prepare prescribed quantum states with high fidelity), Quantum Memories (storage and release of quantum states), and Quantum Absorbers and Quantum Amplifiers (efficiently absorption and detection of quantum states).

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)). Proposal-generating Holland-Burnett states (Phy Rev. Let 71, 1355 (1993)) is also of interest.

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.

Quantum memories with long coherence times >30 ms to several hours and efficiency coupling. Want to show a realistic development path capable of highly efficient coupling to photon number resolving detectors.

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 downconversion 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.
Exploration Systems Development Mission Directorate (ESDMD) and Space Operations Mission Directorate (SOMD)—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.

References:

1. 2019 NASA Fundamental Physics and Quantum Technology Workshop. Washington, DC (April 8-10, 2019).
2. Quantum Communication, Sensing and Measurement in Space. Team Leads: Erkmen, Shapiro, and Schwab (2012):
    - http://kiss.caltech.edu/final_reports/Quantum_final_report.pdf (link is external).
3. National Quantum Initiative Act:
    - https://www.congress.gov/congressional-report/115th-congress/house-report/950/1 (link is external).
    - https://www.congress.gov/congressional-report/115th-congress/senate-report/389 (link is external).
    - https://www.lightourfuture.org/getattachment/7ad9e04f-4d21-4d98-bd28-e1239977e262/NPI-Recommendations-to-HSC-for-National-Quantum-Initiative-062217.pdf (link is external).
4. European Union Quantum Flagship Program: https://qt.eu (link is external).
5. UK National Quantum Technologies Programme: http://uknqt.epsrc.ac.uk (link is external).
6. DLR Institute of Quantum Technologies: https://www.dlr.de/qt/en/desktopdefault.aspx/tabid-13498/23503_read-54020/ (link is external).
7. Degen, C. L.; Reinhard, F.; and Cappellaro, P.: Quantum Sensing, Rev. Mod. Phys. 89, 035002 (2017).
8. Polyakov, Sergey V.: Single Photon Detector Calibration in Single-Photon Generation and Detection, Volume 45, 2013 Elsevier Inc. http://dx.doi.org/10.1016/B978-0-12-387695-9.00008-1.
9. Stobińska, et al.: Quantum Interference Enables Constant-Time Quantum Information Processing. Sci. Adv. 5 (2019).

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. Technologies of interest are components to support the communication of quantum information between quantum computers, or sensors, for space applications or supporting linkages between free space and terrestrial fiber-optic quantum networks. Technologies that are needed include quantum memory, entanglement sources, quantum interconects, quantum repeaters, high-efficiency detectors, as well as Integrated Quantum Photonics that integrate multiple components. A key need for all of these are technologies with low SWaP 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., 100 MHz incidence rate, and 1-sigma time resolution of 50% at the highest incidence rate.
- Quantum memory with high buffering efficiency (>50%), storage time (>10 ms), and high fidelity (>0.9), including heralding capability as well as scalability.
- Stable narrow-band filters for connecting to quantum memory and atomic interferometers. Narrow band (100 MHz or less for spectral bandwidth per channel) has >50 dB extinction and >90% coupling efficiency for either NIR or C-band.
- Very narrow wavelength division multiplexing (~30 GHz channels) with high coupling efficiency.
- High-efficiency and high-speed optical switches.
- High rate and fidelity quantum entangled photon source. Source should produce entangled pairs of rate >1 MHz and rate of multi-pair down rate a factor reduced by at least a factor of 1,000. This could be accomplished through a single source or array of sources.
- Integrated quantum spectrometer. This may utilize a WDM architecture with high coupling efficiency to external sources.
- Quantum sensor with quantum photonic output for quantum sensor network.

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:

- Research
- Analysis
- Prototype
- Hardware

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 4 to 6 TRLs 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:

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 the 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).
7. Ian, Nemitz, Jonathan Dietz, Evan Katz, Brian Vyhnalek, and Benjamin Child: “Bell Inequality Experiment for a High Brightness Time-Energy Entangled Source,” SPIE Photonics West, San Francisco, CA (March 1, 2019).

TX07: Exploration Destination Systems

This area covers the broad range of technologies associated with enabling successful activities in space, from mission operations to in-situ resource utilization.

T7.04 Lunar Surface Site Preparation (STTR)

Related Subtopic Pointers: S13.04, Z12.03, Z13.05, Z14.01, Z14.03
Lead Center: KSC
Participating Center(s): GRC, MSFC

Subtopic Introduction:

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 civil engineering designs of bulk regolith lunar infrastructure, technologies to build the infrastructure, and construction concepts of operations (ConOps) for the south polar region of the Moon. This is the lunar equivalent of terrestrial "Earth Works." Earth-based civil engineering processes and technologies are not adequate for lunar construction; therefore, lunar civil engineering designs and technologies must be developed. The fundamental robotic capabilities of interest are:

- Geotechnical site investigation and topography mapping.
- Rock removal.
- Establishing grade and forming desired ground features.
- Compaction.
- Verification of geotechnical parameters and geometry of structures.
- Routines and sensors for autonomous operations

Scope Title: Site Preparation and 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 civil engineering designs of bulk regolith lunar infrastructure, technologies to build the infrastructure, and construction concepts of operations (ConOps) for the south polar region of the Moon. This is the lunar equivalent of terrestrial "Earth Works." Earth-based civil engineering processes and technologies are not adequate for lunar construction; therefore, lunar civil engineering designs and technologies must be developed. The fundamental robotic capabilities of interest are:

- High-resolution topography mapping.
- Rock removal.
- Establishing grade and forming desired ground features.
- Compaction.
- Verification of geotechnical parameters and geometry of built structures.
- Routines and sensors for autonomous operations.

The desired outcome of this effort is the capability to create "Regolith Works" on the lunar surface. This includes engineered surface features/structures and the design, prototype, testing, analysis, modeling, and demonstration of prototype construction hardware and investigative instruments. These technologies are sought for subscaled lunar construction demonstration missions and site investigation technologies. The following lunar civil engineered structures are of particular interest to NASA. Proposers are welcome to suggest other regolith-based infrastructure concepts.

- Bulk regolith-based launch/landing zones designed to minimize risks associated with landing/launching on regolith surfaces for CLPS (Commercial Lunar Payload Services) and HLS (Human Landing System) class vehicles.
- Rocket Plume Surface Interaction (PSI) ejecta and blast protection structures (e.g., berms).
- Regolith foundations for supporting hardened launch/landing pads, towers, habitats, roads, and other structures.
- Pathways for improved trafficability (e.g., gravel, stabilized paths, and foundations for roads).
- Emplaced regolith overburden for protection from Solar Particle Event (SPE), Galactic Cosmic Ray (GCR), nuclear system radiation, and meteoroid impacts.
- Structures for access to subgrade (e.g., trenches and pits).
- Flat, level, and rock-free operational surfaces for regularly accessed locations such as habitat surroundings, equipment positioning locations, and dust mitigation applications.
- Sloped regolith access ramps and elevated operational surfaces.
- Utility corridors (e.g., electrical, communications, and fluids).
- Holistic designs of regolith-based infrastructure including interfaces between prepared areas (e.g., layout and transitions between infrastructure elements such as hardened launch/landing pad foundations, pad aprons, tower foundations, pathways/roads, habitat areas, and mining sites).

Other areas of significant interest include:

- Definition of moonquake ground accelerations. This includes advanced processing of existing seismic datasets and the development of seismic investigation instruments. Analysis of potential effects on infrastructure, risk assessments, and mitigation strategies are desired.
- Advanced geotechnical site investigation methods and systems, beyond cone penetrometer/shear vane measurements, that provide information on subsurface characteristics such as rock distributions, depth to bedrock, soil stratification, and caverns. This includes orbital remote sensing techniques such as Interferometric Synthetic Aperture Radar (InSAR) and Ground Penetrating Radar (GPR) or surface-based technologies including surface wave techniques, automated robotic borehole investigations, and GPR, etc. The ground-based technology should be suited for a small geotechnical mobility platform. A depth of at least 1 meter should be targeted with the potential to scale up.
- Methods, materials, and systems to stabilize regolith for purposes such as securing launch/landing pad surrounding areas (pad apron), improving trafficability, dust mitigation, and berms. Proposals in this area can include minimal non-regolith-based surface treatments such as deployable surface covers, stabilizing agents, or other solutions. Proposals targeting “lunar concrete” technologies will not be accepted (e.g., slabs produced by sintered regolith, molten regolith, or cementitious materials).

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

Tests and validated models/simulations should be developed to characterize the system and regolith infrastructure performance in its intended environments/applications. 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 references 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 craters, hills, valleys, and surface/subsurface rocks, and end with the completed bulk regolith infrastructure verified to meet design criteria.

Concepts should be appropriate for a CLPS scale demonstration mission on the lunar surface (e.g., 50 kg overall mass and 10 kg budget for implements) and assume that the implements would attach to an existing modular mobility platform with interfaces at the forward and aft position. Mobility platforms are not a focus for this topic. A depiction of the integrated construction system concept should be provided.

Proposers may select one or more systems/structures of interest to develop. Infrastructure designs that maximize risk reduction for the Artemis program will be prioritized. Proposals that show promise for implementation by a single, compact, and robotic regolith manipulation system will rank high. Concepts that employ or build upon higher TRL implements will be prioritized. NASA is seeking systems that can build bulk regolith infrastructure that can be demonstrated by 2030.

Research institute partnering is anticipated to provide analytical, research, testing, 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 design and test of critical attributes associated with the proposed site preparation technology, operations, and achieved site characteristics. Modeling, simulation, or testing must be provided with evidence that the site preparation technology is suitable for operations in lunar environments (e.g., 1/6 gravity, vacuum). Civil engineered design of bulk regolith infrastructure including associated testing, modeling, and simulations must be included. Phase I must include a ConOps 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 result in at least TRL 4 structures and implements.

Phase II deliverables must include demonstration of construction and characterization of bulk regolith infrastructure including mobility. The infrastructure must be constructed using robotic systems and implements. Proof of critical functions of the infrastructure and systems must be demonstrated, simulated, or modeled in relevant environments including reduced gravity, vacuum, and others as appropriate. Structures and systems must be developed to a minimum of TRL 5.

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 gaps associated with the Space Technology Mission Directorate (STMD) strategic thrust "Live: Sustainable Living and Working Farther from Earth" Excavation, Construction, and Outfitting (ECO) capability area.

References:

1. Overview of the ASCE ASD Space Engineering and Construction Technical Committee: Lunar Infrastructure Engineering, Design, Analysis, and Construction Guidelines: Lunar Structural Loads Subgroup http://dx.doi.org/10.13140/RG.2.2.28322.40645
2. Requirements Development Framework for Lunar In Situ Surface Construction of Infrastructure https://doi.org/10.1061/9780784483374.106
3. Design of an Excavation Robot: Regolith Advanced Surface Systems Operations Robot (RASSOR) 2.0 https://ntrs.nasa.gov/citations/20210011366
4. Off Earth Landing and Launch Pad Construction—A Critical Technology for Establishing a Long-Term Presence on Extraterrestrial Surfaces https://doi.org/10.1061/9780784483374.079
5. Plume Surface Interaction (PSI) https://www.nasa.gov/directorates/spacetech/game_changing_development/projects/PSI
6. Rocket Plume Interactions for NASA Landing Systems https://ntrs.nasa.gov/api/citations/20200000979/downloads/20200000979.pdf
7. Gas-Particle Flow Simulations for Martian and Lunar Lander Plume-Surface Interaction Prediction https://doi.org/10.1061/9780784483374.009
8. Understanding and Mitigating Plume Effects During Powered Descents on the Moon and Mars https://baas.aas.org/pub/2021n4i089?readingCollection=7272e5bb
9. STMD Strategic Thrust Live: Sustainable Living and Working Farther from Earth - Excavation, Construction, and Outfitting (ECO) https://techport.nasa.gov/file/143281

TX08: Sensors and Instruments

This area covers technologies for instruments and sensors, including remote observation capabilities.

T10.01 Autonomous Target Identification and Sensor Optimization (STTR)

Related Subtopic Pointers: A3.05, S11.01, S11.02, S11.03, S11.04, S11.05, S12.01, S12.03, S12.04, S12.06, S13.03, S13.05, S14.02, S15.01, S15.02, S16.07, S16.08, Z4.05
Lead Center: MSFC

Participating Center(s): GSFC

Subtopic Introduction:

NASA seeks to develop scientific imaging systems that facilitate enhanced and extended observations of rapidly changing phenomena from the vantage point of low-Earth orbit (LEO). NASA Earth Science relies on various LEO-based imaging systems to study transient events in the Earth system. Thunderstorms are an example of events that are of much interest, and these typically occupy a small fraction of the image scene. Identification of thunderclouds are achieved using lightning mappers, which are high-speed cameras that detect transient optical pulses emitted by lightning flashes. These instruments are currently used by NASA and the National Oceanic and Atmospheric Administration (NOAA) to support science and operational weather decision making. There is a desire to develop higher resolution and multispectral lightning mappers to detect smaller and optically faint lightning flashes that frequent intense thunderstorms. However, onboard storage and downlink constraints must be taken into consideration, especially for small satellite platforms. Also, autonomous observing systems used for science missions require information that directs the platform navigation and attitude. This requires developing new smart cameras, advanced image processing software, and leveraging next-generation hardware accelerators to enable new lightning mapping instruments capable of utilizing small satellite autonomous observing systems. This subtopic is divided into two scopes (software and hardware).

Scope Title: Autonomous Storm Detection and Tracking Software for Active-Pixel Sensors

Scope Description:

Complementary metal-oxide-semiconductor (CMOS) image sensors (CISs) are extremely attractive for use in future lightning mappers from the standpoint of reducing instrument size, weight, and power while enhancing measurement capabilities. CISs can be dynamically windowed to acquire images within regions of interest (ROIs) identified in the image scene and spatially binned to obtain varying image resolution. An identified ROI is of particular interest because it also provides location information that can be used to extend the observation of a thunderstorm as the spacecraft flies over it. New image processing technology is needed to realize these capabilities for future lightning mappers:

- When an active thunderstorm enters the field-of-view, determine an ROI within the image frame that contains the initial pixel event detections and is large enough to encompass the parent thunderstorm and any subsequent lightning activity that may occur in the future image frames. Existing satellite lightning mapper observations can be used to inform expected ROI sizes.
- Predict translation of the ROI across the image as the thunderstorm traverses the field of view. A machine-learning model could be built to predict the movement of thunderstorms through the image scene. The required training data sets can be readily obtained from existing satellite lightning mapper data archives.
- Output the x-y pixel coordinates of the identified thunderstorm ROI that can be used to modify the CIS sampling approach.
- Translate the ROI pixel coordinates to a coordinate system that can be readily used to adjust the host platform orientation relative to the ROI (e.g., satellite attitude control).
- Demonstrate the successful performance of the software for both daytime and nighttime image scenes containing simulated lightning events and noise by employing thresholds based on airborne and spaceborne measurements of lightning cloud-top radiances.

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

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

Secondary 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
- Prototype
- Software

Desired Deliverables Description:

Phase I will develop software that establishes an ROI when an active thunderstorm is present in the image scene and predicts translation of the ROI as the thunderstorm area moves through the sequence of acquired images. The software also must demonstrate performance using a realistic simulation of a lightning event dataset. This is a research and analysis effort that produces the inputs required to Phase II.

Phase II will implement the software developed in Phase I onto a hardware device and demonstrate its storm detection and tracking performance on simulated or actual lightning. The hardware will be developed through a separate project under this subtopic and will require collaboration amongst the various entities involved in both projects

State of the Art and Critical Gaps:

Current LEO-based lightning mappers used to identify and monitor global thunderstorm activity rely on fixed event detection and sampling strategies, which limit the amount of useful information that can be obtained with high-resolution CISs. Also, these satellite-based lightning mappers rely on event detectors that employ analog components, which increases the instrument’s size, weight, and power impeding their use in small satellite missions to study thunderstorms.

Relevance / Science Traceability:

The NASA Science Mission Directorate (SMD) seeks to observe physical processes in the Earth system that improve understanding and prediction of deep convective storms, which are a focus of future satellite missions recommended by the 2017 Decadal Survey for Earth Science and Applications from Space. NASA SMD Earth Science studies the dynamics of the atmosphere to improve understanding of fundamental processes that drive weather. Lightning is intimately tied to the cloud processes governing storm intensification and plays an important role in climate monitoring. Future missions expected to launch within the next decade such as the Atmospheric Observing System (AOS) and Earth Venture Mission Investigation of Convective Updrafts (INCUS) will focus on studying deep convective clouds to improve prediction of severe weather. LEO-based lightning mappers are the only direct means for globally identifying which convective clouds produce lightning.

NASA's Earth Science Technology Office (ESTO) is currently funding an Instrument Incubator Project to develop a three-dimensional lightning mapping concept that could use this technology to greatly enrich its optical measurement of lightning. Additionally, the technology developed in response to this subtopic could enable satellite swarms to function autonomously for high-speed imaging systems. The recently launched Starling mission is an example of swarm technology that could facilitate testing the software developed for this subtopic.

Advocates at NASA Headquarters for new imaging technology, especially those enabling higher resolution observations of thunderstorm and wildfires, are the following Program Managers and Division Directors: Tsengdar Lee, William McCarty, Amber Emory, Mike Seablom, Jack Kaye, Karen St. Germain in SMD's Earth Science Division and Dr. James Spann in SMD's Heliophysics Division.

References:

1. Christian, H. J., Blakeslee, R. J., and Goodman, S. J. (1989): The Detection of Lightning From Geostationary Orbit. J. Geophys. Res., 94(D11), 13329-13337, doi:10.1029/JD094iD11p13329
2. Goodman, S. J., Christian, H. J., and Rust, W. D. (1988): A Comparison of the Optical Pulse Characteristics of Intracloud and Cloud-to-Ground Lightning as Observed above Clouds. J. Appl. Meteor. Climatol., 27, 1369–1381, doi: 10.1175/1520-0450(1988)027<1369:ACOTOP>2.0.CO;2
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4. Peterson, M. (2019). Research Applications for the Geostationary Lightning Mapper Operational Lightning Flash Data Product. Journal of Geophysical Research: Atmospheres, 124, 10205-10231, https://doi.org/10.1029/2019JD031054
5. Quick, M. G., Christian, H. J., Virts, K. S., and Blakeslee, R. J. (2020). Airborne Radiometric Validation of the Geostationary Lightning Mapper Using the Fly's Eye GLM Simulator. J. Applied Remote Sensing, 14(4), 044518, doi: 10.1117/1.JRS.14.044518

Scope Title: Processing Units for Adaptive Imaging and Autonomous Observing Systems

Scope Description:

Future lightning mappers will use complementary metal-oxide-semiconductor (CMOS) image sensors (CIS) to reduce instrument size, weight, and power while enabling novel detection and measurement approaches. One such concept is to exploit the adaptive imaging capabilities of a CIS to enhance the measurement over storm regions of interest. Lightning mappers acquire images at 500 to 2000 frames per second and perform event detection in each image frame. This is a tremendous image processing task leaving little room for additional onboard data processing tasks needed to translate the events into information that can be used for adjusting the CIS resolution over the storm region and for adjusting the satellite attitude to increase observation time of the storm region. Realizing this autonomous capability will require implementing compute intensive tasks such as machine-learning models and as such call for new onboard processing capabilities for a lightning mapper (e.g., edge computing, tensor processing units, or neural processing units). This hardware needs to be compatible with a small- and low-power but high-speed camera system, perhaps taking the form of a specialized chip (e.g., intellectual property core) that can be integrated onto the imaging board of future lightning mappers. It should be capable of implementing the thunderstorm detection and tracking software, which is being developed through a separate project of this subtopic. Ultimately, the hardware will ingest detected lightning event information and will output formatted information that can be used to modify the CIS sampling approach or adjust satellite orientation.

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

Primary Technology Taxonomy:

- Level 1: TX 08 Sensors and Instruments
- Level 2: TX 08.1 Remote Sensing Instruments/Sensors

Secondary Technology Taxonomy:

- Level 1: TX 10 Autonomous Systems
- Level 2: TX 10.1 Situational and Self Awareness

Tertiary Technology Taxonomy:

- Level 1: TX 02 Flight Computing and Avionics
- Level 2: TX 02.X Other Flight Computing and Avionics

Desired Deliverables of Phase I and Phase II:

- Hardware
- Prototype
- Analysis
- Research

Desired Deliverables Description:

Phase I will design a hardware solution for performing the processing tasks required by the thunderstorm detection and tracking software. This software will be developed through a separate project under this subtopic and will require collaboration amongst the various entities involved in both projects.

Phase II will build a prototype of the hardware component and demonstrate its functionality (i.e., implementation of thunderstorm identification and tracking software) in a simulated satellite system. This includes simulation of spatially distributed regions of lightning activity superimposed onto a background scene radiance, successful identification of and ROI, modification of CIS sampling cadence, and slewing of the sensor platform to track the relative motion of the simulated thunderstorm target.

State of the Art and Critical Gaps:

Autonomous platform technology is being developed, but to use these capabilities in future satellite missions requires science instruments to perform some level of data processing onboard and provide relevant output needed to command the platform to optimize observations of features of interest. Current LEO-based lightning mappers use fixed staring digital imaging platforms to identify and monitor global thunderstorm activity, and they are not capable of adaptively adjusting their imaging strategy to enable enhanced and extended observation as they pass over the tops of thunderclouds.

Relevance / Science Traceability:

NASA SMD seeks to observe physical processes in the Earth system that improve understanding and prediction of deep convective storms, which are a focus of future satellite missions recommended by the 2017 Decadal Survey for Earth Science and Applications from Space. NASA SMD Earth Science studies the dynamics of the atmosphere to improve understanding of fundamental processes that drive weather. Lightning is intimately tied to the cloud processes governing storm intensification and plays an important role in climate monitoring. Future missions expected to launch within the next decade such as the Atmospheric Observing System (AOS) and Earth Venture Mission Investigation of Convective Updrafts (INCUS) will focus on studying deep convective clouds to improve prediction of severe weather. LEO-based lightning mappers are the only direct means for globally identifying which convective clouds produce lightning. NASA's Earth Science Technology Office (ESTO) is currently funding an Instrument Incubator Project to develop a 3D lightning mapping concept that could use this technology to greatly enrich its optical measurement of lightning. Additionally, the technology developed in response to this subtopic could enable satellite swarms to function autonomously for high-speed imaging systems. The recently launched Starling mission is an example of swarm technology that could facilitate testing the software developed for this subtopic.

References:

1. Denby, B. and Lucia, B. (2019): Orbital edge computing: Machine Inference in Space. IEEE Computer Architecture Letters, vol. 18, no. 1, pp. 59-62, doi: 10.1109/LCA.2019.2907539
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T8.07 Photonic Integrated Circuits (STTR)

Related Subtopic Pointers: A3.05, S11.01, S11.02, S11.03, S11.04, S11.05, S12.01, S12.03, S12.04, S12.06, S13.03, S13.05, S14.02, S15.01, S15.02, S16.07, S16.08, Z4.05
Lead Center: GSFC
Participating Center(s): GRC, JPL, LaRC

Subtopic Introduction:

Photonic integrated circuits (PICs) are a revolutionary technology that enables complex optical functionality in a simple, robust, reliable, chip-sized package with very low size, weight, and power (SWaP), extremely high performance, and low cost. PICs are the optical analog to electrical integrated circuits (EICs). In the same way that EICs replaced vacuum tubes and other bulk electrical components, PICs are revolutionizing the generation and manipulation of light (photons), replacing free-space optics and parts with chip-based optical waveguides and components. This technology has been pioneered in the telecommunications industry but much of the functionality and components are also directly applicable to science measurements and spacecraft technologies.

Scope Title: Photonic Integrated Circuits

Scope Description:

NASA is interested in the development and maturation of PIC technology for infusion into existing and upcoming instruments. For the purposes of this call, PIC technology is defined as one or more lithographically defined photonic components or devices (e.g., lasers, detectors, waveguides/passive structures, modulators, electronic control, and optical interconnects) on a single platform allowing for manipulation and confinement of light at or near the wavelength scale. PICs can enable SWaP and cost reductions and improve the performance of science instruments, subsystems, and components. PIC technologies are particularly critical for enabling small spacecraft platforms, rovers, and wearable/handheld technology for astronauts. Proposals should clearly demonstrate how the proposed PIC component or subsystem will demonstrate improved performance: reduced SWaP and cost; increased robustness to launch, space, and entry/landing environments; and/or entirely new measurement functionalities when compared to existing state-of-the-art bulk fiber-optic technology. Additional clarifications:

- On-chip generation, manipulation, and detection of light in a single-material system may not be practical or offer the best performance, so heterogenous or hybrid integration and packaging of different material systems are also of interest [1].
- Often the full benefits of photonic integration are only realized when combined with integrated electronics [2]. Proposals that leverage co-integrated electronics and/or new materials for new or improved PIC functionality are invited but should consider the ultimate space environment.
- There are advantages to the development of PIC technology in existing open access foundries (such as AIM [3]) to enable low cost, continued support, commercialization, and cross-compatibility with other development efforts.
- Proposers are strongly recommended to consider the final use case of the proposed component/system and a route to integrate the new technology with NASA's existing instruments/PICs in a potential Phase II activity. For example, standalone PICs should discuss a planned approach for packaging suitable for lab tests without a probe station (TRL 4). Alternatively, proposals to develop a specific on-chip component should discuss how this new

component could be incorporated into existing foundry processes or added as a back-end-of-line process.
- Overlap with other topics: proposals which are developing PIC-based subsystems for applications covered in other SBIR/STTR topics should consider which call is more applicable.
  - Proposals in which more than 50% of the effort is focused on PIC development are encouraged to be submitted to this subtopic.
  - Subtopics which often have overlap with this subtopic include:
    - Optical/laser communications
    - Lidar
    - Quantum sensors
    - Spectroscopy
    - Astronomy

General NASA areas of interest for PIC components and subsystems include, but are not limited to:

- Lidar systems and components for 3D mapping and trace gas sensing.
- Navigational and in situ sensors for rovers, landers, and probes.
- PIC-based analog radio-frequency (RF), microwave, submillimeter, and terahertz signal processing.
- Low insertion loss and environmentally robust PIC-to-fiber packaging.

Several existing needs at NASA for PIC technology include:

- PICs suitable for 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 (e.g., [4]). Ka-band operation of RF photonic up/down frequency converters and filters need wideband tunability (>10 GHz) and <1 GHz instantaneous bandwidth.
- Hybrid or heterogeneous integration of InP gain elements on silicon for on-chip lasers and amplifiers. Proposals responsive to this item should include evanescent couplers, photonic wirebonds, or similar structures/technologies to couple the InP elements to silicon waveguides efficiently and optically. Proposals are strongly encouraged to either work directly with, or ensure direct compatibility with, silicon photonic foundries in the U.S.
- On-chip avalanche photodiodes (APDs) operating at 1550 nm compatible with at least one silicon photonic foundry in the U.S., targeting an eventual “PDK-like” element available in the foundry. APDs may be fabricated in the process itself (i.e., using existing process materials such as Ge) or heterogeneous/hybrid integrated in a back-end-of-line process. APD designs capable of single photon sensitivity are strongly encouraged. Designs requiring cryogenic operation are acceptable; however, room-temperature operation is preferred.
- Spectrometers for remote or in situ sensing of trace gases, sediments, and other small particulates. Proposals in this category should meet one or more of the following requirements to be considered competitive:
  - Spectrometers or enabling spectrally resolving components capable of measuring the isotope ratio of at least one gas common on Earth or a planetary body, especially tunable laser spectrometer designs such as in [5]. The isotope ratio (e.g., D/H or C13/C12) of at least one of the following elements should be measurable: carbon, oxygen, hydrogen, and nitrogen. Isotope ratio could be measured using any of a number of common gases (e.g., CO, CO_2, NH_3, HCN, CH_4, NO_2). Some example wavelengths and gases useful for measuring isotope ratios include: HCN at 3 um, CO

and CH_4 at 4.6 um. Spectrometers capable of achieving a sensitivity of 1 ppm or better are preferred.
  - Spectrometers or spectrally resolving components capable of highly multimode (10+) and/or imaging operation on a single chip.
  - MIR tunable laser heterodyne spectrometer including one or more tunable lasers with center wavelength in the range of 4-5 um and/or high-frequency (2+ GHz) detectors operating in the same wavelength range on a single PIC. Fiber-coupled inputs to the PIC for mixing an external source with the on-chip laser(s) onto the photodiodes are also needed. For more details on the full system see [6].

- Packaging approaches and on-chip coupling components [7] for high-density, high-bandwidth, and/or misalignment-tolerant connections to single mode and multimode optical fiber, in any wavelength range. Note that all proposals responding to this call should target better than 3 dB fiber-to-waveguide coupling loss at the target wavelength, unless stated otherwise.
  - Note that photonic lanterns, mode size converters, 3D-written waveguide arrays, fiber arrays, and other “off-chip” coupling components must be packaged with a PIC to be considered responsive. In this case, the PIC should allow for measurement of total insertion loss but need not have any additional functionality.
  - Note that proposals demonstrating a new coupler design will preferably focus on coupler design in a commercial foundry process.
  - Designs and methods for coupling a multimode fiber directly to a PIC. An initial insertion loss >3 dB is acceptable, but a realistic path to <3 dB insertion loss should be identified.
  - Designs and methods for coupling a single-mode waveguide to a large-area beam (>1 mm diam.) emitted with high efficiency (<6 dB insertion loss) directly from the chip surface without an external lens.
    - Both beam-steering and static approaches are invited. Example approaches include optical phased arrays, large-area grating couplers, and metalens-based structures. Note that approaches utilizing an on-chip fabricated lens (i.e., deposited on the chip surface) are also invited.

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

Primary Technology Taxonomy:

- Level 1: TX 08 Sensors and Instruments
- Level 2: TX 08.1 Remote Sensing Instruments/Sensors

Secondary Technology Taxonomy:

- Level 1: TX 08 Sensors and Instruments
- Level 2: TX 08.3 In-Situ Instruments/Sensor

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 SWaP and cost reductions for spacecraft microprocessors, communication buses, processor buses, advanced data processing, and integrated science instrument optical systems, subsystems, and components. This is particularly critical for small spacecraft platforms.

Relevance / Science Traceability:

Exploration Systems Development Mission Directorate (ESDMD) and Space Operations Mission Directorate (SOMD)—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 and 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.

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TX09: Entry, Descent, and Landing

This area covers entry, descent, and landing technologies needed to enable both current and future missions.

T9.03 Low SWaP-C Terrain Mapping Sensor for Onboard Hazard Detection (STTR)

Related Subtopic Pointers: Z7.01, Z7.03, Z7.07, Z8.13
Lead Center: JSC
Participating Center(s): GSFC, JPL, LaRC, MSFC

Subtopic Introduction:

This subtopic seeks low size, weight, power, and cost (SWaP-C) terrain mapping sensor solutions that are applicable to onboard hazard detection and avoidance for safe and precise landing. The subtopic seeks a standalone sensor solution capable of sensing planetary terrains at altitudes greater than 250 m and generating onboard high-resolution digital elevation maps (DEM) within 2 sec and in any illumination condition. This subtopic is not restrictive to the type of sensing technology solution presuming it can achieve the delineated requirements.

Scope Title: Terrain Mapping Sensor Applicable to Guidance, Navigation, and Control (GN&C) for Precise Safe Landing

Scope Description:

NASA is seeking to advance terrain imaging sensors capable of mapping planetary surfaces from an altitude of at least 250 m regardless of surface illumination conditions. The sensors are to be utilized within entry, descent, and landing (EDL) and deorbit, descent, and landing (DDL) GN&C systems for precise safe landing on solid solar system bodies, including planets, moons, or small celestial bodies such as asteroids and comets. Although NASA funds have been allocated to a handful of projects for the development of technologies for precision landing and hazard avoidance (PL&HA), including various light detection and ranging (LIDAR)-based systems, many of these solutions are predominantly tailored to specific concepts of operation for specific missions and the associated environmental conditions. Further, existing developing solutions lie beyond the fiscal reach of small businesses and smaller-class landers companies looking to enter the commercial planetary exploration market and to include the safe landing capability.

This solicitation is seeking a standalone 3D terrain mapping sensor capable of operating in any illumination condition, and which can be generalized to any mission, vehicle configuration, and concept of operations. Proposals must demonstrate a development path to sensor hardware testing (lab and/or terrestrial flight) in an operationally-relevant environment by the end of a Phase II award. Additionally, proposals must convey a credible development path and timeline for post-Phase-II efforts to achieve fully space-qualified hardware applicable to the EDL/DDL spaceflight environment considering factors such as radiation, thermal protection, vacuum, and vibrational effects. To be considered, proposals must demonstrate a plan to develop an integrated hardware and software system that meets the below requirements:

- Minimized size, weight, power, and cost (SWaP-C). There are no hard constraints on size, weight or power, but the proposed sensor must be comparable to current state-of-the-art space-rated systems (e.g., Lunar Explorer Instrument for Space Biology Applications (LEIA), ASC Flash LIDAR, JENA RVS3000, etc.). For cost, the desire is to target a sensor cost on the order of $1-$5 million per space-qualified unit to enable inclusion into a broad market of smaller-class landers. Proposers are encouraged to contact various lunar lander vendors to further discuss desirable cost targets. Proposals should include a justification of cost target if such contacts occur.
- Generate a digital elevation map (DEM) of 100 x 100 m with a ground sample distance of less than 10 cm/pixel from a range of 250 m (at minimum) and in less than 4 sec. Note that ranges of greater than 500 m are preferable, but 250 m is the minimum allowable range for the development and maturation of a low SWaP-C capability. To provide sufficient margin for the map generation process, the scan time should be limited to less than 2 sec so that the total scan and DEM-generation time is less than 4 sec (the faster the better).
- The generated DEM should be put into a surface-relative fixed frame and the sensor must incorporate alignment and calibration provisions so that generated data and DEMs can be transformed between sensor-relative frames and external mounting frames for tying back to vehicle navigation frames.
- Produce a DEM having an elevation accuracy of less than 5 cm error and lateral accuracy of less than 10 cm error.
- Be able to operate in and account for dynamic vehicular motion, which could be via vibration isolation, measurement of motion/vibration within the sensor, and/or data inputs from external vehicle sensors and navigation.
- Sensing approach and hardware design should allow for the acquisition of multiple DEMs at different altitudes to account for evolving concepts of operation for EDL/DDL, as well as to provide robustness against unforeseen interruptions in acquisition. At altitudes higher than 500 m, it is not expected to maintain the 5 cm ground sample distance (GSD); the GSD could be scaled correspondingly.

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

Primary Technology Taxonomy:

- Level 1: TX 09 Entry, Descent, and Landing
- Level 2: TX 09.4 Vehicle Systems

Desired Deliverables of Phase I and Phase II:

- Prototype
- Hardware
- Software
- Research
- Analysis

Desired Deliverables Description:

The following deliverables are desired for Phase I:

1. Benchtop hardware demonstration of the sensing system acquiring data and generating a terrain map within the delineated specifications at short range.
2. Analysis and/or software simulations of how the system would perform in a relevant environment including at long range, in low-light, and under dynamic and vibratory conditions.

The following deliverables are desired for Phase II:

1. Hardware demonstration of the system in an operationally relevant environment, which could be in a lab or a terrestrial testbed, including a terrestrial flight vehicle. The sensing system must acquire enough data to produce a DEM of the required resolution at long ranges greater than 250 m in the specified time. The system must demonstrate robustness to light conditions, vibration, dynamic motion, and accuracy with no loss of performance.
2. Demonstration of a path for space-qualified hardware and spaceflight infusion, including the consideration of vacuum and radiation effects.

State of the Art and Critical Gaps:

Navigation systems for upcoming exploration missions to the Moon, Mars, and other celestial bodies must meet increasingly challenging requirements to enable highly reliable PL&HA. Many landing sites of exploration interest exhibit low levels of illumination precluding the use of traditional passive-imaging systems. Thus, alternative sensing solutions robust to illumination conditions are required to navigate relative to the terrain. Current path-to-space and state-of-the-art solutions for onboard hazard detection have cost barriers for small businesses and small lunar-class landers to employ. Further, while the SWaP-C of systems with state-of-the-art sensing capabilities designed for terrestrial applications has significantly dropped in recent years, they are not yet suitable for spaceflight. This solicitation addresses this SWaP-C gap to make spaceflight missions requiring terrain-relative sensing capabilities in prohibitive lighting conditions more accessible to small businesses and the space industry as a whole.

Relevance / Science Traceability:

Precision landing and hazard detection/avoidance have maintained consistent prioritization within the NASA and National Research Council (NRC) space technology roadmaps for decades. Existing and vetted high-priority NASA EDL technology gaps continue to call for advancements of PL&HA technologies, and stakeholders from within NASA leadership and the broader U.S. government are advocating for the commercialization of NASA-enabled capabilities. Current state-of-the-art sensing and navigation systems are not yet mature enough to enable consistently reliable operations in hazardous environments, including at a cost appropriate for small businesses and small lunar-class landers. The evolution of technologies able to meet the demanding objectives required for robotic science and human exploration operations to locations with unknown or hazardous terrain is critical to mission success, and small businesses have a key role to play.

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TX10: Autonomous Systems

This new area covers technologies that (in the context of robotics, spacecraft, or aircraft) enable the system to operate in a dynamic environment independent of external control.

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

Related Subtopic Pointers: A2.02, S17.03
Lead Center: LaRC
Participating Center(s): ARC, GSFC, JPL

Subtopic Introduction:

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 uncrewed 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 justified 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 confidence in a system’s trustworthiness, which in turn, is the ability to perform actions with desired outcomes.

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

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

Scope Description:

Because behind every action lies a decision-making problem, the 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. Data may be an output of sensors or the output of models or simulations.

Consider data exchanges in multi-agent CPH teams that include AS, as described in the subtopic introduction. 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 or computational model accuracy.
- 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 design reference mission relevant to NASA missions 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 5

Primary Technology Taxonomy:

- Level 1: TX 10 Autonomous Systems
- Level 2: TX 10.1 Situational and Self Awareness

Secondary Technology Taxonomy:

- Level 1: TX 10 Autonomous Systems
- Level 2: TX 10.2 Reasoning and Acting

Tertiary 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

- 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 uncrewed 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), Exploration Systems Development Mission Directorate (ESDMD), Space Operations Mission Directorate (SOMD), 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.

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T6.09 Human-Autonomous System Integration for Deep Space Tactical Anomaly Response in Smart Habitats (STTR)

Related Subtopic Pointers: A2.02, S17.03
Lead Center: ARC
Participating Center(s): JSC

Subtopic Introduction:

The state of the art in human spaceflight is defined and modeled by current operations for the International Space Station (ISS). ISS is continuously crewed, requires astronauts to perform maintenance activities (both within and outside the habitat), is supported by a large mission control staff in real time, and has nearly continuous, large bandwidth data communications from space to ground. Beyond ISS, NASA's Moon to Mars architecture outlines a very different concept of operations where habitats will be intermittently occupied and there is a reduction in mission control support due to the longer communication latencies as well as the limited data bandwidth.

Future deep space habitats (both orbital and surface) will require to be designed for resiliency and autonomous operations during times when there is crew onboard and when there is none. These new smart habitats need to provide a functional, hospitable, and safe environment for astronauts, necessitating advancements in automated and autonomous systems as well as robotics. New capabilities will address the critical challenges faced by future deep space habitats.

NASA needs systems engineering for smart habitats across the full life cycle of design, implementation, verification, and operations. This subtopic solicits designs for human-autonomous system integration for deep space tactical anomaly response in future smart habitats. Specifically for anomaly response systems, proposals may cover any phase of life cycle, from design tools, system design, and/or verification methods.

Scope Title: Understanding Fault Propagation and Fault Action Impacts in an Integrated/Human-Autonomy System for Smart Habitats

Scope Description:

One critical area for smart habitats is the appropriate and necessary balance between human and autonomous system intervention during anomalies. Onboard autonomous systems will be used, for instance: to collect a wide array of sensor information; integrate heterogeneous data from various vehicle subsystems; identify and predict system/subsystem/hardware required maintenance; diagnose subsystem faults; and recommend resolutions after malfunctions. On the other hand, humans will have to consume all the information and recommendations provided by the autonomous systems. This is true for both onboard astronauts and on-Earth mission control flight controllers. Particular astronauts will have a more challenging time as they will be a smaller team. However, it is essential to provide astronauts with the capability to respond to anomaly events in deep space missions.

When an anomaly occurs in deep space, decision support systems will identify the source(s) of the anomaly as well as recommend a course of action for crew to take. This will require future smart habitats to have data fusion, combining heterogenous onboard sensor data and onboard processing of large data analytics. Developing the task model and system design for an integrated anomaly response functionality in a remote smart habitat will require exceptional systems engineering tools. These anomaly responses will need to be assessed for their ability to provide safe and effective controls in both known and unknown scenarios. Uncertainty, perception, and human situational awareness are all factors that add complexity to the system under design. Tools are needed that can reduce the complexity of the design space and allow for various types of analysis of the anomaly response system design to support eventual verification and validation of the integrated human-autonomy system.

It is unlikely that any astronaut will be constantly monitoring spacecraft health and performance, so they will first need to quickly recover situation awareness when alerted to the anomaly. This will facilitate them to quickly make a judgment regarding the subsequent recommended fault recovery. Additionally, the autonomous system needs to convey the potential of cascading failures that may result due to the recommended recovery action. This is also a type of situation awareness for the astronaut being able to project the state of the spacecraft based on current actions. Astronauts will need to quickly rationalize through a large information space and select a fault recovery action that maintains safety and does not compromise other subsystems. Enabling astronauts to make complex decisions and prioritization in a time- and safety-critical moment is crucial for long-distance, long-duration exploration missions.

NASA needs system engineering tools to design robust human-automation systems in smart habitats, enabling future fault detection, isolation, and resolution (FDIR) that successfully and safely integrates fault propagation and fault action impacts across all subsystems while still supporting astronauts and flight controllers during anomalies.

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

Desired Deliverables Description:

Phase I deliverables include use cases/scenarios, preliminary designs, etc., for anomaly response in smart habitat.
Phase II deliverables include new technology or prototypes demonstrated through integrated demonstration as well as recommendations. Ideally, the delivery would be open-sourced; delivery of technology includes algorithms, models, and/or software prototypes.
Three inter-related subsystems must be modeled (e.g., power, life support, thermal, food system, or payload); they will interface with a smart habitat technology, e.g., prognostic algorithms, Digital Twin, and FDIR, to generate suggested fault recovery actions based on an inserted anomaly or malfunction. Wizard of Oz integration is not permissible (i.e., computer system being operated or partially operated by an unseen human being does not meet success criteria). If applicable (e.g., designing and prototyping user interface), human-in-the-loop evaluation is expected.

State of the Art and Critical Gaps:

Currently, NASA envisions including smart habitats in deep space exploration missions. It requires the development of new autonomous systems that need to support the entire full life cycle of design, implementation, verification, and operation of the anomaly response system. Moreover, human operators who manage the habitat from either within or remotely, need to successfully use these. One particular area of interest is FDIR and the various methods, algorithms, models, and analyses that can be leveraged in the future. Anomaly responses will need to be assessed for their ability to provide safe and effective controls in both known and unknown scenarios.

Relevance / Science Traceability:

This subtopic is most relevant to the Space Technology Mission Directorate (STMD) but also Exploration Systems Development Mission Directorate (ESDMD) and Space Operations Mission Directorate (SOMD). The technology will advance development of planned habitats for Moon and Mars.

References:

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TX11: Software, Modeling, Simulation, and Information Processing

This area covers modeling, simulation, and information technology as well as software technologies that increase NASA’s understanding and mastery of the physical world and are the basis of new solution paradigms across the breadth of NASA’s missions.

T11.06 Extended Reality (Augmented Reality, Virtual Reality, Mixed Reality, and Hybrid Reality) (STTR)

Related Subtopic Pointers: A1.06, S14.01, S17.01, S17.02, S17.04
Lead Center: JSC
Participating Center(s): GSFC, KSC

Subtopic Introduction:

The objective of this subtopic is to develop and mature extended reality (XR) technologies that can support NASA's goal of a sustained presence on the Moon, the exploration of Mars, and the subsequent human expansion/exploration across the solar system. NASA’s current plans are to have boots on the surface of the Moon in late 2024. Over time, lunar, Mars, and other solar system exploration missions will be much longer, 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, analysis tools, and real-time operations support tools possible because a single error during task execution can have dire consequences in the hazardous space environment. Astronauts will also be required to function more autonomously than they have functioned previously. Technologies, such as XR, that can improve training, operations support, health and medicine, and collaboration provide tools with capabilities that were not previously available; while also improving a crew's ability to carry out activities more autonomously.

Training and operations support during the Apollo era required the use of physical mockups in labs, large hangars, or outdoor facilities. These training 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). Industry is using next-generation digital technologies to create XR-based digital twins that facilitate Product Lifecycle Management (PLM). Most of all, an XR-Based Digital Ground Replicate of the physical systems can serve as a common media (i.e., a “window”/viewpoint into the actual system) to communicate among all the stakeholders from different locations, sharing and interacting within the same virtual workspace simultaneously.

Industry has been using XR for gaming successfully and although there are some enterprise-level applications, there are still many opportunities in this domain that have not been realized. NASA has a long history of developing and using XR for training, operations, engineering, collaboration, and human performance applications. These are prime areas where NASA can help guide the development of XR technologies for enterprise applications that could provide significant benefits to industry, other government agencies, and companies forging into the space industry domain.

Furthermore, as industry/academia develops XR technologies, the way NASA is using XR will also change. Previously, NASA would need to develop all the software and hardware needed, but industry is developing XR technologies that allow NASA to focus on specific use cases. We have also identified several gaps/needs in the XR domain that could further support XR use across NASA, so working with industry/academia to address these gaps would be beneficial to NASA.

Scope Title: XR for Health Care and Health Management

Scope Description:

In the upcoming stages of human exploration, astronauts will embark on missions that take them deeper into space and require them to spend extended durations away from Earth. Consequently, these missions will require astronauts to exhibit a higher degree of autonomy. A critical facet of this increased autonomy revolves around healthcare, as astronauts must be capable of managing healthcare situations with limited Earth-based support. Technologies that allow astronauts to do this will become critically important.

The healthcare industry at large is actively using Extended Reality (XR) as a solution for the planning, training, and real-time support of health-related activities. This field has experienced substantial growth in recent years and currently represents a $7 billion industry. XR offers a range of applications, including enhancing the safety and efficiency of surgical planning and execution by providing 3D perspectives from multiple angles. It streamlines the planning process by seamlessly integrating imaging with immersive 3D content. It enables medical students to practice procedures and familiarize themselves with medical instruments in a lifelike digital environment that is both immersive and cost-effective. It is allowing for the transition from traditional cadaver-based training to digital human simulations that allows students to engage in repeated training sessions from the convenience of their homes or any location with a computer. It is also allowing for the simulations of complications during practice sessions to a degree that has not been possible before. Furthermore, XR technology is also making inroads into pain management and being used to help support mental health support services.

Combining the healthcare industry's XR proficiency with NASA's extensive experience in human spaceflight medicine has the potential to enable astronauts to operate more independently and effectively manage medical emergencies in the challenging space environment.

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

Primary Technology Taxonomy:

- Level 1: TX 11 Software, Modeling, Simulation, and Information Processing
- Level 2: TX 11.6 Ground Computing

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:

Currently, NASA relies on limited training performed before flights, support from a flight surgeon on console, or manuals to carry out health care of crew during missions. As mission durations increase and the distance we visit grows, crew must become more autonomous in managing their health and addressing any medical situations that arise. The commercial health care industry is already leveraging some of these technologies in day-to-day operations and NASA could benefit significantly from incorporating some of those technologies and concepts.

Novel concepts related to real-time photorealistic visuals, markerless tracking of people/instruments, human interface systems (including haptics/mixed reality), and wearable XR devices could provide a system that provides significantly more capabilities than are currently in use.

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 Exploration Systems Development Mission Directorate (ESDMD) and Space Operations Mission Directorate (SOMD), 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.
https://www.nasa.gov/directorates/heo/index.html
https://www.nasa.gov/directorates/spacetech/home/index.html
https://science.nasa.gov/
https://www.nasa.gov/specials/artemis/
https://www.nasa.gov/gateway
This type of capability would enable the development of immersive systems that could support planning, analysis, training, and collaborative activities related to surface navigation for Artemis missions.

References:

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Scope Title: Holodeck Technologies for XR

Scope Description:

One particularly notable technology from Star Trek was the holodeck, which served multiple purposes. It functioned as a data analysis environment, a planning tool, offering 3D visualization of data, models, and simulations. The holodeck was also used as a training environment, providing crew members with simulated environments for training. It also served as an engineering design tool, allowing crew members to create and manipulate 3D models of objects and systems piece by piece before their fabrication. Furthermore, it provided a recreational environment, simulating various locations for crew members to visit.

While today's technologies may not replicate the full range and fidelity of capabilities seen in a Star Trek holodeck, there are Extended Reality (XR) technologies that allow for the creation of a "holodeck-like" system that could provide NASA with significant benefits. Some of these technologies include:

1. Multi-user participation - This includes being able to have two or more individuals participating in the same immersive environment.
2. Mobility and Markerless tracking - This includes being able to determine the position/orientation of the torso, limbs, fingers, and other items in the physical environment, while carrying out activities in a much smaller physical environment than the virtual space.
3. Human interfaces - This includes methods by which users can interact with the immersive environment or other users in the system. This can also include interacting with artificial intelligence (AI) and machine learning (ML) agents and/or other intelligent systems.
4. Sensory - This includes improvements to the visuals, incorporation of haptics (full body or limb/finger), acoustics, and olfactory. Also includes the possibility of incorporating temperature control, wind, etc., into the overall physical experience.
5. Wearable or projection XR display systems - Visual display quality (resolution, field of view, refresh rate, etc.), comfort for prolonged use, complexity getting the system operational, and costs to implement are important in this area.
6. Dynamic scene generation - This includes the ability to augment the immersive scene (in real time) with new content that is relevant to the current state of the simulation.

The integration of the XR technologies above, combined with NASA's extensive experience innovating and conducting cutting-edge research in human spaceflight, science, aeronautics, and engineering could lead to the development of next-generation training systems, applications that improve real-time mission support, a framework that facilitates the engineering design process, and tools that enhance our ability to visualize and analyze complex data. These systems and tools can improve NASA's risk posture, reduce costs, and provide capabilities not previously possible. These systems are not only relevant to NASA, but also to the broader commercial industry as a whole.

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

Primary Technology Taxonomy:

- Level 1: TX 11 Software, Modeling, Simulation, and Information Processing
- Level 2: TX 11.6 Ground Computing

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:

The three most used XR immersion methods are projection-based systems, head-mounted displays, or flat screens.

- A cave automatic virtual environment (CAVE) is a type of projection system that can be used to provide users with immersive content. The CAVE consists of a room that has multiple projectors displaying content on the wall. The glasses that users put on provide stereo capabilities. The users usually interact with some of the content being displayed with wand-like controllers. The major drawbacks with this type of system are the scene is not customizable to individuals (everyone has to be in the same virtual area), the ways that users interact with the system are typically very rudimentary, the system is usually limited in the type of nonvisual sensory feedback incorporated, the system requires significant space to implement, and the high cost to deploy this type of system.
- A head-worn display can provide highly immersive visualization for multiple concurrent users and supports having users at different locations. These types of devices can usually provide higher resolution, brighter displays, do not require a large space to use, and have a lower cost to implement than CAVE-like systems. For those reasons, these types of systems have become very popular. Some of the limitations for this type of system include not being able to show immersive content to a large number of people concurrently, they can become uncomfortable to wear, and being problematic when showing content to a large number of people concurrently.
- A flat display (computer monitor, tablet, smartphone, etc.) provides accessibility by a large number of people, can be very portable (smartphones/tablets), and thus is the most widely used. The biggest limitation is the level of immersion that can be provided.

Along with the limitations mentioned above, these types of systems could benefit by integrating some of the holodeck technologies mentioned previously.

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 Exploration Systems Development Mission Directorate (ESDMD) and Space Operations Mission Directorate (SOMD), 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.
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https://www.nasa.gov/directorates/spacetech/home/index.html
https://science.nasa.gov/
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3. https://www.nvidia.com/en-us/design-visualization/technologies/holodeck/

Scope Title: XR Usage for Human Performance Applications

Scope Description:

Industry is using a combination of XR, biometrics, and AI/ML to create applications that monitor and enhance human performance. Examples within the industry include personalized training, real-time monitoring, stress and cognitive load management, task assistance, and cognitive improvement. By merging NASA's extensive expertise in human performance-focused training and operations, with the cutting-edge research conducted by the industry in XR, biometrics, and AI/ML, we can facilitate the development of next-generation training, planning, and operations support systems. Not only would NASA benefit from these systems, but industry would be able to leverage the systems created for NASA to develop variants to use in their own general public products.

Key technologies of interest in this domain include:

1. Multimodal sensor data integration into an XR system. This includes data from wearable and nonwearable biometric devices. The idea is to minimize the number of biometrics sensors required for the task and make the overall system more reliable and easier to use. This includes both optical and non-optical-based biometric systems.
2. Cognitive state determination system. An example of this is an adaptable human interface that can dynamically modulate the XR content based on a person's cognitive state. If the system detects that a person is highly stressed, confused, or about to go into a cognitive overload, then it could dynamically modulate the content and activities being carried to reduce the cognitive workload. If the system detects that the person is bored or in a low cognitive workload state then it would provide more engaging content. We want to keep the users in the cognitive workload goldilocks zone learning/operating state. This means that the XR system needs to be extremely configurable and be able to create and insert, into the scene, new on-demand content of varying fidelity levels in real time.
3. Physiological state determination system. Along with modulating XR content based on a person's cognitive state, the system could modulate XR content based on a person's physiological state. If they are showing signs of high levels of physical fatigue, the system could modulate the content to reduce the physiological workload required to continue. If the user is showing signs of boredom, then the system will take the appropriate action by increasing the exertion required.
4. XR-Based Advanced Object Recognition. This system can support navigation in complex environments by combining concepts related to edge detection and AI/ML to identify partially occluded objects in the field of view and provide full object views to a person wearing a headset. The best way to provide this information is still an open area of applied research.

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

Primary Technology Taxonomy:

- Level 1: TX 11 Software, Modeling, Simulation, and Information Processing
- Level 2: TX 11.6 Ground Computing

Desired Deliverables of Phase I and Phase II:

- Analysis

- Research
- Prototype
- Hardware
- Software

Desired Deliverables Description:

Phase I awards will be expected to develop theoretical frameworks and algorithms and demonstrate the 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:

There are many small businesses that are currently involved in the XR space and developing XR technologies that are unique, innovative, and proving to be very useful for a wide variety of applications. These companies are making good progress advancing the state of the start in this field. The scope and funding defined in the call is such that the small businesses can select a specific technology area and approach to address part of the overall challenge. Funding small businesses to further develop XR capabilities of interest would provide them with additional technologies to include in the applications they are developing and which could be used to support many NASA applications.

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 Exploration Systems Development Mission Directorate (ESDMD) and Space Operations Mission Directorate (SOMD), 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.
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https://www.nasa.gov/directorates/spacetech/home/index.html
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TX12: Materials, Structures, Mechanical Systems, and Manufacturing

This area covers technologies for developing new materials with improved or combined properties, structures that use materials to meet system performance requirements, and innovative manufacturing processes.

T12.01 Additively Manufactured Electronics for Severe Volume Constrained Applications (STTR)

Related Subtopic Pointers: H5.01, H5.05, H8.01, S12.02, Z4.07
Lead Center: JPL
Participating Center(s): GRC, GSFC, MSFC

Subtopic Introduction:

This subtopic is focused specifically on additive manufacturing of electronics. While there is some overlap in the techniques, there are specific challenges in creating structures that utilize both conductive and insulative elements. This area has had activity for well over 10 years, but over the past 5 years, this area has grown significantly as a relevant technology that is approaching/in commercialization. NASA is looking for innovative approaches to address this complex issue related to additive manufacturing of electronics for use in space.

Scope Title: Additive Manufactured Electronics for Severe Volume Constrained Applications

Scope Description:

The field of Additively Manufactured Electronics (AME) has been evolving and can provide enabling capability for future NASA missions that have very severe or unique volume constraints. Several concepts for NASA missions or mission concepts in the decadal survey where these volume constraints can be major technical constraints are advanced mobility concepts [1], atmosphere probes, and Instruments/Subcomponents of Ocean World Landers. Some of the electronics in these missions will likely need to go below cold survival temperatures associated with warm electronics boxes (i.e., colder than -35 °C). Use of AME to incorporate sensor integration into structural elements is of particular interest for volume constrained applications. The inclusion of these elements can allow for self-sensing of a mechanism's state (e.g. force-torque sensors), allow effective interconnectivity along and through structural elements, and sense the local environment [2]. Interconnections to active elements such as heating as well as piezoelectric element for actuation are of direct interest. There is existing literature that has demonstrated additive incorporation of these elements, but for NASA missions, the external structures can be exposed to extreme cold and fairly high levels of radiation. The AME approach should address the following technical and mechanical challenges:

1. AME methodology must address adhesion onto either or both Ti-6AL-4V and Aluminum 6061 substrates through multiple exposures of extreme cold -180 °C.
2. AME processing repeatability should be demonstrated on curved surfaces in terms of processing and functionality of the element.
3. Material stresses and performance over the temperature range should be modeled and understood.

Expected TRL or TRL Range at completion of the Project: 2 to 3

Primary Technology Taxonomy:

- Level 1: TX 12 Materials, Structures, Mechanical Systems, and Manufacturing
- Level 2: TX 12.4 Manufacturing

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype

Desired Deliverables Description:

- Effectiveness of material adhesion and stresses should be understood given the probable coefficient of thermal expansion (CTE) mismatches and the extreme environment temperatures. Material sets and methodologies should be readily available for NASA centers to use on application-specific designs to meet future packaging needs
- Phase I deliverables should demonstrate planned materials can obtain effective adhesion and have the capability to survive exposures to extreme cold such as -180 °C. Phase I should also demonstrate that materials selected have the capability to have repeatable processing.
- Phase II deliverables should include the design, fabrication, and demonstration of incorporated sensing elements. Testing should demonstrate the reliability of AME structures as well as functional performance of the structures. Materials and manufacturing techniques should be formulated and available at small scale for application-specific designs.

State of the Art and Critical Gaps:

Numerous published works have shown multiple material and manufacturing methods able to print conductors and dielectrics at needed resolutions. There are also multiple published examples where nonplanar or 3D circuits have been fabricated [3-6]. The current set of work shows lack of data demonstrating the reliability of these circuits in environments relevant to NASA. Also, the current body of work shows circuits with small numbers of parts and does not demonstrate the repeatability/reproducibility desired for more complex 3D/nonplanar circuits.

Relevance / Science Traceability:

Use of AME is relevant to Exploration Systems Development Mission Directorate (ESDMD), Space Operations Mission Directorate (SOMD), Science Mission Directorate (SMD), and Space Technology Mission Directorate (STMD), all of which have extant efforts in additive manufacturing. Several efforts involving NASA and aerospace companies have used AME on the space station (including major work from NASA centers on fabrication of circuits in space). Future AME missions where there are extreme volume constraints include components of landing systems, probes, and mobility systems that are needed to meet SMD and STMD goals.

References:

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T12.09 Thermoplastic Composites for Repurposable Aerospace Applications (STTR)

Related Subtopic Pointers: H5.01, H5.05, H8.01, S12.02, Z4.07
Lead Center: LaRC
Participating Center(s): JSC

Subtopic Introduction:

Thermoplastic composites are increasingly being used in various aeronautical and aerospace structures due to their lightweight properties along with various strength and impact resistance advantages. This solicitation seeks to exploit these unique properties to assess the feasibility of repurposing primary or secondary spacecraft structures into new infrastructure that will support a sustainable human presence beyond low Earth orbit (LEO). For the purpose of this solicitation, the term "infrastructure" encompasses tools that can be used for excavation, construction, and outfitting [1]. The original spacecraft (e.g., lander or descent module) components would be designed to account for future repurposing requirements. Once the spacecraft has accomplished its mission (e.g., successfully descended onto the lunar surface), its parts would be disassembled and reconfigured into infrastructure components and/or tools. This reconfiguration can be achieved by reheating the thermoplastic resin composing these parts [2] and mechanically modifying the structure into a predetermined repurposed configuration.

Scope Title: Thermoplastic Composites for Repurposable Aerospace Applications

Scope Description:

NASA is developing long-duration, crewed missions to the Moon and beyond. These missions will require crew habitats and, consequently, sourcing materials to construct them and their associated infrastructure. Some examples of such infrastructure are those used for storage, surface transportation, and communications. Use of in-situ resources (e.g., lunar regolith) and reuse of descent vehicles have already been proposed as a means of reducing the amount of material needing to be delivered as payload for a sustainable human presence. The ability to repurpose components of spacecraft structures is one potential benefit of using thermoplastic composites [3, 4]. Thermoplastics also offer the potential to be easily repaired via a reheating process in the event of in-service damage [5].

To reliably assess the feasibility of repurposing thermoplastic composites for space applications, modeling and simulation (M&S), as well as experimental work, need to be conducted in a building block approach. In Phase I, the proposing team shall determine a focus structure where (1) the original geometric configuration and (2) a repurposed configuration is defined along with the corresponding sizing load cases. Repurposing lunar lander fairings and/or components of the micrometeoroid and orbital debris (MMOD) protective structure into a regolith mining scoop or repurposing primary truss structure into an antenna post are examples provided here for illustration purposes only, and the proposing team is encouraged to survey and offer other applications of their choosing. A selected case study shall demonstrate repurposing both from the standpoint of altered geometry and distinct loads. Once the two “stand-alone” cases (original and repurposed) are sized and analyzed, a multiphysics simulation of the repurposing process shall be conducted. The proposing team should ensure different process parameters are explored to determine repurposing process sensitivity and establish the energy required for the repurposing process, along with the full concept of operations. Heating methods shall be explored and may include external and/or internal (pre-embedded) heating devices. Furthermore, the simulation should establish tradeoffs associated with conducting the repurposing process with and without dedicated tooling aids.

These efforts will establish a foundation for hardware demonstrations to be conducted in Phase II. Test data obtained from these Phase II demonstrations will be used to calibrate the initial multiphysics repurposing simulation, enable detailed repurposing assessments, and mitigate prominent risks.

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

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:

- Research
- Analysis
- Prototype

Desired Deliverables Description:

The Phase I deliverables shall include:

1. Design with a dual purpose or requirements, i.e., the original spacecraft component (e.g., primary truss structure, landing gear strut, fairing, etc.) and the repurposed component (e.g., antenna mast, habitat frame, excavation scoop, reconfigurable joint, etc.).
2. A concept of operation for the repurposing process supported by the multiphysics process simulation. This may include energy requirement and source(s), means of delivering required heat, tooling, or any means of process quality assessment and/or repurposed product nondestructive evaluation.
3. Metric(s) that can assess the repurposing hardware weight and other feasibility aspects of the repurposing process to inform mission design.

A lessons learned section shall be a part of the Phase I deliverable report.

The Phase II deliverables shall include:

1. Manufacturing demonstration unit(s) per the design and repurposing process provided in the Phase I deliverable.
2. Report documenting original fabrication and repurposing process, including correlation with the results of the repurposing process modeling conducted in Phase I.
3. Revised or validated metric(s) of performance proposed in Phase I.

A lessons learned section shall also be a part of Phase II deliverable report.

State of the Art and Critical Gaps:

Present composite designs mainly use thermoset materials, which have limited manufacturing rates, are difficult to repair, and can lack the desired tailorability for advanced structures. There is a need for advanced materials that can be used to increase performance and decrease manufacturing and repair demands for in-space applications.

Relevance / Science Traceability:

At the completion of Phase II, the program will gain understanding of where the implementation of repurposed thermoplastic composites can be most advantageous in deep space structural applications, how such a repurposing can be accomplished (concept of operations), and what are the metrics that can be used in assessing feasibility of repurposing. Additionally, the technology gaps limiting even broader implementation of repurposed thermoplastic composites can be identified. This solicitation supports the Langley Strategic Technology Investment Plan [1] in the areas “Safe Human Travel Beyond Low Earth Orbit (LEO)” and “On-Orbit Servicing, Assembly, and Manufacturing (OSAM).”

Thermoplastic composites offer the potential for lightweight composite structures to be repurposed, in contrast to state-of-the-art composites, which are generally made with thermoset resins. This supports applications like the Artemis mission, where in-situ resources, among which are structures from objects like descent modules, become part of native resources that can be used to create infrastructure.

Examples of potential uses include: Space Technology Mission Directorate, Artemis/Human Landing System (HLS) programs, Aeronautics Research Mission Directorate, next-generation airframe technology beyond "tube and wing" configurations (e.g., hybrid/blended wing body or transonic truss-braced wing), and the Hi-rate Composite Aircraft Manufacturing (HiCAM) program.

References:

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TX13: Ground, Test, and Surface Systems

This area covers technologies for preparing, assembling, validating, executing, supporting, and maintaining aeronautics and space activities and operations, on Earth and on other planetary surfaces.

T13.01 Intelligent Sensor Systems (STTR)

Related Subtopic Pointers: A1.08
Lead Center: SSC
Participating Center(s): MSFC

Subtopic Introduction:

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. Tests must yield high-quality results both in data and subsequent analysis, fit into aggressive development schedules, and allow developers to minimize costly test-fail-fix cycles. Intelligent sensor systems have 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. Additionally, advanced, reliable wireless capabilities have the potential to significantly reduce costs and increase data not previously available to advance predictive maintenance and predictive failure analysis.

Scope Title: Intelligent Sensors for Rocket Propulsion Testing

Scope Description:

Intelligent sensor systems would need to function reliably in extreme environments, including rapidly changing ranges of environmental conditions, such as those experienced in space and propulsion test environments. These ranges include extremely cold temperatures, such as cryogenic temperatures, extremely high temperatures, such as those experienced near a rocket engine plume or combustion chambers, as well as high pressure and high flow rates in propellant supply tanks, feedlines, turbine outputs, and combustion chambers and plumes. Additional environmental considerations include high vibration, high flow, high pressure, vacuum, electromagnetic interference (EMI), and radiation. Sensor operational environmental parameters must be suitable for the anticipated environment.

Intelligent sensor systems would provide a highly flexible instrumentation solution capable of monitoring test facility parameters including temperature, pressure, storage vessel liquid level, flow, thrust, power, and/or vibration. Sensor systems should enable the ability to detect anomalies, determine causes and effects, predict future anomalies, and provide an integrated awareness of the health of the facility and test article systems. These intelligent sensors should also be capable of performing in-place calibrations with National Institute of Standards and Technology (NIST) traceability, detecting and diagnosing sensor and sensor system anomalies, and predicting and identifying failure modes. The intelligent sensor system must also provide conversion of raw sensor data to engineering units, synchronization with Inter-Range Instrumentation Group—Time Code Format B (IRIG-B), as well as network connectivity to facilitate real-time integration of collected data with data from conventional data acquisition systems. The intelligent sensor system should be able to provide data to support and enable autonomous operations, development of digital twin models, and more advanced analysis.

This subtopic seeks both wired and wireless solutions to address the need for intelligent sensor systems to monitor and characterize rocket engine performance. Wireless sensors are highly desirable and offer the ability to eliminate facility cabling/instrumentation, which can significantly reduce the cost of operations. It also provides the capability for providing instrumentation in remote or hard-to-access locations and potentially on flight vehicles. These advanced wireless 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. This solicitation is also interested in deterministic wireless functionality with the ability to acquire data quickly and reliably without conflicts, as well as potential solutions for radiation tolerance and hardening.

Rocket propulsion test facilities also provide excellent testbeds for testing and using innovative technologies for possible applications beyond the static propulsion testing environment. It is envisioned this advanced instrumentation would support sensing and control applications beyond those of propulsion testing. For example, inclusion of expert system and artificial intelligence technologies would provide great benefits for predictive maintenance and predictive failure identification, autonomous operations, health monitoring, or self-maintaining systems.

This subtopic seeks to develop advanced intelligent sensor systems capable of performing onboard processing utilizing artificial intelligence/machine learning to gauge the accuracy and health of the sensor, as well as integrating into a larger system model for system-level diagnostics, anomaly detection, preventative maintenance, and failure prediction and analysis. Sensor systems must provide the following functionality:

1. Assess the quality of the data and health of the sensor and sensor systems.
2. Perform in-place calibrations with NIST traceability.
3. Data acquisition and conversion to engineering units for monitoring temperature, pressure, storage vessel liquid level, flow, thrust, power, and/or vibration within established standards for error and uncertainty.
4. Function reliably in extreme environments, including rapidly changing ranges of environmental conditions, such as those experienced in space and propulsion test environments.
5. Collected data must be time-stamped to facilitate analysis with other collected datasets.
6. Provide network connectivity to facilitate real-time transfer of data to other systems for monitoring and analysis.
7. Increase facility and propulsion test system status and awareness through predictive maintenance and predictive failure identification.
8. Advance wireless system reliability and provide deterministic wireless architectures and hardened wireless systems that are not susceptible to interference from ground test such as high temperature, high flow combustion, and nuclear thermal and nuclear electric propulsion, as well as radiation that would be experienced on orbit or destination planets.

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 13.2 Test and Qualification

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 package for NASA testing at the completion of the Phase II contract. Successful Phase II technologies will be candidates for integration and demonstration in the existing Autonomous Systems Lab (ASL) and ground test and support facilities at Stennis Space Center (SSC) and Marshall Space Flight Center (MSFC), as well as potential assistance at other agency sites.

State of the Art and Critical Gaps:

Highly modular, intelligent 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. Intelligent sensor systems enable the ability to assess the quality of the data and health of the sensor and sensor system, increasing confidence in the system. They can be used for thermal and pressure measurement of systems and subsystems and also provide emergency system halt instructions in the case of leaks or fire. Other examples of potential NASA applications include (1) measuring temperature, voltage, and current from power storage and generation systems, (2) measuring pressure, temperature, vibrations, and flow in pumps, and (3) measuring pressure, temperature, and liquid level in pressure vessels.

Intelligent sensor systems also support SSC and Agency-Wide Digital Transformation and Future State Initiative efforts. There are many other applications that would benefit from increased real-time intelligent sensors. For example, these sensors would be capable of addressing multiple mission requirements for remote monitoring such as vehicle health monitoring in flight systems and autonomous vehicle operation. 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. In an effort to build strategies and algorithms to detect faults/anomalies, ground systems is a logical starting point to build the automation libraries to take steps to automate dynamically changing configurations. 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 intelligent sensor system 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 Exploration Systems Development Mission Directorate (ESDMD) and the Space Operations Mission Directorate (SOMD). It supports all test programs and ASL at SSC, MSFC, and other propulsion system development centers. Potential advocates are the Rocket Propulsion Test (RPT) Program Office and all rocket propulsion test programs at SSC.

References:

1. Fernando Figueroa, Lauren Underwood, Duane Armstrong, "Model-Based Systems Engineering, Real-Time Operations, and Autonomy," AIAA ASCEND 2020 (16-18 Nov 2020). https://doi.org/10.2514/6.2020-4091

2. F. Figueroa, L. Underwood, J. Morris, M. Walker, R. Brown, "Risk-Reduction Autonomy Implementation to Enable NASA Artemis Missions," 2022 IEEE Aerospace Conference (AERO), Big Sky, MT, USA, 2022, pp. 1-13. https://doi.org/10.1109/AERO53065.2022.9843815
3. F. Figueroa, L. Underwood, M. Walker, J. Morris, "NASA Platform for Autonomous Systems (NPAS)," AIAA SciTech., 7-10 Jan 2019. https://doi.org/10.2514/6.2019-1963
4. Fernando Figueroa, Randy Holland, David Coote, "NASA Stennis Space Center Integrated System Health Management Test Bed and Development Capabilities," Proc. SPIE 6222, Sensors for Propulsion Measurement Applications, 62220K (10 May 2006). https://doi.org/10.1117/12.669184

TX15: Flight Vehicle Systems

This area covers technologies for aerosciences and flight mechanics. Aerosciences is the prediction of vehicle and component atmospheric flight performance and flow qualities to enable robust and efficient flight vehicle development, achieving performance requirements while minimizing environmental impacts. Flight mechanics provides the analysis, prediction, measurement, and test of vehicle dynamics, trajectories, and performance.

T15.04 Full-Scale (Passenger/Cargo) Electric Vertical Takeoff and Landing (eVTOL) Scaling, Propulsion, Aerodynamics, and Acoustics Investigations (STTR)

Related Subtopic Pointers: A1.10
Lead Center: AFRC
Participating Center(s): LaRC

Subtopic Introduction:

This subtopic is designed to close a large gap in full-scale eVTOL flight vehicle support data with main focuses in aerodynamics, propulsion, flight dynamics, controls and/or acoustics. Full-scale vehicle testing data are still highly sought after and its modeling and testing are essential for advanced air mobility (AAM), urban air mobility (UAM), distributed electric propulsion (DEP), and propulsion-airframe integration (PAI). Ideally, proposals should be focused in the areas of design, experiments, and scaling methods. If successful, the benefits are numerous and include enabling subcomponent testing, providing better decision-making processes, providing lessons learned and best practices, and potentially enabling test beds for future flight and testing experiments. This subtopic is highly relevant and facilitates further research and opportunities to small businesses and research institutions. Under the umbrella of air taxis, eVTOL could create a market worth trillions of dollars in the next 15 to 20 years according to some market reports and predictions.

Scope Title: Full-Scale (Passenger/Cargo) Electric Vertical Takeoff and Landing (eVTOL) Scaling, Propulsion, 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 Thrust #1 (Safe, Efficient Growth in Global Operations), #3 (Ultra-Efficient Subsonic Transports); and #4 (Safe, Quiet, and Affordable Vertical Lift Air Vehicles).

The subtopic is designed to accelerate the development timeline of full-scale eVTOL aircraft via flight test. The main focus areas are aerodynamics, propulsion, flight dynamics, controls, and/or acoustics, with the potential to address focus areas in combination. Proposals are sought to: (1) design and execute experiments in order to gather research-quality data to validate aerodynamics, propulsion, flight dynamics, controls, and/or acoustics modeling of full-scale, multirotor eVTOL aircraft, with an emphasis on rotor interactions with airframe components and other rotors and propellers and additionally (2) develop and validate scaling methods for extending and applying results of the instrumented subscale model testing to full-scale applications (if the proposal includes testing of subscale models).

This solicitation does not seek proposals for designs or experiments that do not address full-scale applications. Full-scale is defined as a payload capacity equivalent to two or more passengers or equivalent cargo, including any combination of pilots, passengers, and/or ballast. However, this solicitation does not seek proposals in which an eVTOL aircraft, scale or subscale, is itself a deliverable, but rather, per (1) and (2) of the preceding paragraph, deliverables intended to accelerate the development timeline of full-scale eVTOL aircraft by addressing the identified technology focus areas.

Although eVTOL is preferred, electric short takeoff and landing (eSTOL) vehicle configurations are acceptable.

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 and/or address significant barriers to market penetration. Also, define what data will be collected, data that will be considered proprietary, and data that will be available for publication. Data includes vehicle specifications, component and subsystem specifications, and performance, geometries, 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 the reasoning/justification.
(3) Clearly propose a path to commercialization and include details 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

Secondary Technology Taxonomy:

- Level 1: TX 15 Flight Vehicle Systems
- Level 2: TX 15.6 Vehicle Concepts

Tertiary Technology Taxonomy:

- Level 1: TX 15 Flight Vehicle Systems
- Level 2: TX 15.2 Flight Mechanics

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:

- Research and development objectives and requirements.
- Initial experiment test plans for gathering experimental results related to the aerodynamic, flight dynamic, control, 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 data and performance models for the vehicle and subsystems/components used to generate the expected results.
- Preliminary design of the instrumentation and data recording systems to be used for the experiment.
- Data that is expected to be collected including data that will be considered proprietary.

It is recommended that the awardee provide kickoff, midterm, and final briefings as well as a final report for Phase I.

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

- Experimental results that capture aerodynamic, flight dynamic, control, 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.

It is recommended that the awardee provide kickoff, midterm, and final briefings as well as a final report for Phase II.

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. Innovative approaches in designing and analyzing highly integrated DEP eVTOL aircraft are needed to reduce energy use, noise, emissions, and safety concerns. Such advances are needed to address ARMD's Strategic Thrusts #1 (Safe, Efficient Growth in Global Operations), #3 (Ultra-Efficient Subsonic Transports), and #4 (Safe, Quiet, and Affordable Vertical Lift Air Vehicles). 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, especially in the areas of aerodynamics, propulsion, flight dynamics, controls, and acoustics. Ultimately, the goal is to model and test multidisciplinary aeropropulsive flight dynamics, controls, and acoustics.

Relevance / Science Traceability:

This subtopic primarily supports ARMD's Strategic Thrust #4 (Safe, Quiet, and Affordable Vertical Lift Air Vehicles), although it also yields benefits for #1 (Safe, Efficient Growth in Global Operations) and #3 (Ultra-Efficient Subsonic Transports). Specifically, the following ARMD program and projects are highly relevant.

This subtopic facilitates further research and opportunities to small businesses and research institutions. Under the umbrella of air taxis, eVTOL could create a market worth trillions of dollars in the next 15 to 20 years according to some market reports and predictions. Although aerodynamics, propulsion, flight dynamics, controls, and/or acoustics are the focus of this subtopic, facilitating flight testing of these vehicles provides platforms for many small business opportunities, including development and marketing of subsystems and support infrastructure such as batteries, electric motors, propellers, rotors, instrumentation, sensors, manufacturing, vehicle support, vehicle operations, and many more.

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

- Advanced Air Transport Technology (AATT) Project
- Revolutionary Vertical Lift Technology (RVLT) Project
- Convergent Aeronautics Solutions (CAS) Project
- Transformational Tools and Technologies (TTT) Project
- University Innovation (UI) Project
- Advanced Air Mobility (AAM) Project and National Campaign

References:

1. ARMD/Advanced Air Transport Technology (AATT) Project: https://www.nasa.gov/directorates/armd/aavp/aatt-project/
2. ARMD/Revolutionary Vertical Lift Technology (RVLT) Project: https://www.nasa.gov/directorates/armd/aavp/rvlt/
3. ARMD/Convergent Aeronautics Solutions (CAS) Project: https://www.nasa.gov/directorates/armd/tacp/cas/
4. ARMD/Transformational Tools and Technologies (TTT) Project: https://www.nasa.gov/directorates/armd/tacp/ttt/
5. ARMD/University Innovation (UI) Project: https://www.nasa.gov/directorates/armd/tacp/ui/
6. ARMD Strategic Implementation Plan: https://www.nasa.gov/aeronautics/nasa-releases-newest-vision-for-flight-research/
7. ARMD Advanced Air Mobility National Campaign: https://www.nasa.gov/directorates/armd/aosp/amp/

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 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 validation in relevant environment.	A medium fidelity system/component brassboard is built and operated to demonstrate overall performance in a simulated operational environment with realistic support elements that demonstrates overall performance in critical areas.	End-to-end software elements implemented and interfaced with existing systems/simulations conforming to target environment. End-to-end software system, tested in relevant environment, meeting predicted performance. Operational environment	Documented test performance demonstrating agreement with analytical predictions. Documented definition of scaling requirements.

		Performance predictions are made for subsequent development phases.	performance predicted. Prototype implementations developed.	
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 current STTR subtopics are organized by the Technology Taxonomy.

Appendix C: 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 provisions, clauses, regulations, and certifications that apply to Phase I submissions and contracts. Each provision, 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. Additional contract clauses may apply at time of award.

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) Provisions and Clauses

52.203-18 PROHIBITION ON CONTRACTING WITH ENTITIES THAT REQUIRE CERTAIN INTERNAL CONFIDENTIALITY AGREEMENTS OR STATEMENTS-REPRESENTATION
52.203-19 PROHIBITION ON REQUIRING CERTAIN INTERNAL CONFIDENTIALITY AGREEMENTS OR STATEMENTS.
52.204-7 SYSTEM FOR AWARD MANAGEMENT.
52.204-8 ANNUAL REPRESENTATIONS AND CERTIFICATIONS (DEVIATION 20-02B)
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.
52.219-6 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)
52.225-1 BUY AMERICAN-SUPPLIES (NOV 2021)
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 Provisions and Clauses
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 PROGRAM. (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.

1852.227-11 PATENT RIGHTS – OWNERSHIP BY THE CONTRACTOR.
1852.227-72 DESIGNATION OF NEW TECHNOLOGY REPRESENTATIVE AND PATENT REPRESENTATIVE.
1852.232-80 SUBMISSION OF VOUCHERS FOR PAYMENT.
1852.233-70 PROTESTS TO NASA.
1852.235-70 CENTER FOR AEROSPACE INFORMATION.
1852.239-74 INFORMATION TECHNOLOGY SYSTEM SUPPLY CHAIN RISK ASSESSMENT. (DEVIATION 15-03D)
1852.235-73 FINAL SCIENTIFIC AND TECHNICAL REPORTS.
1852.235-74 ADDITIONAL REPORTS OF WORK - RESEARCH AND DEVELOPMENT.
1852.237-73 RELEASE OF SENSITIVE INFORMATION.
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
PCD 21-04 CLASS DEVIATION FROM THE FEDERAL ACQUISITION REGULATION (FAR) AND NASA FAR SUPPLEMENT (NFS) REGARDING REQUIREMENTS FOR NONAVAILABILITY DETERMINATIONS UNDER THE BUY AMERICAN STATUTE

Additional Regulations
SOFTWARE DEVELOPMENT STANDARDS
HUMAN AND/OR ANIMAL SUBJECT
HOMELAND SECURITY PRESIDENTIAL DIRECTIVE 12 (HSPD-12)
RIGHTS IN DATA DEVELOPED UNDER SBIR FUNDING AGREEMENT
INVENTION REPORTING, ELECTION OF TITLE, PATENT APPLICATION FILING, AND PATENTS

SBA Certifications required for Phase I
(1) CERTIFICATIONS.
(2) PERFORMANCE OF WORK REQUIREMENTS.
(3) EMPLOYMENT OF THE PRINCIPAL INVESTIGATOR/PROJECT MANAGER.
(4) LOCATION OF THE WORK.
(5) NOVATED/SUCCESSOR IN INTERESTED/REVISED FUNDING AGREEMENTS.
(6) MAJORITY-OWNED BY MULTIPLE VCOCS, HEDGE FUNDS OR PRIVATE EQUITY FIRMS [SBIR ONLY].
(7) AGENCY BENCHMARKS FOR PROGRESS TOWARDS COMMERCIALIZATION.
(8) LIFE CYCLE CERTIFICATIONS