National Aeronautics and Space Administration

Small Business

Technology Transfer (STTR)

Phase I

Fiscal Year 2023 Solicitation

Completed Proposal Package Due Date and Time:
March 13, 2023 - 5:00 p.m. ET

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Executive Summary

This solicitation identifies the objectives for the Small Business Technology Transfer (STTR) Program Phase I projects, deadlines, funding information, eligibility criteria for projects, and proposal instructions.

STTR facilitates cooperative R&D between small business concerns and U.S. research institutions – with potential for commercialization. The STTR program has a statutory requirement to stimulate a partnership of ideas and technologies between innovative small business concerns (SBCs) and research institutions (RIs) through federally funded research or research and development (R/R&D). STTR also adheres to SBA directives to increase participation by Women-Owned, Veteran-Owned and Small Disadvantaged Businesses and outreach to Historically Black Colleges and Universities (HBCUs) and Minority Serving Institutions (MSIs). Outreach is also made to underrepresented areas/regions of the country.

The NASA STTR program focuses on the following:

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

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

NASA requests proposals for the Small Business Technology Transfer (STTR) Program Phase I for fiscal year (FY) 2023. **The STTR subtopics appear in an integrated list in Chapter 9.**

NASA uses an electronic submission system called the Electronic Handbook (EHB) https://sbir.gsfc.nasa.gov/submissions/login and all offerors must use the EHB for submitting a completed proposal package. The EHB guides offerors through the steps for submitting a complete proposal package. All submissions are through a secure connection and most communication between NASA and the offeror is through either the EHB or email via the helpdesk at sbir@reisystems.com. For more information see chapter 3.

The SBIR and STTR Extension Act of 2022 (https://www.congress.gov/bill/117th-congress/senate-bill/4900/text) reauthorizes through FY2025 and modifies the Small Business Innovation Research (SBIR) program, the Small Business Technology Transfer (STTR) program, and related pilot programs.

The bill requires agencies with an STTR program to assess the security risks presented by offerors with financial ties or obligations to certain foreign countries. The programs may not make awards to businesses with certain connections to foreign entities. To comply with this requirement, the program will require all offerors selected for contract negotiation of a 2023 STTR Phase I award to complete additional disclosures regarding ties to the People's Republic of China and other foreign countries prior to award and as needed during the life of the funding agreement.

These disclosures will include:

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 5-year period preceding submission of the proposal; and
G. Any foreign business entity, offshore entity, or entity outside the United States related to the small business concern.

1. Program Description

1.1 Legislative Authority and Background

The SBIR and STTR Extension Act of 2022 (Pub. L. 117-183.) amended the Small Business Act (15 U.S.C. 638) to extend the SBIR/STTR programs until September 30, 2025. Policy is provided by the Small Business Administration (SBA) through the combined Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs Policy Directive. The STTR program is Congressionally mandated to facilitate the transfer of technology developed by a research institution through the entrepreneurship of a small business concern (SBC).

1.2 Purpose and Priorities

This solicitation includes instructions for SBCs, hereforth called offerors in collaboration with a research institution (RI) to submit Phase I proposals to the NASA Small Business Technology Transfer (STTR) program. Furthermore, program background information, eligibility requirements for participants, information on the three program phases, information for submitting responsive proposals and NASA specific research subtopics are contained herein. **The fiscal year 2023 solicitation period for Phase I submission of completed proposal packages begins on January 10, 2023 and ends at 5 p.m. Eastern Time on March 13, 2023.**

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

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

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

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

1.3 Three-Phase Program

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

Phase I

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

Maximum value and period of performance for Phase I:

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

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

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

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

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

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

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

1.4 Availability of Funds
There is no commitment by NASA to fund any proposal or to make a specific number of awards and NASA may elect to make several or no awards in any specific research subtopic. Number of awards will be based on the level of appropriated funding provided to the program in FY 2023.

It is anticipated the STTR Phase I proposals will be selected for negotiation of firm-fixed-price contracts for a period of performance not to exceed thirteen (13) months.

> Under this STTR Phase I solicitation, NASA will not accept more than 10 proposals from any one offeror to ensure the broadest participation of the small business community. 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)
Each Phase I offeror must submit a certification stating that it meets the size, ownership, and other requirements of the STTR program at the time of a completed proposal package submission, award, and at any other time set

forth in SBA's regulations at 13 CFR §§ 121.701-121.705. Socially and economically disadvantaged and women-owned SBCs are particularly encouraged to propose.

1.5.2 SBC Size

A Phase I offeror, combined with its affiliates, must not have more than 500 employees.

1.5.3 STTR Restrictions on Level of Small Business Participation

The small business concern must be the primary performer of the proposed research effort. To be awarded an STTR Phase I contract, at least 40% of the research or analytical effort must be performed by the offeror, and at least 30% of the effort must be performed by a single research institution.

1.5.4 Place of Performance

All work shall be performed in the United States. When purchasing equipment or a product under the STTR Funding Agreement, purchase only American-made items whenever possible. However, based on a rare and unique circumstance (for example, if a supply, material, or other item or project requirement is not available in the United States), NASA may allow a particular portion of the research or work to be performed or obtained in a country outside of the United States.

Completed proposal packages must clearly indicate if any work will be performed outside the United States, including subcontractor performance, and justification must be provided by downloading and completing the "Request to Use a Foreign Vendor/Purchase of Items from a Foreign Vendor" form found at https://sbir.gsfc.nasa.gov/submissions/learning-support/firm-templates and while completing the budget under section 3.5.

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

Note: NASA will not approve purchases from or work with countries that appear on the 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	The primary employment of the principal investigator (PI) shall be with the SBC or the research institution (RI) under the STTR program.
Employment Certification	For Phase I, the primary employment of the principal investigator/project manager must be with the SBC or the research institution at the time of award and during the conduct of the proposed project. Primary employment means that more than one-half of the principal investigator/project manager's employment time is spent in the employ of the SBC or research institution (based on a 40-hour workweek). This precludes full-time employment with another organization.
Co-PIs	Not allowed
Deviation Request	Any deviation requests will be reviewed during negotiation of the award and either approved or declined before final award by the Funding Agreement officer
Misrepresentation of Qualifications	Shall result in rejection of the proposal or termination of the contract
Substitution of PIs	Requires a prior approval from NASA after award

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

1.5.6 Restrictions on Venture-Capital-Owned Businesses

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

1.5.7 Joint Ventures and Limited Partnerships

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

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

1.5.8 Required Benchmark Transition Rate

The SBIR and STTR Extension Act of 2022 (https://www.congress.gov/bill/117th-congress/senate-bill/4900/text) reauthorizes through FY2025 and modifies the Small Business Innovation Research (SBIR) program, the Small Business Technology Transfer (STTR) program, and related pilot programs.

The bill requires minimum performance standards for more experienced firms.

Progress to Phase II - Increased Performance Standards for More Experienced Firms

This new Phase I to Phase II transition standard applies to firms that have won more than 50 Phase I awards during the five fiscal years preceding the most recent year. These firms must double their transition rate. The current minimum standard applies to firms with more than 20 Phase I awards and requires a minimum transition rate of 1 Phase II award per 4 Phase I awards. Firms with more than 50 awards, as detailed above, will now be required to meet an average of at least 2 Phase II awards per 4 Phase I awards.

Progress to Phase III - Increased Performance Standards for More Experienced Firms

Tier one applies to firms that have won more than 50 Phase II awards during the ten fiscal years preceding the two most recent. The performance standard would increase by 150% and require an average of $250,000 of sales and/or investments per Phase II award received during the covered period. The current standard is an average of $100,000 for firms that have won more than 15 Phase II awards during the covered period. This Act codifies the current practice that sales and/or investments shall result from awards within the covered period.

Tier two applies to firms that have won more than 100 Phase II awards during the ten fiscal years preceding the two most recent. The standard would increase by 350% and require an average of $450,000 of sales and/or investments per Phase II award received during the covered period. The current standard is an average of $100,000 for firms that have won more than 15 Phase II awards during the covered period. This Act codifies the current practice that sales and/or investments shall result from awards within the covered period.

Consequence of Failure to Meet Standard. If a firm does meet an increased performance standard, it may not receive more than 20 Phase I or Direct to Phase II awards at each agency in the following year. An agency may implement more restrictive limitations on the number of Phase I or Direct to Phase II awards. For example, the National

Aeronautics and Space Administration (NASA) limits its SBIR program to 10 proposals and 5 awards, and its STTR program to 10 proposals and 2 awards; NASA would be permitted to continue those limitations.

Patents for Increased Standards. Unlike the existing minimum performance standard that allows firms to use sales and investments *or* patents to meet the commercialization standard, patents may not be used under the increased commercialization standards.

Documentation. A small business that is subject to the increased minimum performance standards for Progress to Phase III commercialization shall submit supporting documentation to SBA to verify reported sales associated with their SBIR and STTR awards during the covered period; the requirement relates to the covered sales that the small business reports to SBA as helping to meet the standards. The sales do not include federal transactions because those can be verified through the federal database. The small business must provide documentation for such sales going back five fiscal years.

Waiver. SBA may grant a waiver for a topic that is critical to an agency's mission or relates to national security. For topics that receive waivers, all firms may compete and receive awards for the specific topic, including a firm that did not meet the increased performance standards and would otherwise be subject to a 20 award per agency cap.

Reporting. Not later than July 2023 and annually thereafter until the increased minimum performance standards expire, the Administrator shall submit to Congress a list of the small business concerns that do not meet the minimum performance standards or the increased performance standards and identify those that received an award because of a waiver. The list shall be confidential and exempt from section 552 of title 5, United States Code.

SBA must expand the SBIR/STTR annual report to Congress to include 1) the minimum and increased performance standards and the number of firms that have not met the transition and commercialization performance standards, and 2) the aggregate number and dollar amount of SBIR and STTR awards made pursuant to waivers for firms that did not meet the performance standards. SBA is prohibited from publishing personally identifiable information, the identity of the firm, or otherwise sensitive information.

Implementation. The Administrator (SBA) shall implement the increased minimum performance standards not later than April 1, 2023 (the Fiscal Year 2023 benchmark assessment).

1.6 NASA Technology Available (TAV) for STTR Use

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

Whether or not 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 an offeror intends to use NASA software, a Software Usage Agreement (SUA), on a nonexclusive, royalty-free basis, is necessary, and the clause at 48 C.F.R. 1852.227-88, Government-Furnished Computer Software and Related Technical Data, will apply to the contract. The SUA shall be requested from the appropriate NASA Center Software Release Authority (SRA), after contract award.

1.6.2 Use of NASA Patent

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

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

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

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

1.7 I-Corps™

NASA has partnered with the National Science Foundation (NSF) to allow Phase I awardees the opportunity to participate in the NSF Innovation Corps (I-Corps™) program. Phase I offerors are encouraged to opt into and participate in this training if selected for an award. 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. The NASA I-Corps program enables small businesses, including startup SBCs, to increase the odds of accelerating the process of developing their STTR technologies into a repeatable and scalable business model. The program accomplishes this by putting the SBCs through a version of the Lean Launchpad/I-Corps process, which includes:

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

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

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

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

1.8 Technical and Business Assistance (TABA)

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

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

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

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

1.9 Small Business Administration (SBA) Applicant Resources

The SBA oversees the Federal SBIR and STTR programs. The SBA has resources that small businesses can take advantage of in learning about each of the programs and obtaining help in developing a completed proposal package to submit 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.

1.10 NASA Mentor-Protégé Program (MPP)

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

The evaluation criterion is based on the amount and quality of technology transfer and business development skills that will increase the protégé's Technology Readiness Levels (TRLs). TRLs measure technology readiness on a scale of 1 to 9. A mentor should attempt to raise the TRL of the protégé and outline the goals and objectives in the MPA and the award fee plan. A separate award fee review panel set up by NASA OSBP will use the semiannual reports, annual reviews, and the award fee plan in order to determine the amount of award fee given at the end of the performance period of the agreement.

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

1.11 Fraud, Waste and Abuse and False Statements

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

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

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

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

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

NASA OIG Cyber Hotline: 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

1.12 NASA Procurement Ombudsman Program

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

The cognizant ombudsman is:

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

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

1.13 General Information

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

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

The cutoff date and time for receipt of Phase I solicitation questions requesting clarification of completed proposal package instructions and administrative matters is March 6, 2023, at 5:00 p.m. ET.

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

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

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

    a. Email: sbir@reisystems.com
    b. The requestor must provide the name and telephone number of the person to contact, the organization name and address, and the specific questions or requests.

1.14 Definitions

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

2. Registrations, Certifications, and Other Completed Proposal Package Information

2.1 Small Business Administration (SBA) Company Registry

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

After an offeror registers with SBA and/or updates their commercialization information, the offeror needs to obtain a portable document format (PDF) copy of the SBA Company Registry registration for their SBC. In addition, the offeror must provide their unique SBC Control ID (assigned by SBA upon completion of the Company Registry registration) and must upload the PDF copy of the SBA Company Registry registration in the EHB.

2.2 System for Award Management (SAM) Registration

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

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

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

SAM, 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.

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

2.3 Certifications

Offerors must complete the Firm and Proposal Certifications forms in the Electronic Handbook (EHB), answering "Yes" or "No" to certifications as applicable. Offerors should carefully read each of the certification statements. The Federal Government relies on the information to determine whether the business is eligible for a STTR program award.

A similar certification will be used to ensure continued compliance with specific program requirements at time of award and 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 the final invoice certification and as a condition for payment of the final invoice. The life cycle certification is preset in the EHB, and it shall be completed along with the final invoice certification before uploading the final invoice in the Department of Treasury's Invoice Processing Platform (IPP).

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

2.4 Federal Acquisition Regulation (FAR) Certifications

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

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

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

2.5 Software Development Standards

Offerors proposing projects involving the development of software may be required to comply with the requirements of NASA Procedural Requirements (NPR) 7150.2D, 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

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

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

2.7 HSPD-12

Offerors that require access to Federally controlled facilities or access to a Federal information system (Federally controlled facilities and Federal information system are defined in FAR 2.101(b)(2)) for 6 consecutive months or more must adhere to Homeland Security Presidential Directive 12 (HSPD-12), Policy for a Common Identification Standard for Federal Employees and Contractors, and Federal Information Processing Standards Publication (FIPS PUB) Number 201-3, Personal Identity Verification (PIV) of Federal Employees and Contractors, which require agencies to establish and implement procedures to create and use a Government-wide secure and reliable form of identification no later than October 27, 2005. See See https://nvlpubs.nist.gov/nistpubs/FIPS/NIST.FIPS.201-3.pdf.

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

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

3. Proposal Preparation Instructions and Requirements

3.1 Multiple Proposal Submissions

Each proposal submitted must be based on a unique innovation, must be limited in scope to just one subtopic, and shall be submitted only under that one subtopic within each program. An offeror shall not submit more than 10 proposals to the STTR program. An offeror may submit more than one unique proposal to the same subtopic; however, an offeror shall not submit the same (or substantially equivalent) proposal to more than one subtopic. Submitting substantially equivalent proposals to several subtopics may result in the rejection of all such proposals. To enhance SBC participation, NASA does not plan to select more than two (2) STTR proposals from any one offeror under this solicitation.

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

3.2 Understanding the Patent Landscape

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

3.3 Proprietary Information in the Proposal Submission

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

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

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

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

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

3.4 Release of Certain Proposal Information

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

3.5 Requirements to Submit a Phase I Completed Proposal Package

3.5.1 General Requirements

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

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

1. Describe the proposed innovation relative to the current state of the art;
2. Address the scientific, technical, and commercial merit and feasibility of the proposed innovation as well as its relevance and significance to NASA interests as described in 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 mission programs, the NASA relevant commercial markets, and other potential markets and customers.

3.5.2 Format Requirements

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

Page Limitations and Margins

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

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

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

Suggested Page Limits for Proposal Sections

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

Type Size

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

Header/Footer Requirements

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

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

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

3.5.3 Completed Proposal Package
Each completed proposal package submitted shall contain the following items:

1. Proposal Contact Information
2. Proposal Certifications, electronically endorsed
3. Proposal Summary (must not contain proprietary data)
4. Proposal Budget (including letters of commitment for Government resources and subcontractors/consultants and foreign vendor form, if applicable)
5. Technical Proposal
6. Briefing Chart (must not contain proprietary data)
7. STTR Research Agreement and endorsement of this agreement by the research institution (RI) official
8. NASA Evaluation License Application, only if TAV is being proposed
9. Technical and Business Assistance (TABA) request (optional)
10. I-Corps Interest Form
11. SBC-Level Forms (completed once for all proposals submitted to a single solicitation)

Firm Certifications

   a. Firm Certifications
   b. Audit Information
   c. Prior Awards Addendum
   d. Commercial Metrics Survey (CMS)

12. Electronic Endorsement by the designated small business representative and principal investigator (PI) and research institution (RI) official is completed before the deadline

For many of these forms, offerors can view sample forms located in the NASA SBIR/STTR Resources website: http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html.

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

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

3.5.3.1 Proposal Contact Information Form
The offeror shall provide complete information for each contact person and submit the form as required in the EHB. ***Note: Contact Information is public information and may be disclosed.*** A sample Contact Information form is provided in the NASA SBIR/STTR Resources website: http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html.

3.5.3.2 Proposal Certifications Form
The offeror shall provide complete information for each item and submit and electronically endorse the form as required in the EHB. A sample Proposal Certifications form is provided in the NASA SBIR/STTR Resources website: http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html.

3.5.3.3 Proposal Summary Form

The offeror shall provide complete information for each item and submit the form as required in the EHB. A sample Proposal Summary form is provided in the NASA SBIR/STTR Resources website: http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html.

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

3.5.3.4 Proposal Budget Form

The offeror must complete the Proposal Budget form following the instructions provided. The total requested funding for the Phase I effort shall not exceed $150,000 or $156,500 (if requesting $6,500 for TABA, see section 1.8 and 3.5.3.8 for more information on the TABA opportunity). A sample of the Proposal Budget form is provided in the NASA SBIR/STTR Resources website: http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html.

Note:

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

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

Proposal Budget Requirements for Use of Government Resources

In cases where an offeror seeks to use Government resources as described in Part 8 of the technical proposal instructions, the offeror shall provide the following:

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

Note: Due to the complexity of and general length of time for the approval process to use a Federal laboratory/facility and the thirteen-month period of performance of a Phase I contract, firms are strongly discouraged from requesting the use of a Federal laboratory/facility during the performance of a Phase I contract. Use of a Federal laboratory/facility will be allowed during a Phase II contract; however, firms should also indicate such intent in their Phase I proposal. Approval for use of Federal facilities and laboratories for a Phase I technical proposal requires a very strong justification at time of submission and will require approval by the Program Executive (PE) during negotiations if the proposal is selected for award.

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

Use of Subcontractors and Consultants

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

Offerors that propose using subcontractors or consultants must submit the following:

1. ***List consultants by name and with the number of hours and hourly costs identified for each consultant.***
2. ***Breakdown of subcontractor budget should mirror the offeror's own breakdown in the Proposal Budget form and include breakdowns of direct labor, other direct costs, and profit, as well as indirect rate agreements.***
3. ***A signed letter of commitment is required for each subcontractor and/or consultant. For educational institutions, the letter must be from the institution's Office of Sponsored Programs.***

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

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

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

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

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

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

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

G&A	5%
G&A on subcontractor cost	$29,500 x 5% = $1,475
Subcontractor cost plus G&A	$29,500 + $1,475 = $30,975
Percentage of subcontracting effort*	**$30,975/$150,000 = 20.7%**

***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.

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

Travel in Phase I

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

3.5.3.5 Technical Proposal

This part of the submission should not contain any budget data and **should consist of all 10 parts listed below in the given order. All 10 parts of the technical proposal should be numbered and titled. A completed proposal package omitting any part, other than the table of contents, will be considered nonresponsive to this solicitation and declined without further consideration.** **Parts that are not applicable must be included and marked "Not applicable."**

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

The required table of contents is provided below:

Part 1: Table of Contents *(Suggested page limit – 0.5 page and counts toward the 19-page limit)*

The technical proposal must begin with a brief table of contents indicating the page numbers of each of the parts of the completed proposal package (see below for an example).

Phase I Table of Contents

Part 1: Table of Contents……………………………………………………………Page X
Part 2: Identification and Significance of the Innovation……………………………Page X
Part 3: Technical Objectives…………………………………………………………Page X
Part 4: Work Plan……………………………………………………………………Page X
Part 5: Related R/R&D………………………………………………………………Page X
Part 6: Key Personnel and Bibliography of Directly Related Work…………………Page X
Part 7: The Market Opportunity………………………………………………………Page X
Part 8: Facilities/Equipment…………………………………………………………..Page X
Part 9: Subcontractors and Consultants………………………………………………Page X
Part 10: Related, Essentially Equivalent, and Duplicate Proposals and Awards…………..Page X

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.

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

Part 4: Work Plan *(Suggested page limit – 5 pages)*
Include a detailed description of the Phase I R/R&D plan to meet the technical objectives. The plan shall indicate what will be done, where it will be done, and how the R/R&D will be carried out. Discuss in detail the methods planned to achieve each task or objective. The plan shall also include task descriptions, schedules, resource allocations, estimated task hours for each key personnel, and planned accomplishments (including project milestones). Offerors shall ensure that the estimated task hours provided in the work plan for key personnel are consistent with the hours reported in the Proposal Budget form. If the offeror is a joint venture or limited partnership, a statement of how the workload will be distributed, managed, and charged must be included here.

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

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

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

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

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

Eligibility: This part shall also establish and confirm the eligibility of the PI and shall indicate the extent to which existing projects and other proposals recently submitted or planned for submission in fiscal year 2023 commit the time of the PI concurrently with this proposed activity. Any attempt to circumvent the restriction on PIs working more than half time for an academic or a nonprofit organization by substituting an ineligible PI will result in the proposal package being declined.

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

Phase I offerors should address each of the following:

- Discuss the business economics and market drivers in the target industry.
- How has the market opportunity been validated?
- Describe your customers and your basic go-to-market strategy to achieve the market opportunity.
- Describe the competition.
- How do you expect the competitive landscape may change by the time your innovation enters the market?
- What are the key risks in bringing your innovation to market?
- Describe your commercialization approach.
- Discuss the potential economic benefits associated with your innovation and provide estimates of the revenue potential, detailing your underlying assumptions.
- Describe the resources you expect will be needed to implement your commercialization approach.

Note: Offerors are encouraged to utilize the following opportunities, TABA and NASA I-Corps, to address the market opportunities if selected for a Phase I award and to be well positioned to address additional commercialization requirements and metrics under future STTR proposal submissions including Phase II and Phase III. See sections 3.5.3.8 for how to request TABA and 3.5.3.9 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. Items of equipment to be purchased must be fully justified under this section. **When purchasing equipment or a product under the STTR funding agreement, the small business should purchase only American-made items whenever possible.**

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

Note: Due to the complexity of and general length of time for the approval process to use a Federal laboratory/facility and the thirteen-month period of performance of a Phase I contract, firms are strongly discouraged from requesting the use of a Federal laboratory/facility during the performance of a Phase I contract. Use of a Federal laboratory/facility will be allowed during a Phase II contract; however, firms should also indicate such intent in their Phase I proposal. Approval for use of Federal facilities and laboratories for a Phase I technical proposal requires a very strong justification at time of submission and will require approval by the Program Executive (PE) during negotiations if the proposal is selected for award.

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

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

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

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

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

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

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

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

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

It shall not contain any proprietary data or International Traffic in Arms Regulation (ITAR)-restricted data. An electronic form will be provided during the submissions process. For more information on ITAR see https://www.sbir.gov/tutorials/itar/.

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

3.5.3.7 NASA Evaluation License Application, only if TAV is being proposed
If you have applied for TAV by following the instructions found at http://technology.nasa.gov, upload the application of the TAV request with your completed proposal package.

3.5.3.8 Request for Use of Technical and Business Assistance (TABA) Funds at Phase I
Per section 1.8, offerors can request TABA at Phase I. The goal of TABA is for Phase I awardees to obtain support from a TABA vendor to improve the commercialization success of STTR awardees. As indicated in Part 7: The Market Opportunity of the technical proposal, NASA considers commercialization of funded innovations as a high priority. The ability to commercialize the innovation with NASA STTR funding shows a positive return on investment and can support the research effort throughout Phase I, II and beyond.

Offerors are encouraged to request TABA at Phase I and can choose their own TABA vendor. NASA does not have a TABA preferred vendor, however there are many TABA vendors that market their services and are well positioned to support NASA STTR awardees. Although NASA cannot direct offerors to any specific TABA vendor or website, offerors should plan some time before the proposal is submitted to conduct research and learn about the TABA vendors that currently market their services and decide which vendor they may wish to use.

All requests for Phase I TABA must be included in the Phase I completed proposal package submission. However, offerors are not required to request TABA at Phase I, and there is no prerequisite that an offeror must use Phase I TABA funding to obtain a Phase II award or request TABA funding at Phase II.

Requests for TABA funding are not reviewed during the technical evaluation of the completed proposal package, and the request for TABA funds will not be part of the decision to make an award. All TABA requests will be reviewed after a completed proposal package is selected for award and during the contract negotiation process.

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

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

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

If requesting Phase I TABA funding, offerors are required to provide the following TABA information by following the directions found in the Budget forms in the EHB:

Note: The following information must be provided for each TABA vendor

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

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

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

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

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

Any TABA funding **will be in addition to the Phase I contract award value, is not subject to any profit or fee by the requesting 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. Requests for TABA funding outside of the Phase I period of performance or after a completed proposal package submission will not be considered.

Schedule of Deliverables and Payments for TABA—Offerors that are approved to receive TABA under a Phase I award will be reimbursed for TABA expenses. Reimbursement for TABA will be based on the awardee providing a TABA final report at the end of the contract period of performance. Reimbursement will not be provided for any amounts incurred over the TABA funding amount approved by the Government prior to award.

For additional TABA information see https://www.sbir.gov/node/2088581.

3.5.3.9 I-Corps Interest Form

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

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

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

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

3.5.3.10 SBC Level Forms

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

A. SBC Certifications

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

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

B. Audit Information

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

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

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

C. Prior Awards Addendum

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

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

D. Commercialization Metrics Survey (CMS)

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

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

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

3.5.3.11 STTR Research Agreement between the Small Business and Research Institution

The Research Agreement (different from the Allocation of Rights Agreement) is a single-page document electronically submitted and endorsed by the offeror and research institution (RI).

All STTR Phase I proposals must provide sufficient information to convince NASA that the proposed offeror/RI cooperative effort represents a sound approach for converting technical information resident at the RI into a product or service that meets a need described in a solicitation research topic. The Research Agreement form consists of a model agreement and the template can be found at the NASA SBIR/STTR Resources website: http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html. Additional clauses/conditions can be added if the offeror chooses by inputting them into the text box provided. Offerors can create their own custom agreement by clicking on the “Use Custom Agreement” link and entering the text into the text box. This form must be electronically endorsed by the RI Official and offeror.

4. Method of Selection and Evaluation Criteria

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.

All Phase I proposals will be evaluated and judged 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). Proposals will be initially screened to determine responsiveness. Proposals passing this initial screening will be technically evaluated by subject matter experts to determine the most promising technical and scientific approaches. Offerors should not assume that evaluators are acquainted with the offeror, key individuals, or with any experiments or other information. Each proposal will be judged on its own merit and NASA will not conduct any tradeoff analyses between or among competed proposals. NASA is under no obligation to fund any proposal or any specific number of proposals in each topic or subtopic. NASA may elect to fund several or none of the proposed approaches to the same topic or subtopic.

4.1 Phase I Process and Evaluation Criteria

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

4.1.1 Administrative Review

All complete proposal packages received by the published deadline will undergo an administrative review to determine if the proposal package meets the requirements found in chapters 3 and 6. A complete proposal package that is found to be noncompliant with the requirements in chapters 3 and 6 may be declined and no further evaluations will occur. The offeror will be notified of NASA's decision to eliminate the proposal package from consideration and the reason(s) for the decision.

4.1.2 Technical Responsiveness

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

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

4.1.3 Technical Evaluation Criteria

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

Factor 1: Scientific/Technical Merit and Feasibility
The proposed R/R&D effort will be evaluated on:

- The technical approach and the anticipated agency and commercial benefits that may be derived from the research.
- The adequacy of the proposed effort, and its relationship to the fulfillment of requirements of the research subtopic.
- The soundness and technical merit of the proposed approach and its incremental progress toward subtopic solution.
- The proposal should describe an innovative and feasible technical approach to the identified NASA problem area/subtopic. Specific objectives, approaches, and plans for developing and verifying the innovation must demonstrate a clear understanding of the problem and the current state of the art. The degree of understanding and significance of the risks involved in the proposed innovation must be presented.

Factor 2: Experience, Qualifications, and Facilities
The qualifications of the proposed principal 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 instrumentation or facilities required to accomplish the proposed technical approach will be evaluated to determine if they are adequate. In addition, any proposed reliance on external sources, such as Government-furnished equipment or facilities (section 3.5.3.4 and part 8 of the technical proposal), will be evaluated for reasonableness.

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

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

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

4.1.4 Price Evaluation

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

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

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

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

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

4.3 Prioritization

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

4.4 Selection

In making such a selection determination, the SSO, in their discretion may consider additional programmatic balance factors such as portfolio balance across NASA programs, centers and mission directorates, available funding, first-time awardees/participants, historically underrepresented communities, and geographic distribution.

After the SSO selection has been finalized, the list of proposals selected for negotiation will be posted on the NASA SBIR/STTR website (http://sbir.nasa.gov). All offerors selected by the SSO will receive a formal notification letter. Each proposal selected for negotiation will be evaluated 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.

Under this solicitation, NASA will not accept more than 10 completed proposal packages from any one offeror to ensure the broadest participation of the small business community. NASA does not plan to award more than 2 STTR contracts to any offeror.

4.5 I-Corps Evaluation Process

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

- Proposed team members demonstrate a commitment to the requirements of the I-Corps program.

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

Based on the assessment of the above criteria the NASA SBIR/STTR PMO will provide a recommendation of I-Corps proposals to receive funding to the SSO. The SSO will make the final selections for I-Corps on awards that are completed and in alignment with I-Corps program offerings. NASA anticipates a total of approximately 10 STTR SBCs will be selected for participation in the I-Corps program for Phase I.

4.6 Technical and Business Assistance (TABA)

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

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

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

4.7. Access to Proprietary Data by Non-NASA Personnel

4.7.1 Non-NASA Reviewers

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

4.7.2 Non-NASA Access to Confidential Business Information

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

4.8 Notification and Feedback to Offerors

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

Note: Due to the competitive nature of the program and limited funding, recommendations to fund or not fund a completed proposal package will be final. Any notification or feedback provided to the offeror is not an opportunity to reopen selection decisions or obtain additional information regarding the final decision. Offerors are encouraged to use the written feedback to understand the outcome and review of their completed proposal package and to develop plans to strengthen future proposals.

4.8.1 Phase I Feedback

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

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

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

5. Considerations

5.1 Requirements for Contracting

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

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

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

1. All information in your completed proposal package is current (e.g., your address has not changed, the proposed PI is the same, etc.). If changes have occurred since submittal of your completed proposal package, notify the Contracting Officer immediately.
2. Your 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 D). Confirmation that a VETS-4212 report has been submitted to the Department of Labor, and is current, shall be provided to the Contracting Officer within 10 business days of the notification of selection for negotiation.
4. Your SBC HAS NOT proposed a co-principal investigator.
5. Your SBC will provide timely responses to all communications from the NSSC Contracting Officer. **Note: 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. All letters of commitment are dated and signed by the appropriate person with contact information. If a university is proposed as a subcontractor or a RI, the signed letter shall be on the university letterhead from the Office of Sponsored Programs. If an independent consultant is proposed, the signed letter should not be on a university letterhead. If the use of Government facilities or equipment is proposed, your SBC shall submit a signed letter from the Government facility authorizing the use of the facility and stating the availability and the cost, if any, together with a signed letter from your SBC justifying the need to use the facility.

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

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

5.2 Awards

5.2.1 Anticipated Number of Awards

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

Year	Number of STTR Phase I Proposals Reviewed	Number of STTR Phase I Awards	Percentage of STTR Phase I Awards
2022	154	53	34.4%
2021	192	56	29.1%
2020	265	59	22.2%
2019	204	48	23.5%

5.2.2 Award Conditions

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

- SF26—Contract Cover Sheet
- Contract Terms and Conditions—to include reference to the completed proposal package and budget
- Attachment 1: Contract Distribution List

- Attachment 2: Template of the Final Summary Chart
- Attachment 3: IT Security Management Plan Template
- Attachment 4: Applicable Documents List
- Confirmation of Negotiation
- Phase I Frequently Asked Questions (FAQs)

5.2.3 Type of Contract

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

5.2.4 Model Contracts

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

5.3 Reporting and Required Deliverables

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

All contracts shall require the delivery of technical reports that present (1) the work and results accomplished; (2) the scientific, technical, and commercial merit and feasibility of the proposed innovation and project results; (3) the proposed innovation's relevance and significance to one or more NASA interests (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.

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

A final New Technology Summary Report (NTSR) is due at the end of the contract, and New Technology Report(s) (NTR) are required if 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 TABA is requested, Phase I contracts will require TABA deliverables that summarize the outcome of the TABA services with expected supporting information.

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

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

account maintenance processes for NASA employees, contractors, and remote users such as educators and foreign users. A basic background check and completion of NASA IT Security Training is required for this account. Instructions to create an identity in NAMS will be provided during contract negotiations.

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

5.4 Payment Schedule

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

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

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

5.5 Profit or Fee

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

5.6 Cost Sharing

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

5.7 Rights in Data Developed Under SBIR/STTR Funding Agreements

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

5.8 Copyrights

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

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

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

5.10 Government-Furnished and Contractor-Acquired Property

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

5.11 Essentially Equivalent Awards and Prior Work

If an award is made pursuant to a proposal or completed proposal package submitted under a STTR solicitation, the offeror will be required to certify with every invoice that it has not previously been paid nor is currently being paid for essentially equivalent work by any agency of the Federal Government. **Failure to report essentially equivalent or duplicate efforts can lead to the termination of contracts and/or civil or criminal penalties.**

5.12 Additional Information

5.12.1 Precedence of Contract Over this Solicitation

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

5.12.2 Evidence of Contractor Responsibility

The Government may request the offeror to submit certain organizational, management, personnel, and financial information to establish responsibility of the offeror. Contractor responsibility includes all resources required for contractor performance (e.g., financial capability, workforce, and facilities).

5.13 Use of Government Resources

Federal Departments and Agencies

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

Note: NASA facilities qualify as Federal laboratories.

Support Agreements for Use of Government Resources

Note: Due to the complexity of and general length of time for the approval process to use a Federal laboratory/facility and the thirteen-month period of performance of a Phase I contract, firms are strongly discouraged from requesting the use of a Federal laboratory/facility during the performance of a Phase I contract. Use of a Federal laboratory/facility will be allowed during a Phase II contract; however, firms should also indicate such intent in their Phase I proposal. Approval for use of Federal facilities and laboratories for a Phase I technical proposal requires a very strong justification at time of submission and will require approval by the Program Executive (PE) during negotiations if the proposal is selected for award.

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

For proposed use of NASA resources, a NASA SBIR/STTR Support Agreement template is available in the Resources website (http://sbir.gsfc.nasa.gov/sbir/firm_library/index.html) and must be executed before a contractor can use NASA resources. Offerors shall only include a signed letter of commitment from an authorized NASA point of contact in the completed proposal packages. NASA expects selected offerors to finalize and execute their NASA SBIR/STTR Support Agreement during the negotiation period with the NSSC.

Contractor Responsibilities for Costs

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

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

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

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

6. Submission of Proposals

6.1 How to Apply for STTR Phase I

NASA uses electronically supported business processes for the STTR program. An offeror must have internet access and an email address. Paper submissions are not accepted.

To apply for a NASA STTR Phase I contract all offerors are required to follow the steps found below.

6.1.1 Electronic Submission Requirements via the EHB

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

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

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

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

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

6.1.2 Deadline for Phase I Completed Proposal Package

A complete proposal package for Phase I shall be received no later than 5:00 p.m. ET on Monday, March 13, 2023, via the EHB. See chapter 3. Proposal Preparation Instructions and Requirements.

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

6.1.3 Complete Proposal Package Submission

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

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

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

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

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

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

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

A proposal package that is missing the final endorsements may be considered an incomplete proposal package and may be declined.

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

6.1.4 Acknowledgment of a Completed Proposal Package Receipt

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

6.1.5 Withdrawal of Completed Proposal Packages

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

6.1.6 Service of Protests

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

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 shall 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: http://www.nasa.gov/about/budget/index.html
NASA Organizational Structure: http://www.nasa.gov/centers/hq/organization/index.html
NASA SBIR/STTR Programs: http://sbir.nasa.gov

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

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

NASA Mission Directorates	
Aeronautics Research	http://www.aeronautics.nasa.gov
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	http://nasascience.nasa.gov
Space Technology	http://www.nasa.gov/directorates/spacetech/home/index.html

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

7.2 United States Small Business Administration (SBA)

The SBA oversees the Federal SBIR and STTR programs. The SBA has resources that small businesses can take advantage of in learning about the program and obtaining help in developing a proposal to a Federal SBIR/STTR program. 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 www.sbir.gov or at the following address:

U.S. Small Business Administration

Office of Technology – Mail Code 6470
409 Third Street, S.W.
Washington, DC 20416
Phone: 202-205-6450

7.3 National Technical Information Service

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

Note: 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, use the following checklist to ensure your submission is complete.

1. The proposal and innovation is submitted for one subtopic only.
2. The entire proposal package is submitted consistently with the requirements outlined in chapter 3.
    a. Proposal Contact Information
    b. Proposal Certifications, electronically endorsed
    c. Proposal Summary (must not contain proprietary data)
    d. Proposal Budget
        i. Including letters of commitment for Government resources and subcontractors/consultants (if applicable)
        ii. Foreign Vendor form (if applicable) – Note: NASA and the Office of Management and Budget (OMB) has issued a policy that requires a review of any request to purchase materials or supplies from foreign vendors. Due to the short timeframe to issue a Phase I contract, NASA is strongly encouraging offerors to consider purchasing materials and supplies from domestic vendors only. If a foreign vendor is proposed, the Phase I contract may be delayed or not awarded.
    e. Technical Proposal including all 10 parts as stated in section 3.5.3.5.
    f. Briefing Chart (must not contain proprietary data)
    g. STTR Research Agreement and endorsement of this agreement by the research institution (RI) official
    h. NASA Evaluation License Application, only if TAV is being proposed
    i. Technical and Business Assistance (TABA) request (optional)
    j. I-Corps Interest Form
    k. SBC-Level Forms (completed once for all proposals submitted to a single solicitation)
        i. SBC Certifications (labeled as Firm Certifications in the EHB)
        ii. Audit Information
        iii. Prior Awards Addendum
        iv. Commercial Metrics Survey (CMS)
        v. Foreign Vendor form (if applicable)
    l. Electronic Endorsement by the designated small business representative and principal investigator (PI) and research institution (RI) official
3. **The technical proposal shall not exceed a total of 19 standard 8.5- by 11-inch pages with one-inch margins and shall follow the format requirements (section 3.5.2).**
4. The technical proposal contains all 10 parts in order (section 3.5.3.5).
5. Any additional required letters/documentation.
    a. A letter of commitment from the appropriate Government official if the research or R&D effort requires use of Government resources (sections 3.5 and 5.13).
    b. Letters of commitment from subcontractors/consultants.
    c. If the 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.

    d. NASA Evaluation License Application if proposing the use of NASA technology (TAV).
    e. Supporting documentation of budgeted costs.

6. Proposed funding does not exceed $150,000 (section 1.4), and if requesting TABA, the cost for TABA does not exceed $6,500 (sections 1.8 and 3.5.3.8).
7. Proposed project duration does not exceed thirteen (13) months (section 1.4).
8. Proposal package electronically endorsed by the designated small business representative and the principal investigator (PI) at the published deadline.
9. **Complete proposal packages and all endorsements shall be received no later than 5:00 p.m. ET on March 13, 2023 (section 6.1.2).**

9. Research Subtopics for STTR

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

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

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

For STTR Subtopics:

T – Small Business Technology Transfer (STTR)

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

Related subtopic pointers are identified in the subtopic headers when applicable to assist offerors with identifying related subtopics that also potentially seek related technologies for different customers or applications. As stated in section 3, an offeror shall not submit the same (or substantially equivalent) completed proposal to more than one subtopic. It is the offeror’s responsibility to select which subtopic to propose to.

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Focus Area 3 Autonomous Systems for Space Exploration

The exploration of space requires advanced technologies that will better enable both humans and robotic spacecraft to maintain a sustained lunar presence, support Mars exploration, operate in deep space, and explore other destinations in our solar system. Examples of such missions include robotic platforms like the Europa Lander or crewed missions with extended periods of dormancy such as Gateway. Gateway represents a vital component of NASA's Artemis program, which will serve as a multi-purpose orbital lunar outpost that provides essential support for a long-term human return to the lunar surface. It will serve as a staging point for deep space exploration. Autonomous Systems technologies provide the means of migrating mission control from Earth to spacecraft, habitats, and robotic explorers. This is enhancing for missions in the Earth-Lunar neighborhood and enabling for deep space missions. Long communication delays, for example up to 42 minutes round-trip between Earth and Mars, do not permit time-critical control decisions to be made from Earth mission control centers. Rather, time-critical control decisions for spacecraft operating in deep space must be made by onboard humans, by autonomous systems, or by some combination of astronaut-automation teaming.

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

Specific innovations being sought in this solicitation are described below:

· Neural net software pipelines and radiation hard neuromorphic processing hardware to support in-space autonomy and cognition. Advances in signal and data processing for neuromorphic processors promise to enable artificial intelligence and machine learning for autonomous spacecraft operations.

· Intelligent autonomous agent cognitive architectures are sought after as an onboard spacecraft capability to enable decision-making under uncertainty and to improve system performance through learning over time.

· Onboard fault management capabilities, such as onboard sensing, computing, algorithms, and models to improve the prognostic health management of future spacecraft.

· Multi-agent Cyber-Physical-Human (CPH) systems that operate autonomously from humans or under human direction. This capability will help to address the need for integrated data uncertainty management and a robust representation of "trustworthy and trusted" autonomy in space.

· Technologies for the control and coordination of swarms of planetary rovers, flyers, or in-space vehicles for future space missions.

· Autonomy and artificial intelligence technologies for Gateway operations and health management, for either fully autonomous or crew-supervised operations.

The descriptions and references of each subtopic provide further detail to guide the development of proposals.

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

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

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

Scope Description:
Multi-agent cyber-physical-human (CPH) teams in future space missions must include machine agents with a high degree of autonomy. In the context of this subtopic, by “autonomy” we mean the capacity and authority of an agent (human or machine) for independent decision making and execution in a specified context. We refer to machine agents with these attributes as autonomous systems (AS). In multi-agent CPH teams, humans may serve as remote mission supervisors or as immediate mission teammates, along with AS. AS may function as teammates with specified independence, but under the ultimate human direction. Alternatively, AS may exercise complete independence in decision making and operations in pursuit of given mission goals; for instance, for control of 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 trust are essential in CPH teams. The term “trustworthiness” denotes the degree to which the system performs as intended and does not perform prohibited actions in a specified context. “Trust” denotes the degree of readiness by an agent (human or machine) to accept direction or advice from another agent (human or machine), also in a specified context. In common sense terms, trust is a confidence in a system’s trustworthiness, which in turn, is the ability to perform actions with desired outcomes.
Because behind every action lies a decision-making problem, 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.

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

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

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

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

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

Primary Technology Taxonomy:

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

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Software

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

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

Phase II:

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

State of the Art and Critical Gaps:

Despite progress in real-time data analytics, serious gaps remain that will present an obstacle to the operation of systems in NASA missions that require heavy participation of AS, both in human-machine teams and in 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.

References:

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

Focus Area 4 Robotic Systems for Space Exploration

This focus area includes the development of robotic systems and technologies (hardware and software) that will enable and enhance future space exploration, science, and service missions. In the coming decades, robotic systems will continue to change the way space is explored. Robots will be used in all mission phases: as independent explorers operating in environments too distant or hostile for humans, as precursor systems operating before crewed missions, as crew assistants working alongside and supporting humans, as caretakers of assets left behind, and as remote agents servicing and assembling critical space instruments and infrastructure.

As science and exploration activities reach further into the solar system and humans continue to work and live in space, establishing a sustainable presence on the moon and progressing on to Mars, there will be an increased reliance on intelligent and versatile robots capable of performing a variety of tasks in remote settings under dynamic mission conditions. Technologies are needed to improve robotic mobility across extreme surface terrains, on and around small bodies, and in challenging environmental conditions. This includes hazard detection, sensing/perception, robotic navigation, grappling/anchoring, actuation, novel locomotion paradigms, and innovative technologies to enhance situational awareness and user interfaces for the semi-autonomous command and control of remote robotic systems. Robotic manipulation likewise provides a critical capability for servicing and assembling equipment in space, for sample collection and handling, science utilization in the absence of the crew, and as a means to free crew from mundane logistics management tasks or augment crew performance to increase efficiency and maximize useful work in situ. Effective affordance recognition and scene understanding, grasp planning, robotic end-effectors, force control, task primitives/task parameterization, approaches to human-robot interaction for supervised autonomy, and robust, fail-operational designs are all relevant technologies needed to accomplish robotic manipulation tasks internal to space vehicles and habitats, on the lunar surface, while interacting with orbital assets, and on distant planetary bodies. New technologies are desired to enable or enhance robotic docking and refueling operations, lunar surface site preparation, and the mobile dexterous manipulation required to handle tools, interfaces, and materials not specifically designed for robots in support of establishing, maintaining, and utilizing science and exploration infrastructure.

Advances beyond our current robotic capabilities can be realized through new component technologies, the development and integration of novel robotic systems, ground testing of potential solutions, advances in software and simulation tools, and flight demonstration of new robots and robotic task performance. Hardware and software, both onboard remote robots and contributing to improved human-robot interaction and supervisory control by remote operators, will improve safety and increase the complexity of tasks robots can efficiently and effectively perform in support of NASA's Moon to Mars objectives, the broader space economy, and an array of terrestrial applications with comparable technology needs. Relevant overlap exists with other focus areas targeting advances in autonomy and hardware suited for the extreme environments of space destinations, as technologies are sought to enable productive, sustainable robotic science and exploration in remote, and evermore challenging, reaches of the solar system.

T7.04: Lunar Surface Site Preparation (STTR)

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

Scope Title: Site Preparation and Bulk Regolith Infrastructure

Scope Description:
It is envisioned that some of the first possible lunar infrastructures will be structures composed of bulk regolith and rocks. The intent of this subtopic is to develop lunar civil engineering designs, processes, and technologies that produce such structures, and develop concepts of operations (ConOps) for their construction in the South Polar region of the Moon. This is the lunar equivalent of terrestrial "Earth Works." Earth-based civil engineering processes and technologies are not adequate for lunar construction, therefore lunar civil engineering technologies must be developed. Specific capabilities of interest are:

- Establishing grade.
- Rock removal.
- Compaction.
- Berm building.
- Topography mapping to enable cut/fill operations planning and execution.
- Geotechnical characterization.
- Site preparation autonomous operations.

- Regolith hauling/conveying for distances greater that 1 km.

The desired outcome of this effort is "Regolith Works" (engineered surface features and structures) and the design, prototype, testing, analysis, modeling, and demonstration of prototype equipment. These technologies are sought for scaled lunar construction demonstration missions. The following lunar civil engineered structures are of 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 unprepared surfaces for CLPS (Commercial Lunar Payload Services) and HLS (Human Landing System) vehicles.
- Rocket Plume Surface Interaction (PSI) ejecta and blast protection structures.
- Regolith base and subgrade for supporting hardened launch/landing pads, towers, habitats, and other in situ constructed structures.
- Pathways for improved trafficability.
- Solar Particle Event (SPE) and Galactic Cosmic Ray (GCR) shielding.
- Structures for access to subgrade (e.g., trenches and pits).
- Emplaced regolith overburden on structures and equipment.
- Meteoroid impact protection structures.
- Topographical features for terrain relative guidance for flight and surface vehicles.
- Flat and level operational surfaces for equipment positioning, regularly accessed locations, and dust mitigation applications.
- Sloped regolith ramps for access to challenging locations.
- Utility corridors (e.g., electrical, comm, and fluids).
- Shade structures.
- Elevated operational surfaces.

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

Tests and validated models/simulations should be developed to characterize the 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 reference section.

ConOps should be developed to define the sequence of steps to complete construction tasks. The ConOps should begin with the natural lunar surface including hills, valleys, and surface and subsurface rocks, and end with the completed bulk regolith infrastructure verified to meet design criteria. A sequence of all required functions of robotic systems and implements should be defined to achieve the task. References to recommended existing spaceflight or protype hardware should be provided for each function. In cases where hardware does not exist, conceptual implement designs should be proposed and critical functions demonstrated in laboratory environments. Concepts should be appropriate for a CLPS scale demonstration mission on the lunar surface (e.g., 25 kg overall mass, 8 kg budget for implements) 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. ConOps that show promise for implementation by a single, compact, robotic construction system will rank high. Additionally, concepts that employ high Technology Readiness Level (TRL) implements will be prioritized. NASA is seeking systems that can build bulk regolith infrastructure that can be demonstrated in the near term.

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

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

Primary Technology Taxonomy:

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

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Hardware
- Software

Desired Deliverables Description:
Phase I must include the design and test of critical attributes associated with the proposed site preparation technology, operations, and achieved site characteristics. Civil engineered design of bulk regolith infrastructure including associated testing, modeling, and simulations must be included. Phase I must also 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. The infrastructure must be constructed using robotic systems and implements. Proof of critical functions of the infrastructure and systems must be demonstrated. Structures and systems must be developed to a minimum of TRL 5. Phase II must also include updates to the bulk regolith infrastructure designs, tests, modeling, and simulation based on Artemis program needs refinement and new information.

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

Relevance / Science Traceability:
Construction of bulk regolith infrastructure directly addresses the Space Technology Mission Directorate (STMD) strategic thrust “Land: Increase Access to Planetary Surfaces.” It also addresses the strategic thrust of “Live: Sustainable Living and Working Farther from Earth”

References:

Requirements Development Framework for Lunar In Situ Surface Construction of Infrastructure
https://doi.org/10.1061/9780784483374.106

Design of an Excavation Robot: Regolith Advanced Surface Systems Operations Robot (RASSOR) 2.0
https://ntrs.nasa.gov/citations/20210011366

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

Plume Surface Interaction (PSI)
https://www.nasa.gov/directorates/spacetech/game_changing_development/projects/PSI

Rocket Plume Interactions for NASA Landing Systems
https://ntrs.nasa.gov/api/citations/20200000979/downloads/20200000979.pdf

Gas-Particle Flow Simulations for Martian and Lunar Lander Plume-Surface Interaction Prediction
https://doi.org/10.1061/9780784483374.009

Understanding and Mitigating Plume Effects During Powered Descents on the Moon and Mars
https://baas.aas.org/pub/2021n4i089?readingCollection=7272e5bb

Focus Area 6 Life Support and Habitation Systems

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

A major objective of SMD instrument development programs is to implement science measurement capabilities with smaller or more affordable aerospace platforms so development programs can meet multiple mission needs and therefore make the best use of limited resources. The rapid development of small, low-cost remote sensing and in-situ instruments capable of making measurements across the electromagnetic spectrum is essential to achieving this objective. For Earth Science needs, in particular, the subtopics reflect a focus on remote sensing (active and passive) and in situ instrument development for space-based, airborne, and uninhabited aerial vehicle (UAV) platforms. A strong focus is placed on reducing the size, weight, power, and cost of remote and in situ instruments to allow for deployment on a more affordable and wider range of platforms. Astrophysics has a critical need for sensitive detector arrays with imaging, spectroscopy, and polarimetric capabilities, which can be demonstrated on the ground, airborne, balloon, or suborbital rocket instruments. Heliophysics, which focuses on measurements of the sun and its interaction with the Earth and the other planets in the solar system, needs a significant reduction in the size, mass, power, and cost for instruments to fly on smaller spacecraft. Planetary Science has a critical need for miniaturized instruments with in-situ sensors that can be deployed on surface landers, rovers, and airborne platforms. For the 2023 program year, we are continuing to update the included subtopics. Please read each subtopic of interest carefully. We continue to emphasize Ocean Worlds and solicit the development of in-situ instrument technologies and components to advance the maturity of science instruments focused on the detection of evidence of life, especially extant of life, in the Ocean Worlds. The microwave technologies continue as two subtopics, one focused on active microwave remote sensing and the second on passive systems such as radiometers and microwave spectrometers. NASA has an additional interest in advancing quantum sensing technologies to enable wholly new quantum sensing and measurement techniques focused on the development and maturation towards space application and qualification of atomic systems that leverage their quantum properties. Furthermore, photonic integrated circuit technology is sought to enable size, weight, power, and cost reductions, as well as improved performance of science instruments, subsystems, and components which is particularly critical for enabling the use of affordable small spacecraft platforms.

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

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

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

Subtopic Introduction:
The subtopic "Textiles for Extreme Surface Environments and High Oxygen Atmospheres" has been created to address the critical technology gap in textile technology to allow sustainable human exploration on the Moon. The intent of the 2023 solicitation is to focus on protection of humans and hardware outside of the lunar lander. This protection starts with the development of covers for practically everything that goes outside the lunar lander.

The most problematic challenge is the lunar regolith that is everywhere, levitates as soon as it is disturbed, and settles on anything around it since the Moon's gravity is only 1/6 of the Earth's gravity and there is no atmosphere. This means that the regolith is not weathered by winds and is very sharp. It also means that without oxygen, the regolith is not oxidized like everything is on Earth. Furthermore, the regolith of the lunar South Pole is different from that of the Mare region where the Apollo missions were conducted. The South Pole regolith is more abrasive. Like on Earth, different regions have different soils. The implication is that even with the best lunar dust simulants used in laboratories, we cannot exactly know the effect of the South Pole regolith of materials. Therefore, the need to have covers as impervious to the regolith as possible is of the utmost importance.

Hence, this subtopic has two scopes, one titled "Textiles for Extreme Lunar Environments and High Oxygen Atmospheres" that addresses requirements for the spacesuit, and another one that addresses the need for various types of hardware titled "Lunar Regolith Covers for Hardware."

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

Scope Description:
The environmental protection garment (EPG) is the outer component of the current spacesuit, which is called the Extravehicular Mobility Unit (xEMU). The xEMU is the new spacesuit developed for returning to the Moon. The EPG is a multilayered component consisting of fabrics and thin films. Each layer of this component contributes to the protection of the xEMU from the extreme lunar environment while enabling xEMU functionality of its three subsystems: the Pressure Garment System (PGS), the Portable Life Support System (PLSS), and the informatics system. The EPG is the spacesuit’s first line of defense. It must be designed to perform in the harsh surface environment of the South Pole of the Moon. It incorporates more advanced technologies than the current EMU (designed for use in low Earth orbit.) The xEMU is designed to be the next-generation spacesuit to benefit several space programs, namely the International Space Station, Human Landing System (HLS), Artemis, Gateway, and Orion.

The return of humans on the Moon means that everything outside the lunar lander or a habitat in future missions must be resilient to the lunar surface challenges. The most problematic challenge is the lunar regolith that is everywhere, levitates as soon as it is disturbed, and settles on anything around it. The Apollo spacesuits not only collected gray dust but also deteriorated from the damaging effects of the fine penetrating particles.

Lunar Environments

1. Thermal

The environment temperatures will be the temperature on the outside of the suit. The internal layers of the EPG are higher because of the suit heat leak provided by the astronaut, which warms the surrounding area.

Extreme heat (260 °F, 127 °C)

Extreme cold in permanently shadowed regions (-370 °F, -223 °C)

2. Regolith Terrain

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

In the South Pole region of the Moon, the regolith is highly abrasive and prone to electrostatic and tribo-electrostatic charging. The electrostatic charges are produced by the photoemission of electrons due to vacuum ultraviolet (VUV) sunlight irradiation. The regolith becomes slightly positively charged. In the shadow, these charges reverse. In addition, the tribo-electrostatic charges are created by the friction of fabrics on the regolith.

3. Radiation and Plasma

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

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

4. Architecture

The architecture of the xEMU EPG is based on a “hybrid-segmented” design in which inner layers of the EPG are segmented, with breaks around specific bearings, disconnects, and other components. The goal is to develop an EPG outer layer, which itself may be multilayered, to prevent dust intrusion and accommodate a range of sizes using overlapping sections. These sections are connected by reusable dust barrier zippers.

The EPG layers currently are:

Orthofabric of density 14.5 oz/yd^2 for its mechanical properties of tensile and tear strengths, its optical properties that satisfy the thermal requirements, and to a lesser extent its abrasion resistance since the face of the fabric is made of Gore-Tex yarns.
Gore-Tex fabric of density 9.1 oz/yd^2 per layer with a total of two layers to protect the adjacent thermal layers from solar radiation.
Aluminized Mylar® of density 1.12 oz/yd^2 per layer with a total of seven layers for their heat transfer properties.
Neoprene-coated nylon with density 9.0 oz/yd^2
Additional information on xEMU EPG architecture is given on this link: https://ttu-ir.tdl.org/handle/2346/89783

Requirements

1. Thermal

- Solar absorptivity to infrared emissivity of 0.21.
- Solar absorption is a value of 0.18 or less.

2. Physical

mass ≤42.57 oz/yd^2 xEMU EPG mass

3. Mechanical

- Have properties such that the microns and possibly some submicrons size regolith particles cannot penetrate the EPG.
- Be made of a single material or multilayered materials rather than laminated or composite materials more prone to delamination at cryogenic temperatures.
- Be more resistant to abrasion than Orthofabric to the sharp glassy regolith from the lunar South Pole.
- Be as or more flexible than the Orthofabric in extremely cold temperatures.
- Survive 1,800 bending cycles at temperatures from -370 °F (-223 °C) to 260 °F (127 °C), and not snap from impact at the maximum cold temperatures.

4. Oxygen-rich atmospheres

The EPG outer layer shall not support combustion in the lunar lander's atmosphere of 34% ±2% oxygen at a pressure of 8.2 psia (56.5 kPa). This oxygen concentration may even be higher. Hence, all materials directly exposed to the lunar lander atmosphere are required to be flame retardant.

A spacesuit is essentially a one-person fully equipped spacecraft. It is complex and consists of more than 100 components. One of the primary purposes of the spacesuit is to protect the astronaut from the dangers in space outside the spacecraft. Therefore, it is more than just clothing.

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

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

Desired Deliverables of Phase I and Phase II:
- Research
- Analysis
- Prototype

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

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

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

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

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

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

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

The return of humans on the Moon means that everything outside the lunar lander or a habitat in future missions must be resilient to the lunar surface challenges.

Relevance / Science Traceability:

This scope is included under the Space Technology Mission Directorate (STMD). The xEMU project is under the Exploration Systems Development Mission Directorate (ESDMD) and Space Operations Mission Directorate (SOMD).

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

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

References:

1. “NASA’s Plan for Sustained Lunar Exploration and Development” (a_sustained_lunar_presence_nspc_report4220final.pdf (nasa.gov))
2. Chris Hansen, “Space Suit Developments for Future Exploration,” ASE 2019 Technical Session 7, Planetary Congress Session Replays, Houston, TX, 17 October 2019 (https://ase2019.org/session-replays)
3. Technology Readiness Level Definitions: (https://www.nasa.gov/pdf/458490main_TRL_Definitions.pdf)
4. J. J. Dillon, E. S. Cobb, “Research, Development and Application of Noncombustible Beta Fiber Structures,” Final Report, 17 April 1967–31 December 1974. 24 pp, NASA-CR-144365 (https://ntrs.nasa.gov/api/citations/19750021113/downloads/19750021113.pdf)
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7. *William Lewis Miller,* “Mass Loss of Shuttle Space Suit Orthofabric Under Simulated Ionospheric Atomic Oxygen Bombardment,” November 1985, 14 pp, NASA-TM-87149 (https://ntrs.nasa.gov/api/citations/19860004430/downloads/19860004430.pdf)
8. Andrew E. Potter, Jr., Benny R. Baker, “Static Electricity In The Apollo Spacecraft,” December 1969. 23 pp, NASA-TN-D-5579 (https://ntrs.nasa.gov/api/citations/19700004167/downloads/19700004167.pdf)
9. Timothy J. Stubbs, et al., “Characterizing the Near-Lunar Plasma Environment,” Workshop on Science Associated with the Lunar Exploration Architecture, Tempe, AZ, February 26–March 2, 2007 (https://www.lpi.usra.edu/meetings/LEA/whitepapers/Stubbs_charging_NAC_whitepaper_v01.pdf)
10. Guenther Reitz, Thomas Berger, Daniel Matthiae, “Radiation Exposure in the Moon Environment,” Planetary and Space Science, Volume 74, Issue 1, p. 78-83, December 2012. (https://doi.org/10.1016/j.pss.2012.07.014)
11. Lunar Reconnaissance Orbiter Camera (LROC :: QuickMap (asu.edu))

Scope Title: Lunar Regolith Covers for Hardware

Scope Description:

Human space exploration is always associated with a large amount of hardware that the astronauts need to perform their work. This implies that some of this hardware must also be resilient on the lunar surface. Hence, most of this hardware will also need protection from the lunar regolith. There will be many types of hardware. There will be simple tools, equipment deployed on the lunar surface like cameras, and machines like rovers. Each one will need a cover uniquely designed for its size, shape, and complexity. However, all of them will need covers to prevent contamination and damage from the lunar regolith. Depending on the type of hardware, the cover may not need to be as flexible and may be thicker. Some covers will have additional functions like thermal management of powered devices. The requirements of some covers may be exactly the same as those of the xEMU EPG and its outer layer. Other covers that do not have the mass and mechanical properties limitations as those imposed on the EPG may be developed quicker and serve as steps towards the development of the EPG outer layer. The two scopes will benefit from each other.

This scope invites the researchers to think about what they would develop to a cover for an articulated tool such that it does not lose its ability to be articulated, and then think about what they would do to cover a camera, etc., in the context of extreme temperatures as described in Scope 1.

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

Primary Technology Taxonomy:

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

Desired Deliverables of Phase I and Phase II:

- Prototype

Desired Deliverables Description:

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

Phase II: Phase II deliverables shall include prototypes or finished goods. The prototypes or finished goods shall be delivered to NASA Johnson Space Center with a "Material Inspection and Receiving Report" (Form DD250) OMB No. 0704-0248. Photographs of the delivered prototypes or finished goods shall accompany the DD250 form.

Deliverables shall also include complete documentation such as technical data sheets with detailed description and composition of the material or product, with testing methods and testing data, design sketches or drawings, and full information on material and/or chemical sourcing. The Phase II deliverables shall also include a final report documenting all work accomplished for the Phase II effort and shall not duplicate the Phase II proposal.

Examples of the deliverables for the EPG outer layer and /or hardware covers may include prototype textiles, thin films, and other materials.

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

State of the Art and Critical Gaps:

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

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

Relevance / Science Traceability:

This scope is included under the Space Technology Mission Directorate (STMD). The xEMU project is under the ESDMD and SOMD.

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

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

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11. Lunar Reconnaissance Orbiter Camera (LROC :: QuickMap (asu.edu))

Focus Area 8 In-Situ Resource Utilization

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

- Regolith Transfer
- Non-Water Volatile Capture and Utilization
- Mineral Beneficiation
- Metal Production

- Regolith Inlet/Outlet Valves

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

T7.05 Climate Enhancing Resource Utilization (STTR)

Lead Center: GRC
Participating Centers: null

Scope Title: Sustainable Atmospheric Carbon Dioxide Extraction and Transformation

Scope Description:
Component and subsystem technologies are sought to demonstrate sustainable, energy-efficient extraction of carbon dioxide (CO_2) from a defined planetary or habitable atmosphere fully integrated with CO_2 transformation into one or more stable products such as manufacturing 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: (1) physical and/or chemical processes to be implemented for CO_2 collection and transformation, including reference to the current state of the art; (2) specific engineering approaches to be used in dramatically reducing mass, volume, and end-to-end energy consumption per mass of product carbon content mass; (3) validated performance estimates of high-cycle utilization of any sorption, catalytic, or other unconsumed materials used in the CO_2 collection or transformation processes; (4) suitability or adaptability of the proposed CO_2 capture approach for operation in various ambient CO_2 mixture and partial pressure environments (i.e., ambient Mars atmosphere to ambient Earth atmosphere conditions); (5) substantiated estimates of the mass conversion efficiency of ingested carbon to product carbon; and (6) estimated total end-to-end energy consumption per unit mass of product carbon.
The scope specifically excludes: (1) evolutionary improvements in mature CO_2 collection technologies that do not provide large reductions in mass, volume, and end-to-end energy consumption; (2) CO_2 collection approaches that employ CO_2 absorbing materials that require frequent replenishment or replacement (e.g., greater than 50% reduction in absorption efficiency after 500 cycles); (3) technologies considered as life support systems including air revitalization, water processing, or waste processing; (4) biological or biology-based components or subsystems of any kind; and (5) CO_2 transformation products that are not readily stored at approximately Earth-ambient conditions such as cryogenic propellants.

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

Primary Technology Taxonomy:

- Level 1 07 Exploration Destination Systems
- Level 2 07.1 In-Situ Resource Utilization

Desired Deliverables of Phase I and Phase II:

- Prototype
- Research
- Analysis

Desired Deliverables Description:

Phase I deliverable is defined as a detailed feasibility study that clearly defines the specific technical innovation and estimated performance of CO_2 collection and transformation into products, identifying critical development risks anticipated in a Phase II effort. Technology feasibility evaluation should address the scope proposal elements including: (1) process descriptions; (2) results of engineered mass, volume, and energy consumption efficiency designs; (3) cyclic performance of participating unconsumed process materials; (4) adaptability to different atmospheric CO2 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 CO2 collection and transformation prototype system, including design drawings. Component, subsystem, and integrated system performance test data is a specific deliverable and must include: (1) cyclic performance; (2) ingested atmosphere throughput and carbon conversion efficiency to product carbon; (3) evaluated properties of products; and (4) the results of engineered mass, volume, and energy consumption efficiency designs including measured end-to-end energy consumption per unit mass of product carbon. Analysis deliverables for Phase II should address a credible path toward maturation of the technology and approaches to scaling the technologies to larger processing capacities.

State of the Art and Critical Gaps:

This topic is intended to solicit innovative technologies with clear dual use: (1) adoption by NASA for infusion into long-term mission capabilities enabling mission scale in-situ resource utilization (ISRU) use of the martian atmosphere and (2) commercialization and the potential formation of a terrestrial industry to meet potentially significant future demand for terrestrial atmospheric CO2 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 CO2 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 CO2 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 CO2. Similarly, CO2 processing based on electrochemical reduction of CO2 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 CO2 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 CO2 of the martian atmosphere as a source of both carbon and oxygen to practical, full-scale reality, substantial improvements in system mass, volume, and power requirements are needed. This solicitation is intended to incentivize these innovations in the service of future NASA missions.

Additionally, there is a growing recognition of the planetwide consequences of accumulating CO2 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 CO2 accumulation.

References:

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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. 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 size, weight, and energy consumption and 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 specifically excludes incremental improvements in existing water electrolysis technologies.

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

Primary Technology Taxonomy:

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

Desired Deliverables of Phase I and Phase II:

- Analysis
- Prototype
- Research

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 energy consumption. Phase I feasibility deliverables could be significantly strengthened by 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 technology and approaches to scaling the technologies to larger processing capacities. Phase II hardware delivery may possibly be waived to enable well-secured follow-on technology maturation support.

State of the Art and Critical Gaps:

This topic is intended to solicit innovative technologies with clear dual use: (1) adoption by NASA for infusion into long-term mission capabilities enabling quasi-industrial scale ISRU and energy storage use of indigenous water resources and (2) commercialization and the potential formation of a terrestrial industry to meet potentially significant future demand for hydrogen for energy storage, advanced aviation and surface transportation fuels, and 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. Technologies that successfully address 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.

References:

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T14.01 Advanced Concepts for Lunar and Martian Propellant Production, Storage, and Usage

Lead Center: GRC
Participating Centers: JSC

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

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

- Development of instruments and instrument components suitable for use with lunar regolith. The successful deployment of ISRU technology on the Moon requires processing industrial-scale amounts (thousands of metric tons) of lunar regolith to extract trapped water and/or oxygen. To narrow the critical gaps between the current state of art and the need for sensors in extreme environments, technologies are being sought to increase the robustness and processing speed required for wide area and localized resource assessment. Sensors need to operate for long term (>200 days) in harsh abrasive and thermal environments in both sunlit and permanently shadowed regions, which risks calibration/measurement drift, accuracy decline, or contaminant failure. Most favorable sensors will have low mass, volume, and/or power requirements. Sensor selectivity, dynamic range, and response time appropriate for the targeted resource processing is needed. Proposers should show an understanding of relevant environmental capability, present a feasible plan to fully develop a technology, and infuse it into a NASA program. Proposer should provide a comparison metric for assessing proposed improvements compared to existing capabilities. The proposer should clearly describe the ISRU process targeted, the rationale for the sensor technology proposed, and a clear justification that the proposed technology will have an impact on ISRU processing.

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    - Sensors to determine regolith mineral/chemical composition during transfer for processing: While science instruments have been developed for mineral/chemical composition, instruments need to be refocused for (1) lunar operation, (2) minerals of resource interest, and (3) faster operation. Sensors are needed to better understand minerology during regolith processing (mass flows >1 kg/hr).
    - Sensors for evaluating regolith properties during transfer for preparation and processing: ISRU systems that process resources will need a near-real-time understanding of feed size, shape, and mass flow (>1 kg/hr) to optimize performance. This means that the regolith transfer device needs the ability to support instruments that operate in an abrasive environment that can be used before and/or after regolith preparation (crushing and size sorting) and before transfer for processing.
    - Sensors to monitor ISRU process gases: ISRU processes need to measure O_2, H_2, and CH_4 at high concentrations of the gas; for contaminants including H_2O impurities, CO, CH_4, H_2, HF, HCl, H_2S, etc., and crossover gases on alternative lines (eg., H_2 on O_2 side), measurement is likely needed at ppm levels.
- Develop and implement computational methodology to enhance the evaluation of temperature and species gradients at the liquid/vapor interface in unsettled conditions. Techniques could include arbitrary Lagrangian-Eulerian (ALE) interface tracking methods with adaptive mesh morphing, interface reconstruction methods, immersed boundary approaches, or enhanced-capability level set and volume of fluid (VOF) scheme that decrease numerically generated spurious velocities and increase gradient evaluation accuracy. The uncertainty of such techniques in determining the interfacial gradients should be <5% and on par with accuracies of a sharp interface method applied to a nonmoving, rigid interface. Applications include cryogenic tank self-pressurization, pressure control via jet mixing, and filling and liquid transfer operations. It is highly desirable if the methodology can be implemented via user-defined functions/subroutines into commercial computational fluid dynamics (CFD) codes. The final deliverable should be the documentation showing the detailed formulation, implementation, and validation, and any stand-alone code or customized user-defined functions that have been developed for implementation into commercial codes.

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

Primary Technology Taxonomy:

- Level 1 14 Thermal Management Systems
- Level 2 14.1 Cryogenic Systems

Desired Deliverables of Phase I and Phase II:

- Hardware
- Software
- Prototype

Desired Deliverables Description:

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

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

Deliverables for the sensors: The Phase I project should focus on feasibility and proof-of-concept demonstration (Technology Readiness Level (TRL) 2-3). The required Phase I deliverable is a report documenting the proposed innovation, its status at the end of the Phase I effort, and the evaluation of its strengths and weaknesses compared to the state of the art. The report can include a feasibility assessment and concept of operations, simulations and/or measurements, and a plan for further development to be performed in Phase II.

The Phase II project should focus on component and/or breadboard development with the delivery of specific hardware for NASA (TRL 4-5). Phase II deliverables include a working prototype of the proposed hardware, along with documentation of development, capabilities, and measurements.

State of the Art and Critical Gaps:

NASA's Space Technology Mission Directorate (STMD) has identified ISRU as a main investment area in its strategic framework. Scalable ISRU production and utilization capabilities including sustainable commodities are required to live on the lunar and Mars surfaces. The required commercial-scale water, oxygen, and metals production will be demonstrated at a smaller scale via a pilot production plant envisioned in the 2030s.

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

Relevance / Science Traceability:

NASA's STMD has identified ISRU as a main investment area in its strategic framework. Additionally, NASA has plans to purchase services for delivery of payloads to the Moon through the Commercial Lunar Payload Services (CLPS) contract. The CLPS payload accommodations will vary depending on the particular service provider and mission characteristics. CLPS missions will typically carry multiple payloads for multiple customers and may include commodity production technology demonstrations. Additional information on the CLPS program and providers can be found at this link: https://www.nasa.gov/content/commercial-lunar-payload-services

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

References:

Overview of NASA ISRU Plans, Priorites, and Activities: https://ntrs.nasa.gov/citations/20220007350

Focus Area 9 Sensors, Detectors, and Instruments

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

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

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

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

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, 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), 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)). Also interested in proposal generating Holland-Burnett states (Phy Rev. Let 71, 1355 (1993)).

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.

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

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

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

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

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

References:

- 2019 NASA Fundamental Physics and Quantum Technology Workshop. Washington, DC (April 8-10, 2019).
- Quantum Communication, Sensing and Measurement in Space. Team Leads: Erkmen, Shapiro, and Schwab (2012):
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- National Quantum Initiative Act:
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    - 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).
- European Union Quantum Flagship Program: https://qt.eu (link is external).
- UK National Quantum Technologies Programme: http://uknqt.epsrc.ac.uk (link is external).
- DLR Institute of Quantum Technologies: https://www.dlr.de/qt/en/desktopdefault.aspx/tabid-13498/23503_read-54020/ (link is external).
- Degen, C. L.; Reinhard, F.; and Cappellaro, P.: Quantum Sensing, Rev. Mod. Phys. 89, 035002 (2017).
- 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.
- 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, that is, <0.1 dB/cm, and efficient fiber coupling, that is, coupling loss <1.5 dB.
- Waveguide-integrated single-photon detectors for >100 MHz incidence rate, 1-sigma time resolution of <25 ps, dark count rate <100 Hz, and single-photon detection efficiency >50% at highest incidence rate.
- Quantum 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) wavelength division multiplexing.
- High-efficiency and high-speed optical switches.
- Quantum sensor network components.

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 Technology Readiness Levels (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:

- 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).
- M. Kitagawa and M. Ueda: “Squeezed Spin States," Phys. Rev. A 47, 5138–5143 (1993).
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- Nicolas Gisin and Rob Thew: “Quantum Communication,” Nature Photonics, 1, 165–171 (2007).
- H. J. Kimble: “The Quantum Internet,” Nature, 453, 1023–1030 (June 19, 2008).
- C. L. Degen, F. Reinhard, and P. Cappellaro: “Quantum Sensing,” Rev. Mod. Phys., 89 (July 25, 2017).
- 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).

T8.07: Photonic Integrated Circuits (STTR)

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

Scope Title: Photonic Integrated Circuits

Scope Description:
Photonic integrated circuits (PICs) are a revolutionary technology that enable 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.
NASA is interested in the development and maturation of photonic integrated circuit (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 size, weight, and power (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 hybrid packaging of different material systems is also of interest.
- Often the full benefits of photonic integration are only realized when combined with integrated electronics. Proposals that leverage co-integrated electronics for new/improved PIC functionality are invited but should consider the ultimate space environment.

- There are advantages to development of PIC technology in existing open access foundries to enable low cost, continued support, commercialization, and cross-compatibility with other development efforts.

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

- 3D mapping and spectroscopic lidar systems and components.
- Sensors for rovers, landers, and probes.
- PIC-based analog radio-frequency (RF), microwave, submillimeter, and terahertz signal processing.

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. Ka-band operation of RF photonic up/down frequency converters and filters need wideband tunability (>10 GHz) and <1 GHz instantaneous bandwidth.
- Spectrometers:
    - Spectrometers or enabling spectrally resolving components with sufficient resolution to resolve atomic isotopes (e.g., carbon, oxygen, and hydrogen), with some examples including at least 0.02 cm^{-1} resolution at 2,196 cm^{-1} (>100k resolving power) and at least 0.02 cm^{-1} resolution at 1,294 cm^{-1} (>50k resolving power).
    - Miniature spectrometers with high resolution (resolving power >10k) and high dynamic range (>4 orders of magnitude) in the 1.6 to 2.0 µm band for fire detection.
    - Spectrometers or spectrally resolving components capable of highly multimode (10+) and/or imaging operation on a single chip.
- On-chip detectors with high responsivity/quantum efficiency from 300 to 800 nm and >1.6 µm. Note that approaches which package on-chip waveguides to off-chip detectors using small-form-factor packaging techniques (direct edge coupling, flip-chip, photonic wirebonding, etc.) are also of interest. Additionally, approaches demonstrated in, or compatible with, commercial foundries are of particular interest.
    - Avalanche photodiodes or similar single photon sensitive detectors in any wavelength range.
- Packaging approaches and on-chip coupling components for high-density, high-bandwidth, and/or misalignment-tolerant connections to single mode and multimode optical fiber, in any wavelength range. 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 single mode waveguide to a large-area beam (>1 mm diameter) 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

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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2. Kish, Fred; Lal, Vikrant; Evans, Peter; et al.: System-on-Chip Photonic Integrated Circuits. IEEE Journal of Selected Topics in Quantum Electronics, vol. 24, issue 1, Article Number 6100120, Jan.-Feb. 2018.
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9. Turner, et al.: “Ultra-Wideband Photonic Radiometer for Submillimeter Wavelength Remote Sensing,” International Topical Meeting on Microwave Photonics 2020.

Focus Area 12 Entry, Descent, and Landing Systems

The SBIR/STTR focus area of Entry, Descent, and Landing (EDL) includes the suite of technologies for atmospheric entry as well as descent and landing on both atmospheric and non-atmospheric bodies. EDL mission segments are used in both robotic planetary science missions and human exploration missions beyond Low Earth Orbit, and many technologies have an application to emerging commercial space capabilities such as lunar landing, low-cost space access, small spacecraft, and asset return.

Robust, efficient, and predictable EDL systems fulfill the critical function of delivering payloads to lunar and planetary surfaces through challenging environments, within mass and cost constraints. Future NASA Artemis and planetary science missions will require new technologies to break through historical constraints on delivered mass, enable sustained human presence, or go to entirely new planets and moons. Even where heritage systems exist, no two planetary missions are exactly “build-to-print,” leading to frequent challenges from environmental uncertainty, risk posture, and resource constraints that can be dramatically improved with investments in EDL technologies. EDL relies on validated models, ground tests, high-fidelity simulations, and sensor technologies for system development and certification. Both new capabilities and improved assessment and prediction of state-of-the-art systems are important facets of this focus area.

The subtopics in this Focus Area generally align with the Entry, Descent, and Landing flight regimes, plus include flight instrumentation and ground testing relevant to EDL. In future solicitations, the intent is to maintain these general subtopic categories and revise their content based on Agency needs and priorities along with the evolution and maturation of EDL technologies. Focal STTR solicitations will also be included in the annual solicitations for advancing EDL capabilities.

The SBIR subtopics and their overarching content descriptions are:

· Z7.01 Entry, Descent, and Landing Flight Sensors and Ground Test Technologies: Seeks sensors and components for safe precision landing, entry-environment characterization, heatshield instrumentation, and other EDL flight systems and ground-test diagnostics and electronics capabilities.

· Z7.03 Entry and Descent Systems Technologies: Contains hypersonic materials, aeroshell systems, and modeling advances, including deployable aeroshells for EDL and asset return and recovery. Includes smaller-scale systems appropriate for small spacecraft applications.

· Z7.04 Landing Systems Technologies: Covers landing engines, plume-surface interaction modeling, testing, instrumentation, and landing attenuation systems.

· The STTR subtopic covers various EDL technologies for high-performance simulations, advanced algorithms, materials, sensors, instrumentation, testing, or other EDL-related capabilities.

Please refer to the subtopic write-ups for the specific content and scope solicited this year.

T9.02: Rapid Development of Advanced High-Speed Aerosciences Simulation Capability (STTR)

Lead Center: ARC
Participating Center(s): JSC, LaRC, MSFC

Subtopic Introduction:
The United States is entering an unprecedented era for hypersonic and space vehicle development. The Department of Defense (DoD) is currently pursuing multiple hypersonic weapon development programs to advance boost-glide and air-breathing vehicle concepts and has conducted successful flight tests of both vehicle types in recent years. Total DoD investment in hypersonic research is expected to approach $5B in fiscal year 2023. NASA is preparing to return humans to the Moon for the first time in 50 years, while simultaneously developing a portfolio of ambitious planetary science missions that include returning rock samples from Mars and landing a mobile science platform on Titan. The commercial space sector is booming, with dozens of companies pursuing economic objectives in low Earth orbit that are independent of the US

Government. In 2021, private investment in space startups exceeded $15B, up from roughly $2.5B just five years prior.

Connecting all these efforts is the need for robust, fast, and accurate simulation of novel flight vehicles as they traverse atmospheres at supersonic and hypersonic speeds. Heat transfer and high temperature gas physics become critical design drivers in this regime. Strong shocks and shear layers stress existing simulation technologies. Increasingly complex vehicles defeat the techniques and best practices presently used to conduct analysis in this regime. The U.S. commercial space industry, defense industry, and NASA require advanced simulation tools and technologies that make the design of new hypersonic flight vehicles faster and more economical.

This subtopic seeks to stimulate advances in aeroscience simulation software that will directly address this pressing national need. Specifically, this solicitation seeks mature innovative research into practical simulation solutions that enable: (1) efficient exploitation of exascale computing platforms; (2) highly automated aerothermodynamic analysis of complex vehicles in strongly shocked flows; and (3) economical simulation of unsteady, supersonic fluid phenomena.

Scope Title: Aerothermal Simulation for Exascale Computer Architectures

Scope Description:
Aerothermodynamic simulations of planetary entry vehicles such as Orion and Dragonfly are complex and time consuming. These simulations, which solve the multispecies, multitemperature Navier-Stokes equations, require detailed models of the chemical and thermal nonequilibrium processes that take place in high-temperature shock layers. Numerical solution of these models results in a large system of highly nonlinear equations that are exceptionally stiff and difficult to solve efficiently. As a result, aerothermal simulations routinely consume 20 to 50 times the compute resources required by more conventional supersonic computational fluid dynamics (CFD) analysis, limiting the number of simulations delivered in a typical engineering design cycle to only a few dozen. Moreover, entry system designs are rapidly increasing in complexity, and unsteady flow phenomena such as supersonic retropropulsion are becoming critical considerations in their design. This increases the compute resources required for aerothermal simulation by an additional one to two orders of magnitude, which precludes the delivery of such simulations in engineering-relevant timescales.

To deliver the aerothermal simulations required for NASA’s next generation of entry systems, access to greatly expanded compute resources is required. However, scaling conventional central processing unit (CPU) based supercomputers is problematic due to cost and power constraints. Many-core accelerators, such as the general-purpose graphical processing units (GPGPUs) developed by NVIDIA and AMD, offer increased compute capability with reduced cost and power requirements and are seeing rapid adoption in top-end supercomputers. As of June 2022, 168 of the top 500 fastest supercomputers leveraged accelerators or co-processors, including 7 of the top 10 [1]. The first U.S. supercomputer to break the exascale barrier, Frontier at Oak Ridge National Laboratory, utilizes AMD Instinct GPGPUs to achieve 1.1 exaflops of sustained LINPACK performance, and the other two exascale supercomputers planned by the U.S. Department of Energy will also utilize GPGPUs [2]. NASA deployed a first tranche of NVIDIA V100 GPGPUs as part of the High-End Compute Capability (HECC) project in 2019 [3].

Critically, NASA’s principal aerothermal simulation tools are fundamentally unable to run on many-core accelerators and must be reengineered from the ground up to efficiently exploit such devices. This scope seeks to revolutionize NASA’s aerothermal analysis capability by developing novel simulation tools capable of efficiently targeting the advanced computational accelerators that are rapidly becoming standard in the world’s fastest supercomputers, while simultaneously enabling the tools to run efficiently on conventional CPU architectures with as much code re-use as possible. A successful solution within this scope would demonstrate efficient simulation of a large-scale aerothermal problem of relevance on an advanced many-core architecture, e.g., the NVIDIA Ampere GPGPU, and conventional CPUs using a prototype software package.

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

Primary Technology Taxonomy:

- Level 1: TX 09 Entry, Descent, and Landing
- Level 2: TX 09.1 Aeroassist and Atmospheric Entry

Desired Deliverables of Phase I and Phase II:

- Software

Desired Deliverables Description:
The desired deliverable at the conclusion of Phase I is a prototype software package capable of solving the multispecies, multitemperature, reacting Euler equations on an advanced many-core accelerator such as an NVIDIA A100 GPGPU. Parallelization across multiple accelerators and across nodes is not required. The solver shall demonstrate offloading of all primary compute kernels to the accelerator, but may do so in a nonoptimal fashion, e.g., using managed memory, serializing communication and computation, etc. Some noncritical kernels such as boundary condition evaluation may still be performed on a CPU. The solver shall demonstrate kernel speedups (excluding memory transfer time) when comparing a single accelerator to a modern CPU-based, dual-socket compute node. However, overall application speedup is not expected at this stage. The solver shall be demonstrated for a relevant planetary entry vehicle such as FIRE-II, Apollo, Orion, or the Mars Science Laboratory.

A successful Phase II deliverable will mature the Phase I prototype into a product ready for mission use and commercialization. Kernels for evaluating viscous fluxes shall be added, enabling computation of laminar convective heat transfer to the vehicle. Parallelization across multiple accelerators and multiple compute nodes shall be added. Good weak scaling shall be demonstrated for large 3D simulations (>10M grid cells). The implementation shall be sufficiently optimized to achieve an ~5-time reduction in time-to-solution compared to NASA's Data-Parallel Line Relaxation (DPLR) aerothermal simulation code, assuming each dual-socket compute node is replaced by a single accelerator (i.e., delivered software running on eight GPGPUs shall be 5 times faster than DPLR running on eight modern, dual-socket compute nodes). Finally, the accuracy of the delivered software shall be verified by comparing to the DPLR and/or LAURA codes. The verification study shall consider flight conditions from at least two of the following planetary destinations: Earth, Mars, Titan, Venus, and Uranus/Neptune.

State of the Art and Critical Gaps:
NASA's existing aerothermal analysis codes (LAURA, DPLR, US3D, etc.) all utilize domain-decomposition strategies to implement coarse-grained, distributed-memory parallelization across hundreds or thousands of conventional CPU cores. These codes are fundamentally unable to efficiently exploit many-core accelerators, which require the use of fine-grained, shared-memory parallelism over hundreds of thousands of compute elements. Addressing this gap requires reengineering our tools from the ground up and developing new algorithms that expose more parallelism and scale well to small grain sizes.
Many-core accelerated CFD solvers exist in academia, industry, and government. Notable examples are PyFR from Imperial College London [4], the Ansys Fluent commercial solver [5], and NASA Langley's FUN3D code [6]. However, most of the work to date has focused on perfect gas flow models, which have different algorithmic and resource requirements compared to real gas models. The two notable exceptions are the Sandia Parallel Aerodynamics and Reentry Code (SPARC) [7] and FUN3D's FLUDA library for GPU-accelerated real-gas simulation [8,9], both of which have demonstrated multispecies, multitemperature simulations at scale using GPGPU technology. However, broader infusion of advanced architecture capability into the hypersonic/EDL (entry, descent, and landing) simulation community is still required, as is the development of advanced nonlinear solver technologies that perform well on many-core architectures.

Relevance / Science Traceability:
This scope is directly relevant to NASA space missions in both Exploration Systems Development Mission Directorate and Space Operations Mission Directorate (ESDMD-SOMD) with an EDL segment. These missions depend on aerothermal CFD to define critical flight environments and would derive large, recurring benefits from a more responsive and scalable simulation capability. This scope also has potential crosscutting benefits

for tools used by Aeronautics Research Mission Directorate (ARMD) to simulate airbreathing hypersonic vehicles. Furthermore, this scope directly supports NASA's CFD Vision 2030 Study, which calls for sustained investment to ensure that NASA's computational aeroscience capabilities can effectively utilize the massively parallel, heterogeneous (i.e., GPU-accelerated) supercomputers expected to be the norm in 2030.

References:

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9. C. Stone, A. Walden, et al.: "Accelerating Unstructured-Grid CFD Algorithms on NVIDIA and AMD GPUs." Supercomputing 2021.

Scope Title: Robust and Automated Aerothermal Simulation of Complex Geometries

Scope Description:
NASA's production aerothermodynamic flow solvers all share a common characteristic: they utilize conventional second-order accurate finite volume schemes to spatially discretize the governing flow equations. Schemes of this type are ubiquitous in modern compressible CFD solvers. They are reasonably simple to implement and optimize on conventional CPU-based computer architectures and can provide engineering accuracy for a wide range of problems. Unfortunately, one area where these schemes struggle to deliver acceptable accuracy is at hypersonic speeds when a strong shock wave forms ahead of the vehicle. In such cases, the computed surface heat flux exhibits extreme sensitivity to the design of the computational grid near the shock [1], which must be constructed from cell faces that are either parallel or perpendicular to the shock to minimize error.

This stringent requirement for shock-aligned grids effectively precludes the use of unstructured tetrahedral meshes in aerothermal simulation. Current engineering practice employs a limited form of mesh adaption, commonly referred to as "shock tailoring," whereby cell faces in a block-structured grid are aligned and clustered near the shock [2]. While effective, this approach is extremely limiting and makes it technically difficult and extremely time consuming to generate computational grids for nontrivial vehicle geometries. More general shock tailoring techniques exist based on hybrid prismatic-tetrahedral unstructured grids [3], but current implementations are limited to fitting just the bow shock, do not guarantee accuracy or efficiency of the resulting grid/solution, and can present numerical challenges for some flow solvers due to rapid changes in cell volume at topological boundaries.

Fortunately, recent research has demonstrated several promising avenues to address the strong shock capturing problem. One such avenue is the use of advanced numerical schemes such as the Discontinuous Galerkin (DG) method, which has been shown to deliver high-quality solutions for shock-dominated flows on fully unstructured grids when appropriate stabilization mechanisms are employed [4,5]. Alternatively, advanced algorithms for metric-aligned unstructured grid generation [6,7], combined with techniques for recovering locally structured grids from metric-aligned tetrahedral grids [8], may provide a path forward for accurately capturing strong shocks, either on their own or in combination with advanced numerical schemes.

This scope seeks to revolutionize NASA's aerothermal analysis capability by enabling rapid, robust, and highly automated analysis of complex hypervelocity flight systems. A successful solution within this scope would demonstrate accurate computation of surface heat flux on a complex entry vehicle, e.g., the Space Shuttle, at multiple flight conditions relevant to planetary entry with little-to-no user interaction.

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

Primary Technology Taxonomy:

- Level 1: TX 09 Entry, Descent, and Landing
- Level 2: TX 09.1 Aeroassist and Atmospheric Entry

Desired Deliverables of Phase I and Phase II:

- Software
- Prototype

Desired Deliverables Description:
The desired deliverable at the conclusion of Phase I is a prototype software package capable of accurately resolving gradient-based quantities such as heat flux and shear in the presence of strong shocks. The software shall demonstrate accurate prediction of surface heat flux for an Orion-like spherical heatshield in 2D at a variety of flight conditions without requiring adjustment of algorithm parameters. Surface heat flux predictions shall be verified by comparison with NASA's DPLR and/or LAURA simulation codes and must be free of numerical noise typically observed for second-order finite volume solvers on conventional unstructured grids. Real gas physics need not be included during Phase 1; perfect gas simulations are encouraged for expediency.

A successful Phase II deliverable will mature the Phase I prototype into a product ready for use on mission-relevant engineering problems. The software must be extended to 3D, parallelized for execution on large-scale supercomputers, and generalized to model multispecies and multitemperature gas physics. The software shall be demonstrated for complex vehicle geometries such as the Space Shuttle and exercised on a range of planetary entry problems that include at least two of the following destinations: Earth, Mars, Titan, Venus, and Uranus/Neptune. Computational performance, as measured by total time-to-solution for a given heat flux accuracy, shall be characterized and compared to DPLR/LAURA, but no specific performance targets are required.

State of the Art and Critical Gaps:
Current state-of-the-art engineering practice employs limited forms of mesh adaption, commonly referred to as "shock tailoring," whereby cell faces in a block-structured grid are aligned and clustered near the shock [2][3]. However, these approaches lack generality and can be difficult to employ in a robust manner for complex vehicle geometries.

Multiple academic [4,5,9,10] and NASA [11] groups have demonstrated promising results when using high order DG/FEM methods to perform steady state aerothermodynamic analysis at conditions relevant to planetary entry. However, most current research efforts in this area have focused on a simplistic model problem (heat flux on a sphere/cylinder at 5 km/s flight condition) with basic, nonionized flow models. An infusion of resources is needed to mature these promising algorithms into scalable, production-ready software that can be tested across a full entry trajectory with best-practice thermochemical models.

The current state of the art in anisotropic grid adaption as applied to EDL problems of interest is the Sketch-to-Solution capability based on FUN3D and refine [12], which has demonstrated the ability to accurately resolve integrated aerodynamic quantities (lift, drag, moment, etc.), but has yet to resolve the issue of noise in gradient based surface quantities (heat flux, shear), when using purely tetrahedral grids [13]. A variety of strategies exist to recover prismatic layers near the vehicle surface from anisotropic tetrahedral grids which can more accurately resolve the gradients at the wall [14] and at shocks [8]. Hybrid approaches where a prismatic boundary layer grid is utilized with anisotropic tetrahedra to resolve strong shocks have been demonstrated for various CFD solvers on EDL-relevant problems [15,16], but automation of this process as well as the challenges involved at the grid interface are still open problems.

Relevance / Science Traceability:

This scope is directly relevant to NASA space missions in both ESDMD-SOMD and SMD with an EDL segment. These missions depend on aerothermal CFD to define critical flight environments and would see significant, sustained reductions in cost and time-to-first-solution if an advanced grid adaption capability is developed. This scope also has strong crosscutting benefits for tools used by ARMD to simulate airbreathing hypersonic vehicles, which have stringent accuracy requirements similar to those in aerothermodynamics. Finally, this scope aligns with NASA's CFD Vision 2030 Study, which calls for a "much higher degree of automation in all steps of the analysis process" with the ultimate goal of making "mesh generation and adaptation less burdensome and, ultimately, invisible to the CFD process." In order for the aerothermal community to realize these goals, we must eliminate our dependence on manually designed, carefully tailored, block structured grids. This scope is an enabling technology for that transition.

References:

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15. Nastac, et al.: "Improved Heat Transfer Prediction for High-Speed Flows over Blunt Bodies using Adaptive Mixed-Element Unstructured Grids." AIAA 2021-0111.
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Scope Title: Efficient Grid Adaption for Unsteady, Multiscale Problems

Scope Description:

The current state of the art for production CFD simulation in EDL is the solution of steady-state problems on fixed computational grids. However, most of the current challenge problems in the discipline are unsteady. Examples include supersonic retropropulsion, where engine plumes exhibit unsteady behavior across a wide range of timescales [1]; capsule dynamic stability, where the vehicle pitch motion is amplified by the unsteady wake dynamics [2]; and single-event drag modulation, where a high-drag decelerator is separated from the main vehicle at hypersonic speeds [3]. Successful analysis of these phenomena requires simulating many seconds of physical time while simultaneously resolving all features of the flow field with high accuracy. Since critical features, e.g., shocks, shear layers, etc., will evolve and move through the computational domain over time, current practice requires large, globally refined grids and stringent limitations on simulation time step. This makes these problems computationally infeasible without dedicated access to leadership-class supercomputers.

A promising method to reduce the cost of these simulations is to employ grid adaption such that the computational grid is only refined in the vicinity of critical flow features. Adaptive techniques have been shown to dramatically reduce computational cost for a wide range of steady-state flow problems, often by as much as an order of magnitude, and have been successfully used to solve large-scale, EDL-relevant problems [4][5]. Application of efficient adaptive techniques to unsteady problems is less established, but recent advancements such as space-time adaption [6] have demonstrated a nearly 100-time reduction in compute time required to achieve an equivalent level of space-time accuracy relative to globally refined grids.

This scope seeks to accelerate the infusion of cutting-edge algorithms for unsteady grid adaption that promise to radically reduce the time required to simulate unsteady fluid phenomena. A successful solution within this scope would demonstrate an order-of-magnitude reduction in computational cost without compromising solution accuracy for an unsteady supersonic or hypersonic flow problem relevant to EDL.

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

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
- Software

Desired Deliverables Description:
The desired deliverable at the conclusion of Phase I is a prototype software package employing adaptive grid refinement algorithms for the simulation of unsteady, shocked flows in at least two spatial dimensions. An inviscid, perfect gas model is acceptable for Phase I efforts. The prototype software shall be demonstrated on a suitable challenge problem. Suggested challenge problems are prescribed motion of a cylinder relative to the computation domain subject to Mach 6+ supersonic flow or 2D axisymmetric simulation of a shock tube with an initial pressure ratio >50. Other challenge problems of similar complexity are acceptable. The prototype software is not expected to be scalable or performant at this stage.

A successful Phase II deliverable will mature the Phase I prototype into a product ready for use on mission-relevant engineering problems. The code shall be extended to solve the unsteady laminar Navier-Stokes equations in three spatial dimensions with appropriate controls to manage adaption in the boundary layer and the far field, if needed. Extension to reacting, multitemperature gas physics is desired, but not required. The software shall be parallelized to enable simulation of large-scale problems using modern HPC platforms such as the NASA Pleiades supercomputer. The software shall be demonstrated on a 3D challenge problem such as a single jet supersonic retropropulsion configuration at zero angle of attack; free-to-pitch simulation of the Orion entry capsule at supersonic free-stream conditions; or aerodynamic interaction and separation of multiple spheres in a supersonic free stream. The software shall demonstrate a 10x speedup relative to a nonadaptive, time-marched calculation without significantly degrading simulation accuracy as measured by an appropriate solution metric (average root-mean-square (RMS) pressure fluctuation, final capsule pitch angle, etc.).

State of the Art and Critical Gaps:
Multiple academic, government, and commercial software packages exist that implement some form of solution-adaptive mesh refinement. NASA’s LAURA and DPLR codes offer simplistic clustering algorithms for structured grids that solve the limited problem of resolving strong bow shocks [7][8]. NASA’s FUN3D code implements an advanced metric-based, anisotropic refinement capability that has been demonstrated on large-scale aerospace calculations [7]. However, unsteady solution-adaptive algorithms have yet to be demonstrated for EDL-relevant problems outside of academic research codes. Significant investment is

required to implement these algorithms into a production-quality flow solver with the performance and scaling characteristics required to address NASA's requirements for unsteady flow simulation.

Relevance / Science Traceability:
This scope has extremely broad applicability across multiple NASA mission directorates. In particular, ARMD, ESDMD-SOMD, SMD, and STMD each contend with complex, unsteady flow phenomena that could be more readily analyzed with the aid of the proposed technology: flutter analysis, parachute inflation, fluid slosh, and atmospheric modeling are just a few examples. In EDL specifically, a robust time-space adaption capability would enable simulation of supersonic retropropulsion at Mars using NASA's existing supercomputing assets. Capsule stability could be analyzed in the preliminary design phase, allowing mission designers to utilize low-heritage capsule shapes without adding significant cost or risk to the project. Drag skirt separation could be modeled in detail to reduce risk prior to a technology demonstration mission. The potential benefits of this technology are widespread, making this a critical investment area for the Agency.

References:

1. Korzun, et al.: "Effects of Spatial Resolution on Retropropulsion Aerodynamics in an Atmospheric Environment." AIAA-2020-1749, 2020.
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Focus Area 15 Materials Research, Advanced Manufacturing, Structures, and Assembly

As NASA embarks on its mission for human exploration of the Moon as a step towards the human mission to Mars, taking full advantage of the potential offered by new and existing technologies will be critical to enabling sustainable Lunar and Mars presence. Manufacturing and construction approaches tailored to the Lunar environment will pave the way toward addressing challenges such as lowering the cost of exploration and enabling efficient, reliable operations in extreme environments. The Materials Research, Advanced Manufacturing, Structures, and Assembly focus area seeks innovative advanced materials processing and structural concepts that enable effective use of in-situ resources to establish planetary infrastructures that can support affordable and reliable Lunar surface operations. Integration of advanced tools to accelerate the implementation of the required technologies is critical to closing gaps in the systems architecture.

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

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

Lead Center: JPL
Participating Center(s): GSFC, MSFC

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). Methods of using AME to create circuits in a compact 3D structure or involving nonplanar surfaces (such as a cylinder) are both of interest [2,3]. There have been multiple works that demonstrate the capability of AME for 3D and nonplanar circuitry but limited work that demonstrates its effectiveness for space applications. The AME approach should address the following technical and mechanical challenges:

1. AME methodology should include integration of a variety of standard electronics package types including ball grid arrays (BGAs), quad flat pack nonleaded (QFN)/land grid array (LGA), and chip components.
2. AME circuit should show the capability of surviving the thermal requirements needed for space missions with -35 to 100 °C nonoperational as a minimum criterion and ability to survive extreme cold (such as -125 °C) as a desired capability.
3. The AME approach should show the capability of favorable cost and schedule compared to equivalent approaches using traditional electronics manufacturing and demonstrate repeatability/accuracy.

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:
- Sets of materials and manufacturing techniques that are able to create robust circuitry using printed electronics for volume constrained applications. Material sets and methodologies should be readily available for NASA centers to use on application-specific designs to meet future packaging needs.
- The Phase I deliverables should be fabrication of standalone critical structures and demonstration of approaches to scale to fully functional compact circuits.
- The Phase II deliverables should include the design and fabrication of full circuits. 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. 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:
[1] https://www-robotics.jpl.nasa.gov/how-we-do-it/systems/exobiology-extant-life-surveyor-eels/
[2] MacDonald, Eric et al.: "Multiprocess 3D printing for increasing component functionality." Science, 30 Sep. 2016, DOI: 10.1126/science.aaf2093
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T12.08: Manufacturing and Construction of Lunar Landing Pads Research (STTR)
Lead Center: MSFC
Participating Center(s): ARC, KSC, LaRC

Subtopic Introduction:
Fabrication and assembly of structural systems using advanced construction techniques, including habitats, pressure vessels, and other nonpressurized structures from extraterrestrial materials. Materials extracted from in situ lunar and planetary resources (e.g., the minerals present on the surface, atmosphere, or vapor deposits) have the potential to radically reduce the cost and increase the scale of ambitious future space exploration activities. The design and fabrication of such systems and associated technologies so that construction and outfitting can be effectively accomplished locally is essential to their utilization—including integration of systems such as pumps and valves, airlocks, life support, health management sensors and controls, and others, in addition to structural foundations.
Materials, components, and systems that would be necessary for the proposed technology must be able to operate on the lunar surface in temperatures of up to 110 °C (230 °F) during sunlit periods and as low as -170 °C (-274 °F) during periods of darkness. Systems must also be able to operate for at least 1 year with a goal of 5 years without substantial maintenance in the dusty regolith environment. Proposers should assume that operations involving other systems (e.g., robots) and later astronauts will be ongoing not more than tens of meters away from the local fabrication, construction, and/or outfitting activities. Phase I efforts can be demonstrated at any scale; Phase II efforts must be scalable up to 100-1,000 m^3 of fabricated pressure vessel, and not less than 10 meters of single structural system element.

Each of the following specific areas of technology interest may be developed as a standalone technology.

Scope Title: Novel Reinforcement of Structural Materials for Application in Extreme Environments

Scope Description:
Proposals should research novel reinforcement concepts and techniques for structural systems in extreme environments that will be fabricated from in situ lunar materials. These structural systems—first under consideration launch and landing pads—that can be fabricated from local extraterrestrial materials via additive

manufacturing, assembled locally with robotic and/or astronaut assisted, and are designed for easy and effective maintenance to maintain performance. Phase I should focus on development of reinforcement techniques and concepts for experimentation and testing of different techniques with in situ material to determine viability for use on planetary surfaces and a future flight demonstration mission(s). Outcome: Phase I results should be documented in a report back to the government. Phase II deliverables must be capable of demonstration in terrestrial simulation chambers and technology transfer to a small business for development for flight demonstration and lunar tests. Proposals should also address the technology transfer to a small business that will develop the technology and integrate it into a lunar flight demonstration mission. Proposals should also include a STEM component related to the demonstration mission post-technology transfer. Outcome: Novel reinforcement Technology Transfer of tested Technology Readiness Level (TRL) 4 technology to a small business with follow-on STEM experience in connection with that technology flight demo with the small business. Testing and demonstration results should address the following attributes: low and/or predictable coefficients of thermal expansion, strength, mass, reliability, radiation protection, waste heat rejection in lunar or other planetary environments, and cost.

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 12.4 Manufacturing

Desired Deliverables of Phase I and Phase II:

- Prototype
- Analysis
- Hardware

Desired Deliverables Description:

Phase I deliverables may be a conceptual design with analysis to show feasibility at relevant scales and/or a small demonstration of the concept.

Phase II deliverables should be hardware demonstrations at a relevant scale. See Scope Description for additional information on Phase I and Phase II deliverables.

State of the Art and Critical Gaps:

State of the Art:

1. At present there are additive constructed houses neighborhoods in Austin, TX, and Southern Mexico with a level of secure remote operations capability.
2. NASA Lunar Pad Team—Subscale development landing pad printing and testing at U.S. Army Camp Swift, TX, Oct. 2020.
3. Army Corps of Engineers Development of Forward Operating Base construction technologies Champaign, IL.

Critical Gaps:

1. Larger scale development Earth base landing pads.
2. Autonomous operations.
3. In situ material to minimize launch mass associated with raw materials capabilities "Living off the Land" and remote construction.
    1. Power plants
    2. Habitats, refineries, and greenhouses
    3. Launch and landing pads
    4. Blast shields
4. Design criteria and civil engineering standards for these first pieces of in situ infrastructure.
5. Thermal transfer of heat from plume impingement in in a vacuum environment.

Relevance / Science Traceability:

This technology is very much applicable in Space Technology Mission Directorate (STMD) support of its NASA, government, and industry customers.

STMD for Science Mission Directorate (SMD)—Radio telescope structural support (back side of the Moon).

Exploration Systems Development Mission Directorate (ESDMD) and Space Operations Mission Directorate (SOMD) human habitats, space infrastructure as in buildings, landing pads, roads, berms, radiation protection, and custom-building sizes and shapes.

Aeronautics Research Mission Directorate (ARMD) and Earth base government agencies—in situ construction capabilities both locally and remote.

Rapid construction—small building within 24 hr

References:
Don't Take It – Make It: NASA's Efforts to Address Exploration Logistics Challenges through In Space Manufacturing and Extraterrestrial Construction for Lunar Infrastructure. R. G. Clinton, Jr., Ph.D.; Tracie Prater, Ph.D.; Jennifer Edmunson, Ph.D.; Mike Fiske; Mike Effinger, Novel Orbital and Moon Manufacturing, Materials, and Mass-efficient Design (NOM4D) Kick-Off December 14-15, 2021.
https://ntrs.nasa.gov/api/citations/20210025774/downloads/NOM4D%20KO%2012.15.2021.pdf

Scope Title: Localized Resource Feedstock Development and Application for In-Space Surface Construction/Infrastructure

Scope Description:
Proposals should research both the feedstock development and their application in use/development of surface (space) infrastructure. Proposals may address Moon or Mars construction concepts and requirements to best test out and demonstrate in situ (localized) material feedstock development and its application for construction of space infrastructure—habitats (pressurized), roads, berms, shelters (unpressurized), greenhouses, launch pads, etc. These structural systems that can be fabricated from local extraterrestrial materials via additive manufacturing, assembled locally with robotic and/or astronaut-assisted, and are designed for easy and effective maintenance to maintain performance. Phase I should focus on in situ localized conversion of feedstock (Moon or Mars simulant) and application to a test in situ structure(s) during Phase II. Outcome: Document results in report to government. Phase II deliverables: (1) Feedstock to build two pieces of infrastructure listed above and technology transfer to a small business and (2) Full-scale construction demonstration in 1g Earth environment and technology transfer to a small business for development for flight demonstration and lunar or Mars development/demonstrator tests. Proposals should also address the technology transfer to a small business that will develop the technology and integrate it into a lunar flight demonstration mission or Mars use. Proposals should also include a STEM component related to the post technology transfer. Outcome: Feedstock and application Technology Transfer of tested TRL 4-5 technology to a small business with follow-on STEM experience in connection with that technology flight demo or further technology demonstrations with the small business. Testing and demonstration results should address the following attributes: low and/or predictable coefficients of thermal expansion, strength, mass, reliability, radiation protection, waste heat rejection in lunar or other planetary environments, and cost.

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

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:
- Analysis
- Prototype
- Hardware

Desired Deliverables Description:
Phase I deliverables may be a conceptual design with analysis to show feasibility at relevant scales and/or a small demonstration of the concept.

Phase II deliverables should be hardware demonstrations at a relevant scale. See Scope Description for additional information on Phase I and Phase II deliverables.

State of the Art and Critical Gaps:
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3. In situ material to minimize launch mass associated with raw materials capabilities "Living off the Land" and remote construction.
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    3. Launch and landing pads
    4. Blast shields
4. Design criteria and civil engineering standards for these first pieces of in situ infrastructure.
5. Thermal transfer of heat from plume impingement in in a vacuum environment.

Relevance / Science Traceability:
This technology is very much applicable in STMD support of its NASA, government, and industry customers.

STMD for SMD—Radio telescope structural support (back side of the Moon).

Exploration Systems Development Mission Directorate (ESDMD) and Space Operations Mission Directorate (SOMD) human habitats, space infrastructure as in buildings, landing pads, roads, berms, radiation protection, and custom-building sizes and shapes.

ARMD and Earth base government agencies—in situ construction capabilities both locally and remote.

Rapid construction—small building within 24 hr.

References:
Don't Take It – Make It: NASA's Efforts to Address Exploration Logistics Challenges through In Space Manufacturing and Extraterrestrial Construction for Lunar Infrastructure. R. G. Clinton, Jr., Ph.D.; Tracie Prater, Ph.D.; Jennifer Edmunson, Ph.D.; Mike Fiske; Mike Effinger: Novel Orbital and Moon Manufacturing, Materials, and Mass-Efficient Design (NOM4D) Kick-Off, Dec. 14-15, 2021.
https://ntrs.nasa.gov/api/citations/20210025774/downloads/NOM4D%20KO%2012.15.2021.pdf

Scope Title: Novel Power Systems for Mobile Regolith Manufacturing

Scope Description:
Proposals should address basic research into the design and integration of novel wireless power systems that can be used to deliver energy at required levels to mobile regolith processing systems. Phase II deliverables must be capable of demonstration both in terrestrial simulation chambers and lead to technology transfer into a small business for development as flight units in lunar tests and demonstrations. Proposals should address power delivery as well as adaptive use of power systems to support regolith processing requirements.

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 12.4 Manufacturing

Desired Deliverables of Phase I and Phase II:

- Analysis
- Prototype
- Hardware

Desired Deliverables Description:

Phase I deliverables may be a conceptual design with analysis to show feasibility at relevant scales and/or a small demonstration of the concept.

Phase II deliverables should be hardware demonstrations at a relevant scale. See Scope Description for additional information on Phase I and Phase II deliverables.

State of the Art and Critical Gaps:

State of the Art:

1. At present there are additive constructed houses neighborhoods in the Austin, TX, and Southern Mexico with a level of secure remote operations capability.
2. NASA Lunar Pad Team—Subscale development landing pad printing and testing at U.S. Army Camp Swift, TX, Oct. 2020.
3. Army Corps of Engineers Development of Forward Operating Base construction technologies Champaign, IL.

Critical Gaps:

1. Larger scale development Earth Base Landing Pads.
2. Autonomous Operations.
3. In situ material to minimize launch mass associated with raw materials capabilities "Living off the Land" and remote construction.
    1. Power plants
    2. Habitats, refineries and greenhouses
    3. Launch and landing pads
    4. Blast shields
4. Design criteria and civil engineering standards for these first pieces of in situ infrastructure.
5. Thermal transfer of heat from plume impingement in in a vacuum environment.

Relevance / Science Traceability:

This technology is very much applicable in STMD support of its NASA, government, and industry customers.

STMD for SMD—Radio telescope structural support (back side of the Moon).

Exploration Systems Development Mission Directorate (ESDMD) and Space Operations Mission Directorate (SOMD) human habitats, space infrastructure as in buildings, landing pads, roads, berms, radiation protection, and custom-building sizes and shapes.

ARMD and Earth base government agencies—in situ construction capabilities both locally and remote.

Rapid construction—small building within 24 hours

References:

Don't Take It – Make It: NASA's Efforts to Address Exploration Logistics Challenges through In Space Manufacturing and Extraterrestrial Construction for Lunar Infrastructure. R. G. Clinton, Jr., Ph.D.; Tracie Prater, Ph.D.; Jennifer Edmunson, Ph.D.; Mike Fiske; Mike Effinger, Novel Orbital and Moon Manufacturing, Materials, and Mass-efficient Design (NOM4D) Kick-Off December 14-15, 2021.
https://ntrs.nasa.gov/api/citations/20210025774/downloads/NOM4D%20KO%2012.15.2021.pdf

T12.09: Carbon Fiber Reinforced Thermoplastic Composites for Repurposable Aerospace Applications (STTR)

Lead Center: LaRC
Participating Center(s): JSC

Scope Title: Carbon Fiber Reinforced Thermoplastic Composites for Repurposable Aerospace Applications

Scope Description:
This solicitation seeks to exploit unique properties of thermoplastic composites to assess their feasibility and propose concepts of operations for in situ repurposing of primary and secondary spacecraft structures into deep space exploration infrastructure supporting 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 with future repurposing requirements accounted for in the initial design objectives. Once the spacecraft would accomplish its mission (e.g., successfully descended onto the lunar surface), its parts would be disassembled and reconfigured into infrastructure components and/or tools by reheating thermoplastic resin [2], first consolidated during original manufacturing prior to launch, and mechanically modifying the structure into a predetermined repurposed configuration.

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 the associated infrastructure, such as storage, surface transportation, and means of 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 sustainable human presence. The ability to repurpose components of spacecraft structures, via additive manufacturing or other methods, is one potential benefit of using carbon fiber reinforced 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, both modeling and simulation (M&S), as well as experimental work, needs to be conducted in a building block approach. In Phase I, the proposing team shall select a focus structure where the original geometric configuration and a repurposed configuration are 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 study case shall exemplify repurposing both from the standpoint of altered geometry and distinct loads and environment. Once the two “stand-alone” cases (original and repurposed) are sized and analyzed, a multiphysics simulation of the repurposing process shall be conducted. Exploring repurposing process sensitivity to different process parameters shall be leveraged to arrive to the final repurposing concept of operations and establish the energy required for the repurposing process. Heating methods shall be explored and include external and internal (pre-embedded) heating devices. Furthermore, the simulation shall establish tradeoffs associated with conducting the repurposing process with and without dedicated tooling aids. Success metrics should include a maximum weight penalty of 15% after repair, while still maintaining 100% load-carrying capability.

These efforts will establish a foundation for hardware demonstrations to be conducted in Phase II. Test data obtained from these demonstrations will be used to calibrate the multiphysics repurposing simulation framework to enable detailed repurposing assessment 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/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, etc.); (2) a concept of operation for the repurposing process supported by the multiphysics process simulation (energy requirement and source(s), means of delivering required heat, tooling, and any means of process quality assessment, and/or repurposed product nondestructive evaluation shall be included in the description of the proposed concept); and (3) metric(s) by which the required repurposing hardware weight and other feasibility aspects of the repurposing process can be assessed to inform mission design.

The Phase II deliverables shall include: (1) manufacturing demonstration unit per the design and repurposing process provided in 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) results of nondestructive evaluations before and after repurposing, and (4) revised or validated metric(s) of performance proposed in Phase I. Lessons learned section shall also be a part of the Phase II deliverable report.

State of the Art and Critical Gaps:
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 carbon fiber reinforced 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 of “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:
[1] Hilburger, Mark “Help Us Shape NASA’s Future Technology Investments: Lunar Excavation, Construction, and Outfitting,” YouTube, uploaded by NASA Space Tech, May 26, 2022.
https://www.youtube.com/watch?v=_IQv7C-xakk
[2] Van Ingen, J.W., Buitenhuis, A., Van Wijnaarden, M., and Simmons III., F.: “Development of the Gulfstream G650 Induction Welded Thermoplastic Elevators and Rudder.” SAMPE Conference, Seattle, WA, May 2010.

[3] Nishida, H., Carvelli, V., Fujii, T., and Okubo, K. "Thermoplastic vs. Thermoset Epoxy Carbon Textile Composites." 2018 IOP Conference Series: Materials Science and Engineering. Vol. 406, Paper 012043.
[4] Gramann, P., Rios, A., and Davis, B. "Failure of Thermoset Versus Thermoplastic Materials". Materials Science, ID 106398935, 2005.
[5] Barroeta Robles, J., Dubé, M., Hubert, P., and Yousefpour, A. "Repair of Thermoplastic Composites: An Overview." Advanced Manufacturing: Polymer & Composites Science, Vol. 8, Issue 2, 2022.
[6] Langley Technology Council "Langley Strategic Technology Investment Plan." LSTIP V9, April 2022.

Focus Area 16 Ground & Launch Processing

Ground processing technology development prepares the agency to test, process, launch, and recover the next generation of rockets and spacecraft in support of NASA's exploration objectives by developing the necessary ground systems, infrastructure, and operational approaches for terrestrial and off-planet surface systems.

This topic seeks innovative concepts and solutions for both addressing long-term ground processing and testing complex operational challenges and driving down the cost of government and commercial access to space. Technology infusion and optimization of existing and future operational programs, while concurrently maintaining continued operations, are paramount for cost effectiveness, safety assurance, and supportability.

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

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

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

T13.01: Intelligent Sensor Systems (STTR)

Lead Center: SSC
Participating Center(s): MSFC

Scope Title: Intelligent Sensors for Rocket Propulsion Testing

Scope Description:
Rocket propulsion system development is enabled by rigorous ground testing to mitigate the propulsion system risks inherent in spaceflight. Test articles and facilities are highly instrumented to enable a comprehensive analysis of propulsion system performance. 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. Intelligent sensor systems would provide a highly flexible instrumentation solution capable of monitoring test facility parameters including temperature, pressure, flow, vibration, and/or storage vessel liquid level. 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 system. These intelligent sensors should also be capable of performing in-place calibrations with National Institute of Standards and Technology (NIST) traceability and onboard conversion of raw sensor data to engineering units. 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.

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 the reduce the cost of operations. It also provides the capability for providing instrumentation in remote or hard to access locations. 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.

Rocket propulsion test facilities also provide excellent testbeds for testing and using the innovative technologies for possible application 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 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 to gauge the accuracy and health of the sensor. Sensor systems must provide the following functionality:

- Assess the quality of the data and health of the sensor.
- Perform in-place calibrations with NIST traceability.
- Data acquisition and conversion to engineering units for monitoring temperature, pressure, flow, vibration and/or storage vessel liquid level within established standards for error and uncertainty.
- Function reliably in extreme environments, including rapidly changing ranges of environmental conditions, such as those experienced in space. These ranges may be from extremely cold temperatures, such as cryogenic temperatures, to extremely high temperatures, such as those experienced near a rocket engine plume. Sensor operational environmental parameters must be suitable for the anticipated environment, e.g., extreme temperature (cryogenic or high heat), high vibration, flammable, etc.
- Collected data must be time-stamped to facilitate analysis with other collected datasets.
- Provide network connectivity to facilitate real-time transfer of data to other systems for monitoring and analysis.

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

Primary Technology Taxonomy:

- Level 1: TX 13 Ground, Test, and Surface Systems
- Level 2: TX 13.1 Infrastructure Optimization

Desired Deliverables of Phase I and Phase II:

- Prototype
- Hardware
- Software

Desired Deliverables Description:

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

State of the Art and Critical Gaps:

Highly modular, 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, 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.

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. 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 Space Operations Mission Directorate (SOMD). It supports all test programs at Stennis Space Center (SSC) 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, 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).
2. J. Schmalzel; F. Figueroa; J. Morris; S. Mandayam; R. Polikar, "An architecture for intelligent systems based on smart sensors," IEEE Transactions on Instrumentation and Measurement (Volume: 54, Issue: 4, Aug. 2005).
3. S. Rahman, R. Gilbrech, R. Lightfoot, M. Dawson, "Overview of Rocket Propulsion Testing at NASA Stennis Space Center," NASA Technical Report SE-1999-11-00024-SSC.
4. H. Ryan, W. Solano, R. Holland, W. Saint Cyr, S. Rahman, "A future vision of data acquisition: distributed sensing, processing, and health monitoring," IMTC 2001. Proceedings of the 18th IEEE Instrumentation and Measurement Technology Conference. Rediscovering Measurement in the Age of Informatics (Cat. No.01CH 37188).

Focus Area 18 Air Vehicle Technology

This focus area includes tools and technologies that contribute to both the Advanced Air Vehicles Program (AAVP) and the Transformative Aeronautics Concepts Program (TACP) encompassing technologies in all six Strategic Thrusts within the NASA Aeronautics Mission Directorate (ARMD). AAVP develops the tools, technologies, and concepts that enable new generations of civil aircraft that are safer, more energy-efficient, and have a smaller environmental footprint. The program focuses on enabling major leaps in the safety, efficiency, and environmental performance of subsonic fixed and rotary wing aircraft to meet challenging and growing long-term civil aviation needs; pioneering low-boom supersonic flight to achieve new levels of global mobility and advancing fundamental hypersonic research while sustaining hypersonic competency for national needs. In collaboration with academia, industry, and other Government agencies (e.g., FAA), AAVP pioneers fundamental research and matures the most promising technologies and concepts for transition to system application by the aviation industry. The program works with the DoD to ensure that NASA and DoD vehicle-focused research is fully coordinated and leveraged. TACP cultivates multi-disciplinary, revolutionary concepts to enable aviation transformation and harnesses convergence in aeronautics and non-aeronautics technologies to create new opportunities in aviation. The program’s goal is to demonstrate the initial feasibility of internally and externally originated concepts to support the discovery and initial development of new, transformative solutions for all six ARMD Strategic Thrusts. The program provides flexibility for innovators to explore technology feasibility and provide the knowledge base for transformational aviation concepts through sharply focused activities. The program solicits and encourages revolutionary concepts, creates the environment for researchers to become immersed in new ideas, performs ground and small-scale flight tests, allows failures and learns from them, and drives rapid turnover into new concepts. The program also supports research and development of major advancements in cross-cutting computational tools, methods, and single-discipline technologies to advance the research capabilities of all aeronautics programs.

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

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

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 Thrusts #4 (Safe, Quiet, and Affordable Vertical Lift Air Vehicles) as well as #1 (Safe, Efficient Growth in Global Operations) and #3 (Ultra-Efficient Subsonic Transports).

Proposals are sought in the following areas: (1) design and execution of experiments to gather research-quality data to validate aerodynamic and acoustic modeling of full-scale, multirotor eVTOL aircraft, with an emphasis on rotor interactions with airframe components and other rotors and propellers and (2) development and validation of scaling methods for extending and applying the results of instrumented subscale model testing to full-scale applications.

This solicitation does not seek proposals for designs or experiments that do not address full-scale 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.

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. Also, proposals should define what data will be collected and data that will be considered proprietary. Data includes vehicle specifications, models, results, flight test data, and any other information relative to the work proposed.

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

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

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

Primary Technology Taxonomy:

- Level 1: TX 15 Flight Vehicle Systems
- Level 2: TX 15.1 Aerosciences

Desired Deliverables of Phase I and Phase II:

- Software
- Hardware
- Analysis
- Research
- Prototype

Desired Deliverables Description:

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

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

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 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 and acoustics. Ultimately, the goal is to model and test multidisciplinary aeropropulsive 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 Thrusts #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 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. Although aerodynamics and 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:

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

Focus Area 23 Digital Transformation for Aerospace

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

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

- Accelerate innovation and knowledge growth
- Support data-informed decisions

- Achieve more complex missions
- Enable pervasive collaboration
- Enhance cost-effectiveness
- Build a digital-savvy workforce

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

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

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

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

T11.05: Model-Based Enterprise (STTR)

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

Subtopic Introduction:
Model-based anything (MBx) targets the use of models in any function that might include engineering, design, manufacturing, safety, testing and validation, operations, finance, human resources, facilities and infrastructure, and acquisition. Integration of models across multiple domains will enable the creation of model-based enterprise, which would facilitate high-complexity decision making by embodying agile processes to achieve efficiency, accuracy, confidence, and adaptability in support of NASA's mission, programmatic development, digital transformation, and institutional activities. The model-based enterprise adopts modeling technologies to integrate and manage both technical and business processes related to various NASA missions. The MBx envisions a future where automated analyses and seamless information exchange among engineering, programmatic, and institutional domains enable informed decision making in real-time and engineering of novel systems. In this vision, complexity and capability will be an order of magnitude greater than current systems. Advances in artificial intelligence (AI), machine learning (ML), and deep learning along with MBx will be utilized to make engineering, program management, and institutional decisions. Transformation process efficiency gains can be realized as MBx reduces the effort, time, and cost to execute engineering, program management, and institutional processes.

Key technologies relevant to MBx include modeling and simulation, data analytics, process mining, AI and ML, digital twin, virtual reality (VR) and augmented reality (AR), metaverse, and digital thread. Integration of multiple technologies and interoperability of the tool set across multiple platforms and organizations are essential for the application of MBx to engineering and institutional functions. In addition, a robust MBx approach inherently depends on the ease of data transformation, which is significantly enhanced by the collaborative capabilities of the modeling tools used to create data and the standards used to exchange that data. There is a need for appropriated standards to ensure the seamless flow of data throughout the mission lifecycle and reusability of data.

This subtopic will focus on (1) development of the key technologies previously cited for engineering and business functions that can be integrated to create a model-based enterprise, (2) digital twins of engineering systems, facilities, and business functions, (3) application of VR/AR for engineering system development and operation of various physical assets on ground and in space, (4) application of metaverse for engineering development and operations, and (5) development of digital thread with seamless flow of data and models throughout the mission lifecycle.

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

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

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

As previously indicated, the Agency will need to focus on efforts associated with the new changes in the "future of work" at NASA (Refs. 6 and 8). NASA will likely have fewer people working in buildings post-pandemic, and such buildings may be used differently than at present because many people will be working offsite and less frequently working in NASA facilities—except for special activities and needs. We will need to restructure our present older facilities for this type of change and/or plan to design differently for any new facilities, and we will need models for that.

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

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

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

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

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

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

The model should also be capable of the following:

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

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

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

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

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

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

Desired Deliverables of Phase I and Phase II:
- Research
- Analysis
- Prototype
- Hardware
- Software

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

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

State of the Art and Critical Gaps:
Outside of NASA, industry is rapidly advancing Model-Based Systems Engineering (MBSE) tools and scaling them to larger, more complex development activities. Industry sees scaling as a natural extension of their ongoing digitization efforts. These scaling and extension efforts will result in reusable, validated libraries containing models, model fragments, patterns, contextualized data, etc. They will enable the ability to build upon, transform, and synthesize new concepts and missions, which has great attraction to both industry and

government alike. Real-time collaboration and refinement of these validated libraries into either "single source" or "authoritative sources" of truth provide further appeal as usable knowledge can be pulled together much more quickly from a far wider breadth of available knowledge than was ever available before.
One example of industry applying MB/MBe/MBSE is through Digital Thread™, a communication framework that helps facilitate an integrated view and connected data flow of the product's data throughout its lifecycle. In other words, it helps deliver the right information at the right time and at the right place. Creating an "identical" copy (sometimes referred to as a "digital twin") is another use, a digital replica of potential and actual physical assets, processes, people, places, systems, and devices that can be used for various purposes. These twins are used to conduct virtual cost/technical trade studies, virtual testing, virtual qualification, etc., that are made possible through an integrated model-based network. Given the rise of MBSE in industry, NASA will need to keep pace in order to continue to communicate with industry, manage and monitor supply chain activities, and continue to provide leadership in spaceflight development.

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

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

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9. Keady, R.A.: Equipment Inventories for Owners and Facility Managers: Standards, Strategies, and Best Practices. Wiley Press, 2013.
10. GSA's Emerging Building Technologies Program: https://www.gsa.gov/governmentwide-initiatives/sustainability/emerging-building-technologies

Scope Title: Integration of Digital Twin With Augmented and Virtual Reality in Metaverse

Scope Description:
Digital twins is a critical emerging technology that consists of a physical asset, a virtual counterpart, and the data exchanged between the two. Enabled by models and simulations, advanced computing, and cyber and immersive technologies, digital twins tackle the challenge of integration between the physical and digital world, facilitating rapid analysis and real-time decision making. Digital twins transform the traditional design-

build-test waterfall approach to a model-analyze-build-test spiral approach. This provides the capability to experiment, validate, and optimize solutions in the virtual space before building and testing, potentially jeopardizing the real-world asset. After a higher confidence design is built, measured test results can be used to update the model to forecast performance and evaluate risk of unforeseen operational scenarios. In the early stages of product/mission development, multiphysics models, simulations, and analytics (to include artificial intelligence (AI) and machine learning (ML)) can be used to conduct tradeoff analyses under various mission operating conditions and what-if scenarios in the virtual world. Insights can be obtained on manufacturability, cost, schedule, and performance by experimenting with a wide range of scenarios and evaluating optimized solutions and/or mitigation strategies. This results in significant reduction in time taken for development of design and new product/mission concepts. Digital twins can provide real-time monitoring, diagnostics, and corrective action for the operating assets. For operational assets like aircraft, spacecraft, habitats, power systems on lunar surface, planetary rovers, or large test facilities, digital twins fed by real-time sensor data on as-experienced environmental conditions can transform assumptions that drive the current scheduled and preventive maintenance practices to enable a more efficient predictive maintenance based on the actual condition of the operating asset.

The application of augmented and virtual reality (AR/VR) is undergoing significant growth for many engineering applications that include design and virtual testing of new products/concepts, manufacturing, and operations. The use of AR/VR allows designers, engineers, and end users to be immersed in a simulated environment (virtual reality) and in an environment where actual environments and objects are superimposed (augmented reality), or a hybrid between the two (mixed reality). By experiencing a new product in an immersive environment, designers and engineers can collaborate to accelerate the iterative product development process and reduce development costs. They can conduct research, design, modeling, prototyping, and user testing to validate ideas virtually in ways that would be too costly, impractical, or impossible to recreate in the real world. Besides design and development of new products, AR/VR technologies are also used for training.

Integration of digital twins with AR/VR offers many benefits. Utilizing a virtual or augmented experience for digital twins allows stakeholders to digest, understand and visualize real-world depictions, and the ability to move and interact in these spaces. Digital twins integrated with AR/VR would provide virtual, behaviorally accurate representation of product designs and operating assets. By experiencing a component, subsystem, or system in an immersive environment along with the simulation tools associated with digital twins, engineers and designers can bring a product to life without physically constructing a single thing. An integrated digital twin-AR/VR system would allow training of operators for large facilities and manufacturing operations in a virtual dynamic environment, where they could practice responding to live operational conditions without risk to the asset or down time.

While the computational tools for digital twins, real-time sensors, and AR/VR technologies have been developed in parallel and independent paths, the possibility of the combined use of these tools has grown. Typically, the simulation software used for digital twins lacks the AR/VR functionalities and lacks a mechanism to ingest live sensor data. It is timely to develop the connectivity between the digital twin, sensor data, and VR/AR software to take advantage of their strengths. It is envisioned the metaverse, which is rapidly evolving, will be the platform for integration of digital twins and live data with AR/VR. The metaverse will help recreating the existence of the real world digitally. For the integrated operational digital twin-AR/VR concept to be a reality, the necessary computational tools and architectures need to be developed to integrate digital twins and data streams with immersive technologies.

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

Primary Technology Taxonomy:

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

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis

- Prototype
- Hardware
- Software

Desired Deliverables Description:
Phase I Deliverables—

- Methodology and approach for integrating digital twin in metaverse to design and develop advanced aerospace concepts and design
- Methodology and approach for integrating digital twin with metaverse for a large test facility (like wind tunnel) that will enhance facility operations and collaborative testing among geographically dispersed partners.

Phase II Deliverables—

- Delivery of models/tools/platform prototypes that demonstrate capabilities or performance over the range of NASA target areas identified in use cases. Working integrated software framework capable of direct compatibility with existing programmatic tools.
- All other requirements remain unchanged.

State of the Art and Critical Gaps:
One of the targets for NASA's Digital Transformation (DT) strategic initiative is to transform engineering. Building blocks toward operational digital twins are currently being developed within NASA's DT effort, with a goal of reducing time to develop new systems, significantly reducing time for anomaly detection in operating systems and enabling predictive maintenance of NASA facilities and infrastructure. Integration of operational digital twins with AR/VR technologies in metaverse will accelerate development of new aerospace systems and will offer engineers a better platform to share, interact, and collaborate with multiple partners. In addition, the integration of operational digital twins and AR/VR in the metaverse will enable training of new operators and engineers in large and complex test facilities.

Relevance / Science Traceability:
Covers Aeronautics Research Mission Directorate (ARMD) priorities, such as zero-emission aircraft and green aviation as potential targets, along with OSI (Office of Strategic Infrastructure) priorities such as large test facilities and laboratories across the Agency, under the stewardship of the SETMO (Space Environments Testing Management Office). This would help with upskilling and training the current and future cohort of facility technicians and collaboration with external partners.

References:
Digital Twin: Reference Model, Realizations & Recommendation Available for download at
https://www.aiaa.org/resources/digital-twin-implementation-white-paper/

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

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. The initial lunar missions will be short in duration, provide limited objectives related to science and exploration and focus on the checkout of core vehicle systems. Over time, lunar, subsequent 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. Given the mission distances and mission durations, astronauts will also be required to function much more autonomously than they have had to function 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 laboratories, 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.

Given the increased duration, distances, and complexity of future missions, astronauts will also be required to function much more autonomously. XR can provide astronauts with tools that can improve an astronaut’s ability to function “more” autonomously by facilitating refresher training during missions, providing real-time operations support, allowing for the visualization of complex data, enhancing the collaboration environment, as well as between the mission participants and the support personnel back on Earth.

Although XR is being widely used in government and industry for an assortment of activities, XR technology is still being developed and maturing at an incredible pace. Capabilities that were only seen in video games or in movies are now part of enterprise-level applications. This fast growth presents challenges and opportunities to NASA. The challenge is the need to continually carry out horizon scans to stay up to date on the latest-and-greatest XR capabilities available. This challenge is also an opportunity to help identify new capabilities that can help address some of the shortcomings/gaps associated with XR. These gaps can limit the use of the technology in certain use cases that are important to NASA, government, and industry in general.

Scope Title: Extractable High-Resolution Terrain Database System

Scope Description:
The system would provide an extractable, high-resolution terrain database (<1 meter resolution) with all the correct metadata that is created from digital elevation terrain data, 3D rock models, 3D human-made structure models, photos, lidar scans, etc., that can be used with the most used game/scene rendering engines at NASA (Unreal, Omniverse, Unity, or Edge) to support the creation of highly immersive and highly performant simulation environments. The system should support large areas of interest >90 km, be able to ingest and store all the data needed to create the desired high-resolution/performant simulation environment, and output terrain data files at desired levels of detail, which can be used within the game/scene rendering engines mentioned above. The initial regions of interest are possible future NASA lunar landing sites, but the concept/system should be usable for Mars or other Earth locations of interest. The system should also provide a high level of automation that reduces the overall manual effort that is currently required to build these types of systems. Graphical user interfaces (GUIs) should be part of the system to facilitate the use of the system.

This capability can be used to create an immersive environment to support training, collaboration, analysis, planning, and real-time operations of future Artemis missions.

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

Primary Technology Taxonomy:

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

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Hardware
- Software

Desired Deliverables Description:

Phase I awards will be expected to develop theoretical frameworks, algorithms, and demonstrate feasibility (Technology Readiness Level (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, the development of the products being requested from the system requires extensive manual, time-consuming steps that can be difficult to execute. The process that is typically followed requires users to search for all the data required to create the models. The data can include Digital Elevation Model (DEM), rock models, human-made structures, other features of interest, etc. Next, the developer manually adds metadata to the different models. The metadata can include geo-reference information, the size of the object, and any other features deemed important. Next, handcrafting is performed to assure that any digital elevation data models from all the sources are sized appropriately, color corrected, and inserted into the initial terrain models created from the DEM. Additional handcrafting is performed for certain models to assure that they have the resolution/fidelity required. Upon the integration of all the data sources, further handcrafting is required to assure that the system has the necessary multiresolution model features so that it can be rendered at the necessary frame rates. This is typically done by creating models at multiple resolutions. High-resolution models are used for areas near to the user and lower resolution models are used for regions further away from the user. As the user moves around, new high-resolution versions of the models are brought into the scene for the new area where the user is located and the high-resolution models for the area that the user just left is swapped out for lower resolution versions. This swapping of models is sometimes required to allow for the system to render the scene at the required frame rates.

The system proposed would include a central storage location where data can be retrieved from for the creation of the models. This central storage location would facilitate the integration of the data. The system would also automate many of the manual and time-consuming steps that are currently required. New methods that create higher fidelity models using photogrammetry or other model creation methods could also be integrated into the system.

Current approaches NASA is using to develop the necessary 3D high-resolution models are time consuming and difficult to follow. As NASA continues to develop simulations for use on future missions, these capabilities will become more important. Having access to a system that can overcome some of the challenges will be increasingly more important.

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), 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. Earth Science could also benefit from this type of capability by allowing systems to be developed that can support vegetation dispersion, human interaction with the environment, etc.

References:

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https://ieeexplore.ieee.org/document/609187

Scope Title: Augmented Reality Navigation

Scope Description:
The system should provide google maps style navigation outdoors and also inside of buildings. The system will allow for AR applications to be developed that do not require QR style visual markers, while still providing highly accurate six degrees of freedom position (6DOF) (< 1 cm); as well as highly accurate altitude and attitude information. The system should be usable with smart devices (tablets, smartphones) that support both iOS and Android operating systems. The system should also support with head worn AR devices. This type of system will allow for AR applications to be developed that can be used to accurately overlay points of interest and meta-information about those points of interest. The system allows for creation of applications that can be used to carry out activities more autonomously by allowing the system to guide a user through unfamiliar facilities and through steps that are required to carry out procedures.

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

Primary Technology Taxonomy:

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

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Software
- Hardware

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. Software implementation of the developed solution along with the simulation platform must be included as a deliverable.

State of the Art and Critical Gaps:
Industry has made significant progress developing markerless navigation technologies. These technologies are typically used on smartphones/tablets and require calibration steps for their use. A key player in the outdoor AR navigation field is the automobile industry, where navigation information can be displayed directly on the windshield or on a screen that the driver has a direct line of sight. A significant user of indoor navigation technologies includes warehouses, where people can be guided to certain locations to find items. Improvements to both the indoor and outdoor AR navigation system is important, since NASA has use cases for both indoor and outdoor AR navigation.

Current gaps that should be addressed for future systems include the overall use of the technology on head-worn devices, along with smartphone/tablets. Additionally, the accuracy of the system should be improved to allow NASA to use the capability to support indoor electronic procedure use cases that require high precision 6DOF data. How one should interact with the AR navigation systems (i.e., the GUIs and other human interface methods that users will use to interact with the system) should also be investigated further.

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), 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

Being able to have head-up displays (HUDs) in a helmet bubble, head-mounted displays (HMDs), or windshields that provide navigation cues to locations of interest or augment those locations with additional information will be important in the future design of next generation vehicles and suits. Furthermore, navigation aids will augment an astronaut's ability to carry out medical procedures more autonomously. It will also allow for certain procedures to be carried out that would not otherwise be possible by providing instructions on the exact placement and movement of medical instruments. Any system that reduces risks, improves operations, and allows for more autonomous operations are important for many different NASA directorates that includes ESDMD, SOMD, STMD, and SDM. Artemis and Gateway programs will also be able to infuse these technologies into future missions.

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Scope Title: Metaverse/Digital Twin

Scope Description:
The popularity of the metaverse has continued to grow with companies hailing it as the immersive visualization system of the future. Many of these companies are investing billions of dollars towards its development. Although many people have different definitions of what the metaverse is, the fundamental idea is that it provides a shared, multiuser, persistent, and highly immersive environment. This environment can be used for people to collaborate, to carry out training, to carry out design activities, to host entertainment activities, etc. These are activities that are important to NASA. An important component of the metaverse is a digital twin. Digital twins are a digital representation of a physical system that mimic the actual systems for its lifecycle. The twin receives real-time telemetry to stay current, provides situational awareness, and uses simulation, machine learning, and model-based reasoning to predict future outcomes and help decision making. Digital twins are sometimes referred to as the "building blocks" for the metaverse.

The scope of this focus area is to develop an XR architecture and applications that will enable easy access and collaboration of digital content within a metaverse/digital twin environment. The system developed should investigate the value added by a metaverse/digital twin environment to improve training, real-time operations support, collaboration, data visualization and analysis, and predictive analytics. The system should also optimize the human interfaces (GUIs and input devices) so that interaction between people and between people, facilities, instruments, etc., is optimized.

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

Primary Technology Taxonomy:

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

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Hardware
- Software

Desired Deliverables Description:
Phase I 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. Software implementation of the developed solution along with the simulation platform must be included as a deliverable.

State of the Art and Critical Gaps:
Many organizations have jumped on the metaverse/digital twin bandwagon. Although there are many definitions to what the metaverse means, most will agree that it is an immersive environment (AR or VR), that is persistent, online, and multiuser. Currently, metaverse technologies are being driven by companies that have specialized in gaming, entertainment, or social networking; there are many engineering and science applications to the technologies. Some examples of the current state of the art includes:

1. Earth 2.0 Project that pairs a data-rich Earth digital twin simulation with a highly immersive visualization application to carry out climate/weather forecasting.
2. Industry's use of digital twins to design and operate their next-generation buildings and warehouses. Warehouses use digital twins of the facility and all the operators in the building (robots, people, other systems) to improve operations. These digital twins are also used to carry out predictive analytics and to train autonomous robots how to operate in a physical environment.
3. Epic games Fortnite system has been used to host concerts and other events attended by tens of millions of people. The system has allowed for limited interaction to take place by a large number of people in a purely digital environment.
4. Roblox system that allows users to create custom worlds that can then be linked. This further demonstrates how content can be created and linked into a metaverse that is then visited by a large number of people.
5. NVIDIAs omniverse platform that allows for applications to seamlessly communicate with each other to create highly immersive experiences.

The following are the challenges/gaps that should be addressed during this effort:
1. The need to improve/optimize the human interfaces needed for the interaction between the people and the digital/physical environments. This includes both the input devices and the display devices.
2. The computation needed for the metaverse/digital twin environment and where this computation would take place (cloud vs. edge).
3. The IT security requirements to run the distributed, multilocation, and multiuser environments.
4. The need for platform interoperability. The system should be device diagnostic and be able to run on an assortment of devices.

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), 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

Metaverse/digital twin technologies are being used in industry to reduce risks/costs, improve operations/training/collaboration, support education/outreach, etc. The improvements provided in these areas would also provide value added to many NASA Programs/Directorates that include Aeronautics, Human Exploration, Science, Space Technology, Artemis, Gateway, etc.

References:

https://en.wikipedia.org/wiki/Metaverse

https://www.wired.com/story/what-is-the-metaverse/

https://www.accenture.com/us-en/services/metaverse-index?c=acn_glb_technologyvisiogoogle_12891735&n=psgs_0322&gclid=Cj0KCQjwxIOXBhCrARIsAL1QFCb0WjqL_qhe28IQZNH_uBWfUvXUN9mzsn52hrT242TdUx7l9WVjhE8aArN2EALw_wcB&gclsrc=aw.ds

Appendices

Appendix A: Technology Readiness Level (TRL) Descriptions

The Technology Readiness Level (TRL) describes the stage of maturity in the development process from observation of basic principles through final product operation. The exit criteria for each level document that principles, concepts, applications, or performance have been satisfactorily demonstrated in the appropriate environment required for that level. A relevant environment is a subset of the operational environment that is expected to have a dominant impact on operational performance. Thus, reduced gravity may be only one of the operational environments in which the technology must be demonstrated or validated 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	A medium fidelity system/component brassboard is built and operated to demonstrate	End-to-end software elements implemented and interfaced with existing systems/simulations conforming	Documented test performance demonstrating agreement with analytical

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

Definitions

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

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

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

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

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

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

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

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

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

Appendix B: STTR and the Technology Taxonomy

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

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

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

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

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

2020 TX Mapping Level 1	2020 TX Mapping Level 2	STTR Subtopic Number	Subtopic Title
TX06 - Human Health, Life Support, and Habitation Systems	TX06.2 - Extravehicular Activity Systems	T6.08	Textiles for Extreme Surface Environments and High Oxygen Atmospheres
TX07 - Exploration Destination Systems	TX07.1 - In-Situ Resource Utilization	T7.05	Climate Enhancing Resource Utilization
	TX07.2 - Mission Infrastructure, Sustainability, and Supportability	T7.04	Lunar Surface Site Preparation
TX08 - Sensors and Instruments	TX08.1 - Remote Sensing Instruments/Sensors	T8.07	Photonic Integrated Circuits
	TX08.X - Other Sensors and Instruments	T8.06	Quantum Sensing/Measurement and Communication
TX09 - Entry, Descent, and Landing	TX09.1 - Aeroassist and Atmospheric Entry	T9.02	Rapid Development of Advanced High-Speed Aerosciences Simulation Capability
TX10 - Autonomous Systems	TX10.1 - Situational and Self Awareness	T10.05	Integrated Data Uncertainty Management and Representation for Trustworthy and Trusted Autonomy in Space
TX11 - Software, Modeling, Simulation, and Information Processing	TX11.X - Other Software, Modeling, Simulation, and Information Processing	T11.05	Model-Based Enterprise
		T11.06	Extended Reality (Augmented Reality, Virtual Reality, Mixed Reality, and Hybrid Reality)
TX12 - Materials, Structures, Mechanical Systems, and Manufacturing	TX12.2 - Structures	T12.09	Carbon Fiber Reinforced Thermoplastic Composites for Repurposable Aerospace Applications
	TX12.4 - Manufacturing	T12.08	Manufacturing and Construction of Lunar Landing Pads Research
		T12.01	Additively Manufactured Electronics for Severe Volume Constrained Applications
TX13 - Ground, Test, and Surface Systems	TX13.1 - Infrastructure Optimization	T13.01	Intelligent Sensor Systems
TX 14 Thermal Management Systems	TX 14.1 Cryogenic Systems	T14.01	Advanced Concepts for Lunar and Martian Propellant Production, Storage, and Usage
TX15 - Flight Vehicle Systems	TX15.1 - Aerosciences	T15.04	Full-Scale (Passenger/Cargo) Electric Vertical Takeoff and Landing (eVTOL) Scaling, Propulsion, Aerodynamics, and Acoustics Investigations

Appendix C: Potential Transition and Infusion Opportunities

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

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

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

Commercial Lunar Payload Services (CLPS) - NASA is working with several American companies to deliver science and technology to the lunar surface through the CLPS initiative.

Flight Opportunities (Flight Opps) – This NASA program rapidly demonstrates promising technologies for space exploration, discovery, and the expansion of space commerce through suborbital testing with industry flight providers. The program matures capabilities needed for NASA missions and commercial applications while strategically investing in the growth of the U.S. commercial spaceflight industry. Offerors are encouraged to consult with the Flight Opportunities team and their resources for any technology development that benefits from microgravity testing.

International Space Station (ISS) - Conducting experiments on the International Space Station (ISS) is a unique opportunity to eliminate gravity as a variable, provide exposure to vacuum and radiation, and have a clear view of the Earth and space.

Below is a listing of all the STTR subtopics by focus area and a designation of potential transition and infusion opportunities available to each subtopic. Offerors should think of this as a starting point; however, offerors are encouraged to consider these opportunities and their resources for advancing technology development under any of the subtopics.

NASA is not placing any priority on subtopics or awards that fall under these specific opportunities, but rather this is to assist in future planning. Offerors that submit a proposal under a subtopic that is aligned with these opportunities do not increase their chance for an award.

Subtopic #	Subtopic Title	Climate	Moon to Mars	CLPS	Flight Opps	ISS
Focus Area 3 Autonomous Systems for Space Exploration						
T10.05	Integrated Data Uncertainty Management and Representation for Trustworthy and Trusted Autonomy in Space	Yes	Yes	Yes		Yes
Focus Area 4 Robotic Systems for Space Exploration						
T7.04	Lunar Surface Site Preparation		Yes	Yes	Yes	

Subtopic #	Subtopic Title	Climate	Moon to Mars	CLPS	Flight Opps	ISS
Focus Area 5 Communications and Navigation						
T5.04	Quantum Communications		Yes	Yes	Yes	Yes
Focus Area 6 Life Support and Habitation Systems						
T6.08	Textiles for Extreme Surface Environments and High Oxygen Atmospheres		Yes	Yes	Yes	Yes
Focus Area 8 In-Situ Resource Utilization						
T14.01	Advanced Concepts for Lunar and Martian Propellant Production, Storage, and Usage		Yes	Yes	Yes	Yes
T7.05	Climate Enhancing Resource Utilization	Yes	Yes			Yes
Focus Area 9 Sensors, Detectors, and Instruments						
T8.06	Quantum Sensing/Measurement and Communication		Yes	Yes	Yes	Yes
T8.07	Photonic Integrated Circuits		Yes	Yes	Yes	Yes
Focus Area 12 Entry, Descent, and Landing Systems						
T9.02	Rapid Development of Advanced High-Speed Aerosciences Simulation Capability		Yes	Yes	Yes	
Focus Area 15 Materials Research, Advanced Manufacturing, Structures, and Assembly						
T12.01	Additively Manufactured Electronics for Severe Volume Constrained Applications		Yes		Yes	Yes
T12.08	Manufacturing and Construction of Lunar Landing Pads Research		Yes		Yes	Yes
T12.09	Carbon Fiber Reinforced Thermoplastic Composites for Repurposable Aerospace Applications		Yes		Yes	Yes
Focus Area 16 Ground & Launch Processing						
T13.01	Intelligent Sensor Systems		Yes	Yes	Yes	Yes
Focus Area 18 Air Vehicle Technology						
T15.04	Full-Scale (Passenger/Cargo) Electric Vertical Takeoff and Landing (eVTOL) Scaling, Propulsion, Aerodynamics, and Acoustics Investigations	Yes				
Focus Area 23 Digital Transformation for Aerospace						
T11.05	Model-Based Enterprise		Yes			Yes
T11.06	Extended Reality (Augmented Reality, Virtual Reality, Mixed Reality, and Hybrid Reality)		Yes	Yes	Yes	Yes

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

Introduction

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

Below are 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