AMENDMENT OF SOLICITATION/MODIFICATION OF CONTRACT

1. CONTRACT ID CODE	PAGE 1 OF PAGES 3

2. AMENDMENT/MODIFICATION NUMBER	3. EFFECTIVE DATE	4. REQUISITION/PURCHASE REQUISITION NUMBER	5. PROJECT NUMBER *(If applicable)*
P00004	See Block 16C		

6. ISSUED BY CODE NSSC	7. ADMINISTERED BY *(If other than Item 6)* CODE NSSC
NASA/Shared Services Center (NSSC) Building 1111, Jerry Hlass Road Stennis Space Center MS 39529-0001	NASA/Shared Services Center (NSSC) Building 1111, Jerry Hlass Road Stennis Space Center MS 39529-0001

8. NAME AND ADDRESS OF CONTRACTOR *(Number, street, county, State and ZIP Code)*

CODE | FACILITY CODE

(X)	
☒	9A. AMENDMENT OF SOLICITATION NUMBER 80NSSCFY25STTRPI 9B. DATED *(SEE ITEM 11)* 01/08/2025
☐	10A. MODIFICATION OF CONTRACT/ORDER NUMBER 10B. DATED *(SEE ITEM 13)*

11. THIS ITEM ONLY APPLIES TO AMENDMENTS OF SOLICITATIONS

☒ The above numbered solicitation is amended as set forth in Item 14. The hour and date specified for receipt of Offers ☒ is extended. ☐ is not extended.

Offers must acknowledge receipt of this amendment prior to the hour and date specified in the solicitation or as amended, by one of the following methods:
(a) By completing items 8 and 15, and returning ____________ copies of the amendment; (b) By acknowledging receipt of this amendment on each copy of the offer submitted; or (c) By separate letter or electronic communication which includes a reference to the solicitation and amendment numbers. FAILURE OF YOUR ACKNOWLEDGMENT TO BE RECEIVED AT THE PLACE DESIGNATED FOR THE RECEIPT OF OFFERS PRIOR TO THE HOUR AND DATE SPECIFIED MAY RESULT IN REJECTION OF YOUR OFFER. If by virtue of this amendment you desire to change an offer already submitted, such change may be made by letter or electronic communication, provided each letter or electronic communication makes reference to the solicitation and this amendment, and is received prior to the opening hour and date specified.

12. ACCOUNTING AND APPROPRIATION DATA *(If required)*
See Schedule

13. THIS ITEM APPLIES ONLY TO MODIFICATIONS OF CONTRACTS/ORDERS. IT MODIFIES THE CONTRACT/ORDER NUMBER AS DESCRIBED IN ITEM 14.

CHECK ONE	
☐	A. THIS CHANGE ORDER IS ISSUED PURSUANT TO: *(Specify authority)* THE CHANGES SET FORTH IN ITEM 14 ARE MADE IN THE CONTRACT ORDER NUMBER IN ITEM 10A.
☐	B. THE ABOVE NUMBERED CONTRACT/ORDER IS MODIFIED TO REFLECT THE ADMINISTRATIVE CHANGES *(such as changes in paying office, appropriation data, etc.)* SET FORTH IN ITEM 14, PURSUANT TO THE AUTHORITY OF FAR 43.103(b).
☐	C. THIS SUPPLEMENTAL AGREEMENT IS ENTERED INTO PURSUANT TO AUTHORITY OF:
☐	D. OTHER *(Specify type of modification and authority)*

E. IMPORTANT: Contractor ☒ is not ☐ is required to sign this document and return __________ copies to the issuing office.

14. DESCRIPTION OF AMENDMENT/MODIFICATION (*Organized by UCF section headings, including solicitation/contract subject matter where feasible.)*

NASA has issued an amendment to the solicitation to change the requirement of the Offeror being registered under NAICS code 541713 or 541715 at time of proposal submission to at the time of contract award.
If your proposal has already been received, no action is required on your part.
There is no requirement to acknowledge this amendment.
The proposal period is hereby extended to 5:00 p.m. EDT., May 21, 2025.

Except as provided herein, all terms and conditions of the document referenced in Item 9A or 10A, as heretofore changed, remains unchanged and in full force and effect.

15A. NAME AND TITLE OF SIGNER *(Type or print)*		16A. NAME AND TITLE OF CONTRACTING OFFICER *(Type or print)*	
		Charles "Chris" Bridges, Contracting Officer	
15B. CONTRACTOR/OFFEROR *(Signature of person authorized to sign)*	15C. DATE SIGNED	16B. UNITED STATES OF AMERICA Charles Bridges Digitally signed by Charles Bridges Date: 2025.05.19 12:03:10 -05'00' *(Signature of Contracting Officer)*	16C. DATE SIGNED 5/19/2025

This Amendment makes the following changes to the solicitation:

Cover Page:

Proposal Package Due Date and Time changed,

From: March 10, 2025 – 5:00 p.m. ET

To: May 21, 2025 – 5:00 p.m. ET

Page 1:

In the section "Notable Changes in the 2025 Phase I solicitation:", the following bullet has been removed,

• Note that being registered under the NAICS code 541713 or 541715 as a small business is required at time of proposal submission, not proposal selection.

Page 2:

First paragraph, last sentence of Section 1.2 Purpose and Priorities has been changed,

From: You must submit completed proposal packages by Monday, March 10, 2025, 5:00 p.m. Eastern.

To: You must submit completed proposal packages by Wednesday, May 21, 2025, 5:00 p.m. Eastern.

Page 8:

Third paragraph, Section 1.12.1 Questions About This Solicitation and Means of Contacting NASA SBIR Program, has been changed,

From: The Help Desk will not guarantee a timely answer to questions received after March 3, 2025, at 5:00 p.m. ET.

To: The Help Desk will not guarantee a timely answer to questions received after May 20, 2025, at 5:00 p.m. ET.

Page 9:

Second paragraph of Section 2.2 System for Award Management (SAM) Registration, the following sentence has been changed,

From: To be eligible for SBIR awards, you must have an active SAM registration under North American Industry Classification System (NAICS) code 541713 or 541715 as a small business at the time of proposal submission.

To: To be eligible for SBIR awards, you must have an active SAM registration at time of proposal submission. You must be registered under North American Industry Classification System (NAICS) code 541713 or 541715 as a small business at the time of proposal award.

Page 26:

Section 5.1 Requirements for Negotiations, bullet numbered "2" has been changed,

From: Your SBC is registered with System for Award Management (SAM) under the required NAICS codes (section 2.2).

To: Your SBC is registered with System for Award Management (SAM) (section 2.2).

Page 31:

First paragraph, Section 6.1.2 Deadline for Phase 1 Proposal Package, has been changed:

From: NASA must receive your proposal package for Phase I no later than 5:00 p.m. ET on Monday, March 10, 2025, via the ProSAMS.

To: NASA must receive your proposal package for Phase I no later than 5:00 p.m. ET on Wednesday, May 21, 2025, via the ProSAMS.

Page 32:

Second Paragraph, Section 6.1.6, Service of Protests, Contracting Officer has been changed:

From: Kenneth Albright

To: Charles Bridges

Page 35:

Last bullet, Section 8.1 SBIR Phase I Checklist, is changed,

From: Confirm you received an acknowledgement of submission email before 5:00 p.m. ET on March 10, 2025 (section 6.1.4).

To: Confirm you received an acknowledgement of submission email before 5:00 p.m. ET on May 21, 2025 (section 6.1.4).

National Aeronautics and Space Administration

Small Business

Technology Transfer (STTR)

Phase I

Fiscal Year 2025 Solicitation

Proposal Package Due Date and Time:
May 21, 2025 - 5:00 p.m. ET

Contents

Executive Summary

This solicitation sets the requirements for you, the offeror, to submit a proposal to NASA for Small Business Technology Transfer (STTR) Program Phase I projects in fiscal year (FY) 2025. Chapters 1-8 contain the objectives, deadlines, funding information, eligibility criteria, and instructions to submit a proposal package**.** Chapter 9 contains research and technology topics, categorized by Mission Directorate and subtopics.

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

The NASA STTR program focuses on the following:

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

Important considerations:

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

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

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

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

Notable changes in the 2025 SBIR Phase I solicitation:

- The maximum number of submissions to the 2025 STTR Phase I solicitation per firm was reduced from 10 to 5 (see section 3.2)
- The length of the technical proposal was reduced from 19 pages to 15 pages, and the requirement for a table of contents was removed (see section 3.1.2)
- The technical evaluation criteria and scoring and weighting have changed (see sections 4.1.3, 4.2, and Appendix A)

1. Program Description

1.1 Legislative Authority and Background

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

The Small Business Administration (SBA) provides policy through the combined Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs. The SBIR and STTR Extension Act of 2022 amended the Small Business Act *(15 U.S.C. 638*) to extend the SBIR and STTR programs until September 30, 2025.

1.1.1 Due Diligence Program to Assess Security Risks

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

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

1.2 Purpose and Priorities

This solicitation sets the requirements for you, the offeror, in collaboration with a research institution (RI) to submit a proposal to NASA Small Business Technology Transfer (STTR) Program Phase I projects in fiscal year (FY) 2025. **NASA will release its FY 2025 Phase I STTR solicitation on January 7, 2025. You must submit completed proposal packages by Wednesday, May 21, 2025, 5:00 p.m. Eastern Time.**

The Space Technology Mission Directorate (STMD) directs implementation of the NASA SBIR and STTR programs. The NASA SBIR/STTR Program Management Office (PMO), hosted at the NASA Ames Research Center, operates the programs together with NASA mission directorates and centers. The NASA Shared Services Center (NSSC) manages SBIR and STTR procurements.

Each year NASA’s Center Chief Technologists (CCTs) identify the research problems and technology needs that the STTR program will solitict. The range of problems and technologies is broad, and the list of research subtopics varies in content from year to year to maintain alignment with current interests.

For details on the research subtopic descriptions by Technology Taxonomy, see chapter 9.

1.3 Three-Phase Program

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

Phase I

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

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

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

Phase II

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

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

Post-Phase II Opportunities for Continued Technology Development

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

Phase III

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

1.4 Availability of Funds

NASA does not commit to fund any proposal or to make a specific number of awards. NASA may elect to make several or no awards in any specific research subtopic. NASA will determine the number of awards based on the level of appropriated funding provided to the program in FY 2025.

NASA will not accept more than five (5) proposal packages from any one offeror. NASA does not plan to award more than two (2) STTR contracts to any offeror. See sections 3.1 and chapter 4.

1.5 Eligibility Requirements

1.5.1 Small Business Concern (SBC)

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

1.5.2 SBC Size

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

1.5.3 STTR Restrictions on Level of Small Business Participation

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

1.5.4 Place of Performance and American-made Products and Equipment

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

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

If a foreign vendor is proposed, the Phase I contract may be delayed or not awarded.

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

1.5.5 Principal Investigator (PI) Employment Requirement

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

1.5.6 Restrictions on Venture-Capital-Owned Businesses
Small businesses owned in majority part by multiple venture capital operating companies, hedge funds, or private equity firms are not eligible to submit a proposal to this solicitation.

1.5.7 Joint Ventures and Limited Partnerships
Both joint ventures and limited partnerships are permitted, provided the entity created qualifies as an SBC as defined in 1.5.1. Include in the proposal package a copy or summary of the joint venture or partnership agreement that includes, at a minimum, a statement of how the workload will be distributed, managed, and charged. See definitions for Joint Ventures along with examples at 13 CFR 121.103(h).

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

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

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

NASA provides these technologies "as is" and makes no representation or guarantee that additional effort will result in infusion or commercial viability. Whether or not an offeror proposes the use of a NASA patent or computer software within its proposed effort will not in any way be a factor in the selection for award.

1.6.1 Use of NASA Software
If you intend to use NASA software, a Software Usage Agreement (SUA), on a nonexclusive, royalty-free basis, is necessary, and the clause at 48 C.F.R. 1852.227-88, Government-Furnished Computer Software and Related Technical Data, will apply to the contract. Awardees will request the SUA from the appropriate NASA Center Software Release Authority (SRA) after contract award.

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

Inventor Knowledge Transfer
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 with this request; however, 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 also be required to reimburse NASA for knowledge transfer activities. **Preparation of the agreements for knowledge transfer may require a significant amount of time to complete; therefore, NASA does not recommend pursuing inventor access for Phase I projects.**

1.7 I-Corps™

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

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

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

1.8 Technical and Business Assistance (TABA)

Under the Small Business Act, you may request a Technical and Business Assistance (TABA) supplement up to $6,500 above the award amount of the Phase I contract. At Phase II, you may request a TABA supplement up to $50,000. For more information on this opportunity, see https://legacy.www.sbir.gov/node/2088581.

If your project is selected for award and the TABA supplement is approved, you must use the TABA supplement to contract with one or more vendors to assist in:

- Making better technical decisions concerning this SBIR project
- Solving technical problems that arise during the conduct of this SBIR project
- Minimizing technical risks associated with this SBIR project
- Developing and commercializing new products and processes resulting from your SBIR project
- Business-related services aimed at improving commercialization success

TABA can be used for:

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

For additional approved and restricted uses of TABA funding, see https://www.nasa.gov/sbir_sttr/taba/.

TABA vendors may include private commercialization assistance or business development service providers, public-private partnerships, other entrepreneurial support organizations (ESOs), and attorneys or other IP or licensing professionals. TABA funds may not be used to fund activities conducted internally by the small business awardee. NASA does not guarantee approval of requests for a TABA supplement. Awardees who receive a TABA supplement must deliver a description of services obtained and results at the completion of their Phase I contract.

For information on requesting a TABA supplement at Phase I, please see section 3.1.3.8.

1.9 Small Business Administration (SBA) Applicant Resources

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

1.10 Fraud, Waste and Abuse and False Statements

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

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

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

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

NASA OIG Cyber Hotline: https://oigforms.nasa.gov/wp_cyberhotline.html

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

1.11 NASA Procurement Ombudsman Program

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

The cognizant ombudsman is:

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

In accordance with NFS 1852.215-84, the ombudsman does not participate in any way with the evaluation of proposal packages, the source selection process, or the adjudication of formal contract disputes. Therefore, before consulting with the ombudsman, you must first address your concerns, issues, disagreements, and/or recommendations to the Contracting Officer for resolution. The process set forth in this solicitation provision (and described at NFS 1852.215-84) does not change your right to file a bid protest or the period in which to timely file a protest.

1.12 General Information

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

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

If you have questions requesting clarification of proposal package instructions and administrative matters, refer to the NASA SBIR/STTR website or contact the NASA SBIR/STTR Helpdesk.

The Help Desk will not guarantee a timely answer to questions received after May 20, 2025, at 5:00 p.m. ET.

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

1.13 Definitions

NASA strongly encourages you to review the list of definitions available at https://www.nasa.gov/sbir_sttr/program-definitions/. These definitions include those from the combined SBIR/STTR Policy Directives as well as terms specific to NASA.

2. Registrations, Certifications, and Other Information

2.1 Small Business Administration (SBA) Company Registry

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

2.2 System for Award Management (SAM) Registration

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

Per FAR 4.1102(a) "Offerors and quoters are required to be registered in SAM at the time an offer or quotation is submitted in order to comply with the annual representations and certifications..." To be eligible for SBIR awards, you must have an active SAM registration at time of proposal submission. You must be registered under North American Industry Classification System (NAICS) 541713 or 541715 as a small business at the time of contract award. Note that SAM registration must remain active through entire process from proposal submission to contract performance.

If you are not registered, apply for registration immediately upon receipt of this solicitation. Typically, SAM registration and updates to SAM registration take several weeks. In order to receive an SBIR/STTR award from NASA, purpose of registration must be listed as "All Awards" on your SAM Registration.

Note that your SAM registration Doing Business As (DBA) name will appear on all contract documents.

2.3 Certifications

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

NASA uses a similar certification to ensure continued compliance with specific program requirements at time of award and at the time of final payment. The definitions for the terms used in this certification are set forth in the Small Business Act, SBA regulations (13 CFR Part 121), the SBIR/STTR Policy Directives, and any statutory and regulatory provisions referenced in those authorities.

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

If the Contracting Officer believes that you may not meet certain eligibility requirements for award, they may request you provide clarification or additional supporting documentation. If the Contracting Officer still believes you are not eligible, you must file a size protest with the SBA, who will determine eligibility.

2.3.1 Disclosures of Foreign Affiliation or Relationships to Foreign Countries

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

The disclosures require the following information:

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

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

During award, you must regularly report to NASA as stated in your contract any changes to a required disclosure.

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

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

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

2.5 Software Development Standards

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

2.6 Human and/or Animal Subject

NASA requires a protocol approved by a NASA review board if proposed work includes human or animal subjects. **Due to the complexity of the approval process, NASA does not allow use of human and/or animal subjects for Phase I projects.** Reference 14 CFR 1230 and 1232.

2.7 Flight Safety Standards

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

2.8 Commercial Air Service and NASA Airworthiness Requirements

Any desired flight elements or flight activities under the SBIR program are subject to Commercial Air Service (CAS) and NASA Airworthiness reviews, per AFOP-7900.3-027, AFOP-7900.3D-023 and NPR 7900.3. These review requirements may preclude SBIR Phase-1 flight activities due to their short contractual period, combined with ongoing NASA flight project reviews and staffing availability.

2.8 Homeland Security Presidential Directive 12

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

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

3. Proposal Preparation Instructions and Requirements

3.1 Requirements to Submit a Phase I Proposal Package

3.1.1 General Requirements

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

Proposal packages contain a Technical Proposal as described in section 3.1.3.5 below. A Technical Proposal must clearly and concisely:

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

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

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

3.1.2 Format Requirements

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

Required Page Limits and Suggested Page Lengths
A Phase I technical proposal—all 9 parts including all graphics—must not exceed a total of 15 standard letter size (8.5- by 11-inch or 21.6- by 27.9-cm) pages.

NASA will not accept technical proposal uploads with any page(s) over the 15-page limit. The additional forms required for proposal package submission do not count against the 15-page limit.

As a guideline to help you address each part of the technical proposal within the 15-page limit, NASA suggests a page length for each of the 9 parts.

Technical Proposal Part	Suggested Number of Pages
Part 1: Identification and Significance of Innovation	3.5 pages
Part 2: Technical Objectives	1 page
Part 3: Work Plan	3 pages
Part 4: Related R/R&D	1 page
Part 5: Key Personnel and Bibliography of Directly Related Work	2.5 pages

Part 6: The Market Opportunity	1 page
Part 7: Facilities/Equipment	1 page
Part 8: Subcontractors and Consultants	1 page
Part 9: Related, Essentially Equivalent, and Duplicate Proposals and Award	1 page

Margins
Use 1.0-inch (2.5 cm) margins.

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

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

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

3.1.3 Proposal Package

Each proposal package must contain the following items:
1. Proposal Contact Information
2. Proposal Certifications, electronically endorsed
3. Proposal Summary (must not contain proprietary data)
4. Proposal Budget (including letters of commitment for government resources, subcontractors/consultants, and Foreign Vendor Form, if applicable)
5. Technical Proposal
6. Briefing Chart (must not contain proprietary data)
7. NASA Evaluation License Application, only if NASA Technology Available (TAV) is being proposed
8. Technical and Business Assistance (TABA) request (optional)
9. I-Corps Interest Form
10. SBC-Level Forms (completed once for all proposals submitted to a single solicitation)
    a. Firm Information
    b. Firm Certifications
    c. Audit Information
    d. Disclosures of Foreign Affiliations or Relationships to Foreign Countries Audit Information
    e. Prior Awards Addendum
    f. Commercial Metrics Report (CMR)
11. Electronic Endorsement by the designated small business representative and principal investigator (PI), is completed before the deadline

For many of the required forms, offerors can view sample forms located in the NASA SBIR/STTR Resources website: https://www.nasa.gov/sbir_sttr/firms_library/.

What Not to Include
NASA will not consider the following items during evaluation:
- Letters of interest, support, or funding commitment
- Technical papers

- Product samples
- Videos
- Slides
- PowerPoint slide decks
- Other ancillary items

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

3.1.3.1 Proposal Contact Information Form

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

3.1.3.2 Proposal Certifications Form

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

3.1.3.3 Proposal Summary Form

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

3.1.3.4 Proposal Budget Form

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

Note that if the Principal Investigator is working less hours than other proposed direct labor elements or if there are individuals listed as direct labor that are not employees of your firm, it shall be explained in your proposal.

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

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

- **Justification for submitted rates. Submit one of the following to justify the submitted rates for your proposal:**
    1. Approved rate agreement or provisional rate agreement with DCAA
    2. Mathematical cost basis of estimate on how rates were developed
       (You can use your own template, or you can utilize the DCAA ICE Template found at https://www.dcaa.mil/Checklists-Tools/ICE-Model/
- **Use of a Foreign Vendor.** If you are requesting to purchase products and equipment from a foreign vendor, you must complete the Foreign Vendor Form (see section 1.5.4 for more information).
- **Use of Government Resources.** If you plan to use government resources (such as, services, equipment, facilities, laboratories, etc.), as described in Part 7 of the technical proposal instructions, you must provide the following:
    1. Statement, signed by the appropriate Federal department or agency official, verifying that the resources are available during the proposed period of performance, authorizing their use, and if applicable, including the associated cost.
    2. Signed letter on your company letterhead explaining why your STTR research project requires the use of government resources. Include data that verifies the absence of non-federal facilities or

personnel capable of supporting the research effort, and, if applicable, the associated cost estimate.

Due to the complexity and length of time for the approval process, NASA strongly discourages you from requesting the use of government resources during the performance of a Phase I. Approval for the use of government resources for a Phase I technical proposal requires a strong justification at the time of submission and will require approval by the Contracting Officer during negotiations if selected for award.

- **Use of Subcontractors and Consultants.** You may establish business arrangements with other entities or individuals to perform some of the proposed R/R&D effort, within the limits in section 1.5.3 and below. Subcontractors' and consultants' work must also be performed in the United States (see section 1.5.4 for more information).

If you propose using subcontractors or consultants, submit the following with your proposal:

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

Failure to submit this documentation could lead to delays in the processing/negotiation of your contract and could ultimately result in proposal selection being withdrawn by NASA and no contract awarded to your firm.

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

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

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

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

Example:	In this example it’s assumed the subcontractor cost is $29,500	
	G&A	5%
	G&A on subcontractor cost	$29,500 x 5% = $1,475
	Subcontractor cost plus G&A	$29,500 + $1,475 = $30,975
	Percentage of subcontracting effort*	**$30,975/$150,000 = 20.7%**
	***Subcontractor cost plus G&A/Total price less profit**	

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

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

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

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

3.1.3.5 Technical Proposal

The technical proposal must contain all 9 parts in order, number, and title as listed below. NASA will decline any proposal package that does not have all 9 parts and it will not be evaluated. If a part is not applicable to your proposed effort, you must include the part and mark it "Not applicable." Do not include any budget data in the technical proposal.

Part 1: Identification and Significance of the Proposed Innovation (Suggested page limit – 3.5 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 2: 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.

Address any technical risks and potential mitigations. Use data to support your claims and provide references as appropriate.

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

Part 3: Work Plan (Suggested page limit – 3 pages)
Include a detailed plan to meet the Phase I technical objectives. The plan must include:

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

Part 4: Related R/R&D (Suggested page limit – 1 page)
Describe significant existing R/R&D that is directly related to the technical proposal including any conducted by the PI or by the company. Describe how it relates to the proposed effort and any planned coordination with outside sources. You must demonstrate awareness of key recent R/R&D conducted by others in the specific subject area. Include any pertinent references or publications.

Part 5: Key Personnel and Bibliography of Directly Related Work (Suggested page limit – 2.5 pages)
Identify all personnel involved in Phase I activities whose expertise and functions are essential to the success of the project. Provide biographical information, including directly related education and experience. Where the resume/vitae are extensive, you may summarize the most relevant experience or publications. If any team ability gaps exist, provide any plans to address those gaps if possible.

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

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

Part 6: The Market Opportunity (Suggested page limit – 1 page)
Describe the potential commercialization approach for the innovation by addressing the following:

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

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

Part 7: Facilities/Equipment (Suggested page limit – 1 page)
Describe the types, location, and availability of equipment necessary to carry out the work proposed. You must justify any proposed equipment purchase. **When purchasing equipment or a product under the STTR contract, you should purchase only American-made products or equipment.**

Although use of government-furnished laboratory equipment, facilities, or services (collectively, "government resources") is strongly discouraged in Phase I proposals, describe in this part why the use of such government resources is necessary and not reasonably available from the private sector if applicable. See sections 3.1.3.4 and 5.13 for additional requirements when proposing use of such government resources. The narrative description of resources should support the proposed approach and documentation in the Proposal Budget form.

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

Part 8: Subcontractors and Consultants (Suggested page limit – 1 page)
Describe all subcontracting or other business arrangements, including who they are with and for what expertise, functions, services, and number of hours. You must ensure that all organizations and individuals are available for the time periods proposed. The narrative description of subcontractors and consultants in the technical proposal should support the proposed approach and documentation in the Proposal Budget form, section 3.1.3.4 . **If partnering beyond your research institution partner is not required to successfully mature your technology, please explain why.**

Part 9: Related, Essentially Equivalent, and Duplicate Proposals and Awards (Suggested page limit – 1 page)
WARNING: It is illegal to enter into multiple funding agreements for essentially equivalent work. While you may submit similar or identical proposals to multiple solicitations, it is risky. You must notify the agencies in advance and resolve the matter prior to award.

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

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

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

3.1.3.6 Briefing Chart

The 1-page briefing chart is required and will be used by evaluators to assist in the ranking of technical proposals prior to selection. Summarize the following on the provided electronic form:

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

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

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

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

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

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

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

TABA requests must be made within the Proposal Budget form in ProSAMS. You must provide a quote that includes the following from each vendor on their letterhead:

- Contact information of the vendor (name, address, phone number, email address, and website)
- Description of vendor(s) expertise and knowledge of providing the desired TABA services
- Itemized list of services and associated cost for each service the TABA vendor will provide. This includes the number of hours and hourly cost for each service, when appropriate.
- Description of the deliverable(s) the TABA vendor will provide for each service summarizing the outcome of the TABA services.

All TABA vendors must be legal businesses in the United States. NASA will consider TABA requests that are missing any requested TABA information as incomplete and will not review the TABA request or provide TABA approval under the award.

The TABA supplement is in addition to the Phase I contract award value, is not subject to any profit or fee by the requesting offeror and cannot be used in the calculation of indirect cost rates or general and administrative expenses (G&A). The TABA cost(s) and service(s) to be provided by each vendor will be based on the original Phase I period of performance. NASA will not consider requests for TABA funding outside of the Phase I period of performance or after a proposal package submission.

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

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

3.1.3.9 I-Corps Interest Form

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

Based on the initial level of interest in the I-Corps program, NASA plans to open the opportunity to all Phase I awardees to ensure a successful cohort of teams participate in the program. Phase I awardees will receive a Call for I-Corps Proposal from the STTR PMO during contract negotiations describing the process to provide a 5-page proposal to participate in the I-Corps program. NASA will provide directions for completing the proposal including due dates, training dates, and available funding by email. NASA reserves the right to limit the number of offerors to participate in the I-Corps program based on the assessment of the I-Corps proposals and funding availability.

3.1.3.10 SBC Level Forms

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

A. Firm Information

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

B. Firm Certifications

You must complete the Firm Certifications section of by answering “Yes” or “No” as applicable. An example of the certifications can be found in the NASA SBIR/STTR Resources website: https://www.nasa.gov/sbir_sttr/firms_library.

C. Audit Information

Although you are not required to have an approved accounting system, it is easier for NASA to determine that your rates are fair and reasonable if you have an approved accounting system. To assist NASA, you must complete the questions in the Audit Information form regarding your rates and upload the Federal agency audit report or related information that is available from the last audit. There is a separate Audit Information section in the Proposal Budget form that you must also complete. If you have never been audited by a federal agency, then answer “No” to the first question, and you do not need to complete the remainder of the form. An electronic form will be provided during the submissions process. The Contracting Officer uses this Audit Information to assist with negotiations if the proposal package is selected for award. The Contracting Officer will advise you what is required to determine reasonable cost and/or rates in the event the Audit Information is not adequate. Please refer to section 3.1.3.4 regarding what information can be submitted to justify proposed rates.

D. Disclosures of Foreign Affiliations or Relationships to Foreign Countries

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

E. Prior Awards Addendum

If you have received more than 15 Phase II awards in the prior 5 fiscal years, submit the name of the awarding agency, solicitation year, phase, date of award, funding agreement/contract number, and subtopic title for each Phase II. If you have received any SBIR or STTR Phase II awards, even if fewer than 15 in the last 5 years, NASA still recommends that you complete this form as the information will be useful to you when completing the Commercialization Metrics Report (CMR).

F. Commercialization Metrics Report (CMR)

NASA uses a commercialization report /data-gathering process to track the overall commercialization success of its SBIR and STTR programs. You must complete the Commercialization Metrics Report or update an existing report if applicable, via https://www.sbir.gov/ (the report is available in the “My Dashboard” section of your company’s sbir.gov profile) as part of the proposal package submissions process. Companies with no SBIR/STTR awards or awards within the last 3 to 5 years will not be penalized under past performance for the lack of past SBIR/STTR commercialization.

If you have received any Phase III awards resulting from work on any NASA SBIR or STTR awards, provide the related Phase I or Phase II contract number, name of Phase III awarding agency, date of award, Funding Agreement number, amount, project title, and period of performance. The report will also ask you to provide financial, sales, and ownership information, as well as any commercialization success you have had because of SBIR or STTR awards. You must update this information annually during proposal package submission via ProSAMS

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

3.2 Multiple Proposal Submissions

Each proposal must be based on a unique innovation, limited in scope to just one subtopic, and submitted only under that one subtopic within each program. **You may not submit more than 5 proposals to the STTR program**. You may submit more than one unique proposal to the same subtopic; however, you must not submit the same (or substantially equivalent) proposal to more than one subtopic. If you submit substantially equivalent proposals to several subtopics, NASA may decline all such proposals.

3.3 Understanding the Patent Landscape

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

3.4 Proprietary Information in the Proposal Submission

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

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

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

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

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

3.5 Release of Certain Proposal Information

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

4. Method of Selection and Evaluation Criteria

4.1 Phase I Process and Evaluation Criteria

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

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

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

4.1.1 Administrative Review

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

4.1.2 Technical Responsiveness

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

4.1.3 Technical Evaluation Criteria

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

- NASA Benefits
  - The value and benefits of the technology and how the technology addresses NASA’s needs
  - Alignment of the technology to the subtopic’s priorities
  - Expected impact of the technology on the subtopic need
- Technical Risk
  - Technical feasibility of the technology with respect to scientific and/or engineering principles
  - Technical risks and mitigation plans
  - Quality of the data used to support your technical claims
- SBIR Project Plan
  - Comprehensiveness of the work plan including the timeline, milestones, and deliverables
  - Feasibility of achieving the proposed schedule given the available resources and labor

- Team Ability
  Qualifications of the proposed principal investigator/project manager, supporting staff and consultants and subcontractors, if any. Alignment of qualifications and experience to the research effort and personnel's degree of commitment and availability.
- Advancing the State of the Art
  How your technology improves on the state of the art
- Commercial Potential
  - Differentiation in the commercial market (your competitive edge)
  - Qualifications and/or experience of the business personnel
- Submission Quality
  Indication that care was taken to prepare the proposal including clean appearance, content free of typographical errors that could impact understanding, and clear presentation of concepts

For more details about these criteria, please refer to Appendix A where the evaluation criteria, weighting, and definitions are provided. Please review the rubric to ensure your submission addresses all areas being evaluated.

4.1.4 Price Evaluation

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

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

4.2 Scoring and Weighting to Determine the Most Highly Rated Proposals

NASA will score each criterion numerically. Numerical scores are then weighted and summed to reach the proposal rating. The most highly rated proposals are eligible for prioritization.

Evaluation Criterion	Weight
NASA Benefits	30%
Technical Risk	20%
SBIR Project Plan	15%
Team Ability	15%
Advancing the State of the Art	10%
Commercial Potential	5%
Submission Quality	5%

4.3 Prioritization

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

4.4 Selection

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

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

4.5 I-Corps Evaluation Process

For awardees that submit an I-Corps proposal pursuant to sections 1.7 and 3.1.3.9, NASA will provide a programmatic assessment based on the following criteria:

- Proposed team members demonstrate a commitment to the requirements of the I-Corps program.
- The proposed team includes the proper composition and roles as described in the I-Corps proposal requirements.
- The I-Corps proposal demonstrates that there is potential for commercialization in both NASA and commercial markets.

Based on the assessment of the above criteria the NASA SBIR/STTR PMO will provide a recommendation to the SSO of I-Corps proposals to receive funding. The SSO will make the final selections. NASA anticipates selecting approximately 4 STTR SBCs for participation in the I-Corps program for Phase I.

4.6 Technical and Business Assistance (TABA)

NASA conducts a separate review of all Phase I requests for TABA after the SSO makes the final selection of projects to enter negotiation for a Phase I contract. The SBIR/STTR PMO conducts the evaluation of the TABA request and informs the Contracting Officer of the final determination to allow TABA funding under the contract. NASA will notify you of the approval or denial of TABA funding prior to TABA award.

During this review, NASA will consider:

- If request meets the requirements found in section 3.1.3.8.

4.7. Access to Proprietary Data by Non-NASA Personnel

4.7.1 Non-NASA Reviewers

In addition to utilizing government personnel in the review process, NASA, at its discretion and in accordance with 1815.207-71 of the NASA FAR Supplement, may utilize individuals from outside the government with highly specialized expertise not found in the government. Qualified experts outside of NASA (including industry, academia, and other government agencies) may assist in performing evaluations as required to determine or verify the merit of a proposal package. In deciding to obtain an outside evaluation, NASA will take into consideration requirements for the avoidance of organizational or personal conflicts of interest and any competitive relationship between the prospective contractor or subcontractor(s) and the prospective outside evaluator. Outside evaluators will certify that the information (data) contained in the proposal package is for evaluation purposes and will not be further disclosed.

4.7.2 Non-NASA Access to Confidential Business Information

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

4.8 Notification and Feedback to Offerors

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

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

4.8.1 Phase I Feedback

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

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

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

5. Considerations

5.1 Requirements for Negotiations

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

1. All information in your proposal package is current (e.g., your address has not changed, the proposed PI is the same, etc.). If changes have occurred since submittal of your proposal package, notify the Contracting Officer immediately.
2. Your SBC is registered with System for Award Management (SAM) (section 2.2).
3. Your SBC complies with the FAR 52.222-37 Employment Reports on Special Disabled Veterans, Veterans of the Vietnam Era, and Other Eligible Veterans (VETS-4212) requirement (See Appendix D).
4. Your SBC HAS NOT proposed a co-principal investigator.
5. Your SBC will provide timely responses to all communications from the NSSC Contracting Officer. **Failure to respond in a timely manner to the NSSC Contracting Officer may result in your firm's selection being cancelled and no contract award.**
6. Proposed costs are supported with documentation, such as a quote, previous purchase order, published price lists, etc.

Failure to submit this documentation could lead to delays in the processing/negotiation of your contract and could ultimately result in proposal selection being withdrawn by NASA and no contract awarded to your firm.

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

5.1.1 Requirements for Contracting

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

(1) Standards of Work. Work performed under the contract must conform to high professional standards.
(2) Inspection. Work performed under the contract is subject to government inspection and evaluation at all times.
(3) Examination of Records. The Comptroller General (or a duly authorized representative) must have the right to examine any pertinent records of the Awardee involving transactions related to this contract.
(4) Default. The Federal Government may terminate the contract if the contractor fails to perform the work contracted.
(5) Termination for Convenience. The contract may be terminated at any time by the Federal Government if it deems termination to be in its best interest, in which case the Awardee will be compensated for work performed and for reasonable termination costs.
(6) Disputes. Any dispute concerning the contract that cannot be resolved by agreement must be decided by the Contracting Officer with right of appeal.
(7) Contract Work Hours. The Awardee may not require an employee to work more than 8 hours a day or 40 hours a week unless the employee is compensated accordingly (for example, overtime pay).
(8) Equal Opportunity. The Awardee will not discriminate against any employee or applicant for employment because of race, color, religion, sex, or national origin.
(9) Equal Opportunity for Veterans. The Awardee will not discriminate against any employee or application for employment because he or she is a disabled veteran or veteran of the Vietnam era.
(10) Equal Opportunity for People with Disabilities. The Awardee will not discriminate against any employee or applicant for employment because he or she is physically or intellectually disabled.

(11) Officials Not to Benefit. No Federal Government official may benefit personally from the SBIR/STTR contract.
(12) Covenant Against Contingent Fees. No person or agency has been employed to solicit or secure the contract upon an understanding for compensation except bona fide employees or commercial agencies maintained by the Awardee for the purpose of securing business.
(13) Gratuities. The contract may be terminated by the Federal Government if any gratuities have been offered to any representative of the government to secure the award.
(14) Patent Infringement. The Awardee must report each notice or claim of patent infringement based on the performance of the contract.
(15) American Made Equipment and Products. When purchasing equipment or a product under the SBIR/STTR contract, purchase only American-made items whenever possible.

5.1.2 Research Agreement

The Research Agreement (different from the Allocation of Rights Agreement; see definitions section 1.13) is a single-page document electronically submitted and endorsed by the SBC and RI. A model agreement is available at https://www.nasa.gov/sbir_sttr/firms_library/, or firms can create their own custom agreement. The Research Agreement shall be submitted during contract negotiation. All STTR Phase I proposals must provide sufficient information to convince NASA that the proposed SBC/RI cooperative effort represents a sound approach for converting technical information resident at the RI into a product or service that meets a need described in a solicitation research subtopic.

5.2 Awards

5.2.1 Anticipated number of Awards

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

Year	Number of STTR Phase I Proposals Evaluated	Number of STTR Phase I Selections	Percentage of STTR Phase I Selections
2024	208	51	24.5%
2023	126	50	39.6%
2022	131	53	40.4%

5.2.2 Award Conditions

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

- SF26—Contract Cover Sheet
- Contract Terms and Conditions—to include reference to the proposal package and budget
- Attachment 1: Contract Distribution List
- Attachment 2: Template of the Final Summary Chart
- Attachment 3: IT Security Management Plan Template
- Attachment 4: Applicable Documents List
- Confirmation of Negotiation
- Phase I Frequently Asked Questions (FAQs)

5.2.3 Type of Contract

NASA STTR Phase I awards are firm fixed price contracts.

5.2.4 Model Contracts

Examples of the NASA STTR contracts can be found in the NASA SBIR/STTR Resources website: https://www.nasa.gov/sbir_sttr/firms_library. 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: https://www.nasa.gov/sbir_sttr/firms_library. For more information, see NASA FAR Supplement clause 1852.204-76.

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

You must provide to NASA all technical reports and other deliverables required by the contract. These reports must document progress made on the project and activities required for completion. Periodic certification for payment is required as stated in the contract. You must submit a final report to NASA upon completion of the Phase I R/R&D effort in accordance with applicable contract provisions.

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

If you receive the TABA supplement, your Phase I contract requires TABA deliverables that summarize the outcome of the TABA services. NASA bases reimbursement for TABA on delivery of a TABA final report at the end of the contract period of performance.

5.4 Payment Schedule

The exact payment terms are included in the contract. Invoices are submitted electronically through the Department of Treasury's Invoice Processing Platform (IPP).

If you are approved to receive the TABA supplement under a Phase I award, you will submit an invoice for TABA reimbursement at the end of the contract period of performance. You must submit TABA reimbursement per the payment and deliverable report schedule in your contract. NASA will not reimburse any amounts incurred over the TABA funding amount in your contract. Reimbursement must only be for actual services the TABA vendor(s) provided to the SBC during the period of performance of the contract. NASA will not reimburse any amounts of services that were not received by the SBC during the Phase I contract period of performance.

5.5 Profit or Fee

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

5.6 Cost Sharing

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

5.7 Rights in Data Developed Under SBIR Funding Agreements
The STTR program provides specific rights for data developed under 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 must provide New Technology Reports (NTR) for any new subject inventions, and the New Technology Summary Reports (NTSR) for the interim and final contract periods. Please review SBA SBIR/STTR Policy Directive provided in section 1.1.1 to understand these requirements.

5.10 Government-Furnished and Contractor-Acquired Property
In accordance with the SBIR/STTR Policy Directive, the Federal Government may transfer title to property provided by the SBIR/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
Awardees must certify with every invoice that they have not previously been paid nor are currently being paid for essentially equivalent work by any agency of the Federal Government. **Failure to report essentially equivalent or duplicate efforts can lead to the termination of contracts and/or civil or criminal penalties.**

5.12 Additional Information

5.12.1 Precedence of Contract Over this Solicitation

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

5.12.2 Evidence of Contractor Responsibility

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

5.13 Use of Government Resources
Federal Departments and Agencies
Use of STTR funding for unique federal/non-NASA resources from a federal department or agency that does not meet the definition of a federal laboratory as defined by U.S. law and in the SBA Policy Directive on the STTR program requires a waiver from the SBA. Proposal packages requiring waivers must include an explanation of why the waiver is appropriate. NASA will provide your request, along with an explanation to SBA, during the negotiation process. NASA cannot guarantee that a waiver can be obtained from SBA. Specific instructions to request use of government resources are in sections 3.1.3.4 of the solicitation. **NASA facilities qualify as federal laboratories.**

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

For proposed use of NASA resources, a NASA SBIR/STTR Support Agreement template is available in the Resources website (https://www.nasa.gov/sbir_sttr/firms_library) and must be executed before a contractor can use NASA resources. NASA expects selected offerors to finalize and execute their NASA SBIR Support Agreement during the negotiation period with the NSSC.

Contractor Responsibilities for Costs
In accordance with FAR Part 45, it is NASA's policy not to provide services, equipment, or facilities (resources) for the performance of work under SBIR contracts. Generally, any contractor will furnish its own resources to perform the proposed work on the contract.

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

5.14 Agency Recovery Authority and Ongoing Reporting

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

1) require a small business concern receiving an award under its STTR program to repay all amounts received from the Federal agency under the award if—
   (A) the small business concern makes a material misstatement that the Federal agency determines poses a risk to national security; or
   (B) there is a change in ownership, change to entity structure, or other substantial change in circumstances of the small business concern that the Federal agency determines poses a risk to national security; and
2) require a small business concern receiving an award under its SBIR program to regularly report to the Federal agency and the SBA throughout the duration of the award on—
   (A) any change to a disclosure required under subparagraphs (A) through (G) of section 2.3.1 above.
   (B) any material misstatement made under section 5.14 paragraph (A) above; and
   (C) any change described in section 5.14 paragraph (B) above.

6. Submission of Proposals

6.1 How to Apply for STTR Phase I

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

To apply for a NASA STTR Phase I contract, you must follow the steps found below.

6.1.1 Electronic Submission Requirements via the ProSAMS

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

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

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

6.1.2 Deadline for Phase I Proposal Package

NASA must receive your proposal package for Phase I no later than 5:00 p.m. ET on Wednesday, May 21, 2025, via ProSAMS.

You are responsible for ensuring that all files constituting the proposal package are uploaded and endorsed prior to the deadline. **If a proposal package is not received by the 5:00 p.m. ET deadline, NASA will determine the proposal package to be incomplete and will not evaluate it.** Start the submission process early to allow sufficient time to upload the complete proposal package.

If you wait to submit a proposal package near the deadline, you are at risk of not completing the required uploads and endorsements by the required deadline and NASA may decline the proposal package.

6.1.3 Proposal Package Submission

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

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

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

You may upload a proposal package multiple times, with each new upload replacing the previous version, but only the final uploaded and electronically endorsed version will be considered for review. Embedded animation or video, as well as reference technical papers for “further reading,” will not be considered for evaluation. **NASA may decline a proposal package that is missing the final endorsements.**

6.1.4 Acknowledgment of a Proposal Package Receipt

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

6.1.5 Withdrawal of Proposal Packages

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

6.1.6 Service of Protests

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

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

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

6.2 STTR Phase II Information

If you are awarded a Phase I contract, you will be eligible to submit a proposal for an STTR Phase II follow-on contract. NASA will send instructions directly to you with information on how to submit your Phase II proposal(s). You will receive details on the due date, content, and submission requirements for Phase II proposals. The Phase II proposal submission will open approximately 60 days prior to the end of your Phase I contract original period of performance.

If you submit your Phase II proposal outside of the timeframe specified by NASA, your proposal will be declined without evaluation. Additional guidance can be found in your Phase I contract (Request for Proposal for Phase II Follow-on Contract).

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: https://www.nasa.gov/organization/
NASA SBIR/STTR Programs: https://www.nasa.gov/sbir_sttr/

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

Office of Technology, Policy, and Strategy	
2024 NASA Technology Taxonomy	https://www.nasa.gov/otps/2024-nasa-technology-taxonomy/

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

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

STMD Civil Space Shortfalls	
Background and Ranking	https://www.nasa.gov/spacetechpriorities/

7.2 United States Small Business Administration (SBA)

The SBA oversees the Federal SBIR and STTR programs. The SBA has resources that small businesses can use to learn about the program and to get help for developing a proposal package to a Federal SBIR/STTR program. Offerors are encouraged to review the information that is provided at the following links: www.sbir.gov, https://www.sba.gov/local-assistance, and at https://www.sbir.gov/apply.

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

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

7.3 National Technical Information Service

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

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

8. Submission Forms

Previews of all forms and certifications are available via the NASA SBIR/STTR Resources website, located at https://www.nasa.gov/sbir_sttr/firms_library

8.1 STTR Phase I Checklist

For assistance in completing your Phase I proposal package, use the following checklist:

- ☐ The technical proposal and innovation are submitted for one subtopic only.
- ☐ The entire proposal package is submitted consistent with the requirements outlined in chapter 3.
    - ☐ Proposal Contact Information
    - ☐ Proposal Certifications
    - ☐ Proposal Summary
    - ☐ Proposal Budget
        - ☐ Including letters of commitment for government resources and subcontractors/consultants (if applicable)
        - ☐ Foreign Vendor form (if applicable)
    - ☐ Technical Proposal including all 9 parts in order as stated in section 3.1.3.5.
    - ☐ Briefing Chart
    - ☐ NASA Evaluation License Application, only if TAV is being proposed
    - ☐ I-Corps Interest Form
    - ☐ Technical and Business Assistance (TABA) Request, if applicable
    - ☐ SBC-Level Forms completed once for all proposal packages submitted to a single solicitation
        - ☐ SBC Certifications
        - ☐ Audit Information
        - ☐ Prior Awards Addendum
        - ☐ Commercialization Metrics Report (CMR)
        - ☐ Disclosure of Foreign Affiliations
- ☐ The technical proposal does not exceed a total of 15 standard 8.5- by 11-inch pages with one-inch margins and follows the format requirements (section 3.1.2).
- ☐ All required letters/documentation are included.
    - ☐ A letter of commitment from the appropriate government official if the research effort requires use of government resources (sections 3.1.3.4 and 5.13).
    - ☐ Letters of commitment from subcontractors/consultants.
    - ☐ If the SBC is an eligible joint venture or a limited partnership, a copy or comprehensive summary of the joint venture agreement or partnership agreement is included.
    - ☐ NASA Evaluation License Application if proposing the use of NASA technology (TAV).
    - ☐ Supporting documentation of budgeted costs.
- ☐ Proposed funding for the technical effort does not exceed $150,000 (section 1.3), and if requesting TABA, the cost for TABA does not exceed $6,500 (sections 1.8 and 3.1.3.8).
- ☐ Proposed project duration does not exceed thirteen (13) months (section 1.3).
- ☐ Confirm you received an acknowledgement of submission email before 5:00 p.m. ET on May 21, 2025 (section 6.1.4).

9. Research Subtopics for STTR

The STTR subtopics are organized by subtopic number. Appendix B contains a list of the subtopics as they align to the 2024 NASA Technology Taxonomy to help you identify subtopics based on technology areas.

In addition, there are some SBIR subtopics that may be closely aligned with the NASA STTR program. Consider both programs when planning to apply.

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

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

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

Guidance for Locating Subtopic Reference Materials

Each subtopic contains references that are intended to provide additional information about the technology need. Some of those references include technical articles that may be available through NASA's Technical Reports Server (NTRS) or through other technical journals or sources. NTRS (https://ntrs.nasa.gov/) provides access to publicly available scientific and technical documents, images and videos created or funded by NASA. While we work to only reference publicly available documents, if you find that referenced technical articles are behind a paywall, please contact your local library to request assistance in obtaining access.

Subtopic Pointers

Related subtopic pointers are identified in some subtopic headers to assist you with identifying other subtopics that seek related technologies for different customers or applications. It is your responsibility to select which subtopic to propose.

Contents

T3.05: Lunar Orbital Power Beaming Technology Development (STTR)

Related Subtopic Pointers: Z-LIVE.01
Lead Center: GRC
Participating Center(s): N/A

Subtopic Introduction:

Solar arrays that replenish batteries are a mainstay for most space missions. Unlike spacecraft, however, conducting science missions on the Moon is severely restricted due to its motion relative to the Sun. Near the lunar equator, operations are limited to two weeks or less due to long lunar nights that plunge systems into very cold temperatures for weeks at a time and typically force those systems to shut down permanently. Near the lunar poles, the topography creates permanently shadowed regions (PSRs) that make it impossible to collect solar power in those regions, significantly hampering exploration.

Carrying enough battery power to operate through these conditions is not a tractable solution as this would require much larger landers or alternative energy sources such as radioisotopes that are cost prohibitive. Although surface-based power beaming is being considered as a cost-effective solution for some missions, this option limits the scope and reach to just tens of kilometers from fixed locations on the lunar surface. Alternatively, an orbiting beamed power spacecraft would complement more traditional solutions and be able to extend the scientific reach across much of the lunar surface. Adopting this approach could add years of science operations to lunar rovers and other systems.

A recent study found that orbiting laser beamed power using currently available technology could reduce the cost of globally distributed lunar science missions by as much as 30%. Technology development to bring this technology to flight readiness could make this a practical solution for many different NASA missions. These technologies include:

- Photovoltaic cells with high efficiency for use with both laser and broadband-solar spectrums, with a particular interest in performance at laser wavelength around 1.06 microns.
- Photovoltaic arrays that retain high efficiency under non-uniform illumination.
- Improved laser efficiencies and lifetimes with high optical beam quality.
- Methods to achieve sub-microradian pointing, including effects of vibration and jitter of the platform.

These same technologies would also benefit many other important applications, including higher bandwidth and longer-range communications, position, navigation, and timing (PNT), and high-performance remote-sensing applications. The proposed technology developments could also advance prior work done through the NASA Space Technology Mission Directorate (STMD) programs including the Lunar Surface Technology Research (LuSTR) program, Project Moonbeam-Beamed Lunar Power within the Deep-Space Optical Communications (DSOC) program, and NASA Space Technology Graduate Research Opportunities (NSTGRO) university programs.

Scope Title: Lunar Orbital Power Beaming Technology Development

Scope Description:

A recent study found that orbiting laser beamed power using currently available technology could reduce the cost of globally distributed lunar science missions by as much as 30%. Technology development to bring this technology to flight readiness could make this a practical solution for many different NASA missions. These technologies include:

- Dual-use photovoltaics efficient for use with both laser and broadband-solar spectrums.
- Photovoltaic arrays that retain high efficiency under non-uniform illumination.
- Improved laser efficiencies and lifetimes.
- High optical beam quality for large aperture systems under large thermal loads.
- Active optics with sub-microradian pointing.
- Ultra-stable space platforms with very low levels of vibration and jitter.

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

Primary Technology Taxonomy:

- Level 1: TX 03 Aerospace Power and Energy Storage
- Level 2: TX 03.3 Power Management and Distribution

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype

Desired Deliverables Description:

Phase I deliverables would include research, analysis, and test results showing the feasibility of the problem solutions as well as improvements in efficiency and usability of laser power beaming systems.

Phase II deliverables ideally would include samples and/or prototypes suitable for testing at NASA.

State of the Art and Critical Gaps:

Small-scale demonstrations of laser beamed power have shown that the technology is feasible, but bringing this innovation to flight readiness will require advances in our technological readiness. Efficiency is always of critical interest in power systems, and improvements in efficiency of both the photovoltaic converter and the laser would be desirable. In particular, many laser beaming proposals suggest use of a laser at a wavelength at or near 1.06 microns. Further, development of laser-conversion cells capable of commercial large-area production with high efficiency at this wavelength is desirable. Since most operational uses envision use of the same cells with solar input when sunlight is available, dual-use (laser and solar) performance is also important.

Another technology gap stems from the fact that laser illumination differs from solar input because it may be non-uniform; therefore, approaches to dealing with arrays that do not lose efficiency under non-uniform illumination are desired. Finally, for applications envisioning laser beaming from orbital stations to users on the planetary or lunar surfaces, analyses show that beam pointing, including the effects of spacecraft vibrations and jitter, may be a critical factor in performance, and thus practical concepts for dealing with sub-microradian beam pointing from spacecraft platforms will be of interest.

Relevance / Science Traceability:

This technology will be relevant to multiple NASA missions as a means of sending power from where it is produced to where it is needed. In particular, lunar exploration is currently focused on the south polar regions of the Moon, including permanently shadowed regions, where solar power is not available. Power beaming by laser will be useful for these applications for human and robotic missions.

References:

1. G. Landis, S. Oleson, *et al.,* “Power Beaming from Lunar Orbit for Small Science Landers,” paper AIAA-2024-4938, *AIAA ASCEND (Accelerating Space Commerce, Exploration, and New Discovery) Conference 2024*, 30 July-1 August 2024, Las Vegas NV.
2. G. Landis, S. Oleson, *et al*., “Design Study of Surface to Surface Laser Power Beaming on the Moon,” *Lunar Surface Innovation Consortium Spring Meeting*, April 23-25, 2024, Laurel, MD.
3. K. Jin and W. Zhou, “Wireless Laser Power Transmission: A Review of Recent Progress,” *IEEE Transactions on Power Electronics*, Volume 34, No. 4, pp. 3842 - 3859. 2018. DOI: 10.1109/TPEL.2018.2853156.

4. Green, M.A., Zhao, J., Wang A., and Wenham, S.R., "45% efficient silicon photovoltaic cell under monochromatic light", *Electron Device Lett.*, vol. 13, no. 6, pp. 317-318, 1992. https://ieeexplore.ieee.org/document/145070
5. Jomen, R., Tanaka, F., Akiba, T., Ikeda, M., Kiryu, K., Matsushita, M., Maenaka, H., Dai, P., Lu, S. and Uchida, S., "Conversion efficiencies of single-junction III–V solar cells based on InGaP, GaAs, InGaAsP, and InGaAs for laser wireless power transmission," *Japanese Journal of Applied Physics, Vol. 57*, No. 8S3, July 17, 2018. https://iopscience.iop.org/article/10.7567/JJAP.57.08RD12
6. Moonbeam - Beamed Lunar Power (LuSTR): https://www.nasa.gov/directorates/stmd/space-tech-research-grants/moonbeam-beamed-lunar-power/

T5.06: Non-Earth Orbit Conjunction Risk Analysis (STTR)

Related Subtopic Pointers: H9.03, S14.01
Lead Center: GSFC
Participating Center(s): HQ, JPL

Subtopic Introduction:

Because there is no catalog of objects available to compute close approach predictions for spacecraft orbiting about locations other than Earth, conjunction assessment (CA) screenings may only be determined by screening provided ephemerides against each other. This function is performed by the NASA Multi-mission Automated Deep-space Conjunction Assessment Process (MADCAP) team at the Jet Propulsion Laboratory (JPL). MADCAP currently screens spacecraft orbiting the Moon, Mars, and various libration points. The MADCAP team identifies close approaches and notifies operator teams so they can work together to mitigate the close approach, as necessary.

The ability to perform close approach risk assessment and make mitigation decisions more accurately and rapidly will improve space safety for all spaceflight operations. This subtopic seeks innovative technologies to improve the CA risk assessment process for MADCAP.

Scope Title: Non-Earth Orbit Conjunction Risk Analysis

Scope Description:

There is an increasing number of spacecraft orbiting other solar system bodies, such as the Moon and Mars. Unlike for Earth-orbiting objects, deep space spacecraft are not tracked by the Space Surveillance Network, so all trajectory data must be provided by the respective navigation teams that compute orbits based on tracking data obtained from suitable deep space antenna. These orbit determination solutions are provided as ephemerides to MADCAP for screening to predict close approaches against other objects flying in the same orbit regime.

This subtopic seeks innovative technologies to improve the risk assessment process, including the following specific areas (see Reference 1 for the 2020 NASA Technology Taxonomy (TX) areas TX05.6.4, TX10.1.4, TX10.1.5, and TX10.1.6):

- Novel, efficient methods for locating the minimum distance and location of the closest approach between objects with reduced run times and/or increased accuracy: Solutions that assume elliptical orbits are acceptable, but those that allow for hyperbolic orbits are preferred. An efficient method that applies universally to noncoplanar orbits would also be beneficial as it would eliminate the need to check for coplanarity and to switch algorithms.
- Methods to detect and track debris objects and inactive satellites in the lunar or Martian orbital environments: Objects in these environments currently cannot be passively tracked from Earth ground stations and can pose a hazard to spacecraft actively operating there. A method for a spacecraft/lander to

find debris objects and maintain tracking knowledge of them with regular updates would allow MADCAP to perform conjunction assessments and warn active satellites of possible collisions.
- Frame representation and conjunction risk calculation for cislunar orbits: When not in orbit about a central body, and with hyperbolic or weak-stability orbits, it is not entirely clear what coordinate system representation should be used to achieve Gaussian error representations and to produce probabilities of collision (or other risk metrics) that will be representative. The problem requires a detailed investigation that considers the full range of cislunar orbit types to determine recommendations for possible scenarios.
- Collision risk thresholds and mitigation recommendations: Some cislunar destinations will preserve any created debris essentially forever (luminaries with little to no atmosphere; stable Lagrange points), so collision risk aversion may need to be much higher than for many Earth orbits. A parameterized examination of the situation is required to develop recommendations for collision risk thresholds and sizes/strategies of resultant mitigation actions.
- Data Actionability Criteria: An embryotic cislunar catalogue is likely to contain many entries with low tracking densities and long propagation times. Accuracy tolerances for different orbits, perhaps as a function of tracking density, are necessary to develop criteria to identify situations in which the data quality is too poor to serve as a basis for risk assessment.

Disclaimer: Technology Available (TAV) subtopics may include an offer to license NASA Intellectual Property (NASA IP) on a nonexclusive, royalty-free basis for research use under the STTR award. When included in a TAV subtopic as an available technology, use of the available NASA IP is strictly voluntary. Whether a firm uses available NASA IP within their proposal effort will not in any way be a factor in the selection for award.

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

Primary Technology Taxonomy:

- Level 1: TX 05 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems
- Level 2: TX 05.6 Networking and Ground Based Orbital Debris Tracking and Management

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Software

Desired Deliverables Description:

Phase I research should demonstrate technical feasibility and include delivery to NASA of preliminary software and a plan toward Phase II integration.

Phase II new technology development efforts shall deliver components at the TRL 5 to 6 level to NASA, with mature algorithms and software components complete and preliminary integration and testing in a quasi-operational environment.

State of the Art and Critical Gaps:

The number of conjunction events is expected to increase with the increase of resident space objects from large constellations, the ability to track smaller objects, the increasing numbers of CubeSat/SmallSats, and the proliferation of space debris. Thus, MADCAP has identified the following challenges to which we are actively looking for solutions:

- Efficient ways to perform conjunction analysis and assessments such as methods for bundling events and performing ensemble risk assessment.

- Middle-duration risk assessment (longer duration than possible for discrete events but shorter than decades-long analyses that use gas dynamics assumptions).
- Improved CA event risk evolution prediction.
- Machine Learning/Artificial Intelligence (ML/AI) applied to CA risk assessment parameters and/or event evolution.

The decision space for collision avoidance relies not only on the quality of the data (state and covariance) but also the tools and techniques for CA.

Relevance / Science Traceability:

This technology is relevant and needed for all missions in the near-Earth, cislunar, lunar, and other solar system environments. The ability to perform conjunction risk analysis more accurately will improve space safety for all operations involving orbiting spacecraft.

References:

1. 2020 NASA Technology Taxonomy: https://www.nasa.gov/otps/2020-nasa-technology-taxonomy/
2. Alfano, S. “A numerical implementation of spherical object collision probability.” The Journal of the Astronautical Sciences 53, no. 1 (2005): 103-109, https://link.springer.com/article/10.1007/BF03546397
3. Balch, M. S., Martin, R., and Ferson, S., “Satellite conjunction analysis and the false confidence theorem.” Proceedings of the Royal Society A 475, no. 2227 (2019): 20180565, https://royalsocietypublishing.org/doi/10.1098/rspa.2018.0565
4. Frigm, R. C., Hejduk, M. D., Johnson, L. C., and Plakalovic, D. “Total probability of collision as a metric for finite conjunction assessment and collision risk management.” Proceedings of the Advanced Maui Optical and Space Surveillance Technologies Conference, Wailea, Maui, Hawaii. 2015. https://ntrs.nasa.gov/api/citations/20150018410/downloads/20150018410.pdf
5. NASA Conjunction Assessment Risk Analysis (CARA) Office: https://www.nasa.gov/conjunction-assessment
6. Office of the Chief Engineer, “NASA Procedural Requirements: NASA Spacecraft Conjunction Analysis and Collision Avoidance for Space Environment Protection,” NPR 8079.1. https://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=8079&s=1
7. NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook: https://nodis3.gsfc.nasa.gov/OCE_docs/OCE_50.pdf
8. Consultative Committee for Space Data Systems (CCSDS) Recommended Standard for Conjunction Data Messages: https://public.ccsds.org/Pubs/508x0b1e2c2.pdf
9. Tarzi, Z., Berry, D., and Roncoli, R. “An Updated Process for Automated Deep Space Conjunction Assessment,” Paper AAS 14-373, 25th International Symposium on Space Flight Dynamics, Munich, Germany, October 2015. https://www.nasa.gov/sites/default/files/atoms/files/an_updated_process_for_automated_deepspace_conjunction_assessment.pdf.
10. Berry, D., Tarzi, Z., Roncoli, R., Wilson, R. “Automated Spacecraft Conjunction Assessment at Mars and the Moon-A Five Year Update”, Paper 2810036, 14th International Conference on Space Operations, Marseille, France, May 2018, https://www.nasa.gov/wp-content/uploads/2022/08/madcap-spaceops-2018-paper.pdf?emrc=cb8474
11. Tarzi, Z. B., Young, B. T., Berry, D. S. “Deriving Event Thresholds and Collision Probability for Automated Conjunction Assessment at Mars and the Moon”, AAS 22-042, 2022 AAS/AIAA Astrodynamics Specialist Conference, Charlotte, NC, August, 2022. https://www.nasa.gov/wp-content/uploads/2022/08/aas_22-042_paper.pdf?emrc=878ced
12. NASA's Space Sustainability Strategy: https://www.nasa.gov/spacesustainability

T5.07: Communications Quality of Service (QoS) Optimization Through Network Autonomy (STTR)

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

Subtopic Introduction:

The goal of this subtopic is to address a significant technology gap to enable Adaptive Space Network Management (ASNM) and cognitive networking for future missions supporting Artemis and beyond. Communication QoS is a measure of network performance and reliability for a particular network service. Autonomous network management and cognitive networking can be used to ensure a guaranteed level of network performance based on a system optimization policy, rather than human operator input. Maturation of QoS optimization and network autonomy will enable high-rate multimedia streaming from the lunar surface (greater than 4K streaming bandwidth), management of resources in multi-node/multi-hop networks, dynamic service requests, and seamless roaming between service providers.

The topic seeks research and prototype development of an autonomous network management system, including secure multimedia streaming capabilities, autonomous node configuration, and user policy management. This topic improves upon a previous Space Technology Research Grants (STRG) Early-Stage Innovations Topic, "Cognitive Networking Advancements for Lunar Communication and Navigation," which focused on cognitive routing for delay tolerant networking (DTN) multi-hop networks on the lunar surface. DTN network management, network security, and multimedia streaming are among the top priorities for investigation and development within several agency and international working groups (NASA DTN Working Group, Consultative Committee for Space Data Systems, and the Internet Engineering Task Force).

This subtopic is of interest to several NASA centers that participate in these working groups including Glenn Research Center, Jet Propulsion Laboratory, Marshall Space Flight Center, Goddard Space Flight Center, and Johnson Space Center.

Scope Title: Quality of Service Policy Management

Scope Description:

Network service management is a key technology focused on enabling the future interplanetary internet, supporting programs such as the International Space Station, Artemis, and beyond. High-rate optical links will enable increased science data return, provide high-quality multimedia capabilities essential for human space exploration, and serve as trunk lines connecting the Earth to the Moon. Future space networks are soon to become a combination of commercial service providers, NASA space assets, and international agency partners. This diverse network will require interoperable standards, services that are efficient, reliable, and secure, and solutions for scalable network management. Technologies such as DTN address the basic challenges of the space communication environment (long round-trip times, link asymmetry, intermittent connectivity) while providing a framework to address the requirements of the modern space network.

NASA's Space Communication and Navigation (SCaN) program is focused on infusing DTN into space networks and science missions. The first generation of DTN protocols and architecture has been implemented and demonstrated; however, several major areas have been identified that will improve the efficiency, reliability, and scalability of network operations. Network management capabilities are required to administer and configure DTN nodes and must operate within and complement existing spacecraft scheduling and management systems. Secure architectures, protocols, and applications must be developed to provide end-to-end security of mission data. User applications and operator interfaces must be developed to increase the utility of DTN technologies. High-rate and high-definition multimedia streaming will enable crewed missions and improve science data returns.

Examples of specific research and/or technology development areas of interest include:

- Path-to-standardization of DTN node configuration and management.
- Multimedia, secure streaming over DTN.
- Analysis of interplanetary security architectures.
- User policy management for service providers.
- Scalable network management approaches.

Proposals to this subtopic should consider application to a lunar and/or Martian communications architecture consisting of surface assets (e.g., astronauts, science stations, and surface relays), communication relay satellites, and gateway and ground stations on Earth. Relay satellites and surface assets require technology with low size, weight, and power (SWaP) suitable for small satellite (e.g., 50 kg) or CubeSat operations. Proposed solutions should highlight advancements to provide the needed communications capability while minimizing use of onboard resources, such as power and propellant. Proposals should consider how the technology can mature into a successful demonstration in the Moon to Mars architecture.

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

Primary Technology Taxonomy:

- Level 1: TX 05 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems
- Level 2: TX 05.3 Internetworking

Desired Deliverables of Phase I and Phase II:

- Analysis
- Prototype
- Hardware
- Software

Desired Deliverables Description:

Phase I will study technical feasibility, infusion potential for lunar and deep space operations, and clear/achievable benefits, and show a path toward a Phase II implementation. Phase I deliverables include a feasibility assessment and concept of operations of the research topic, simulations and/or measurements, validation of the proposed approach to develop a given product (Technology Readiness Level [TRL] 4), and a plan for further development of the specific capabilities or products to be performed in Phase II. Early development, integration, test, and delivery of prototype hardware/software is encouraged.

Phase II will emphasize hardware/software/model development with delivery of a specific product for NASA targeting future demonstration missions. Phase II deliverables include a working prototype (engineering model) of the proposed product/platform or software, along with documentation of development, capabilities, related documents, and tools. NASA will then be able to modify and use the capability, or hardware component(s), and evaluate performance in the lunar or deep space architecture for greater infusion potential. Hardware prototypes shall show a path toward flight demonstration, such as a flight qualification approach and preliminary estimates of thermal, vibration, and radiation capabilities of the flight hardware. Software prototypes shall be implemented on platforms that have a clear path to a flight-qualifiable platform. Algorithms and channel models must be implemented in software and should be ready to be run on an appropriate general-purpose processor.

Opportunities and plans should be identified for technology commercialization. Software applications and platform/infrastructure deliverables shall comply with the latest NASA standards. The deliverable shall be demonstrated in a relevant emulated environment and have a clear path to a flight implementation on a SWaP-constrained platform.

State of the Art and Critical Gaps:

NASA and private industry have developed several baseline DTN implementations. Common components include Bundle Protocol version 7, Licklider Transmission Protocol, and Bundle Protocol Security. The Consultative Committee for Space Data Systems (CCSDS) is tracking these components, along with Schedule Aware Bundle Routing, for standardization. Variations of their implementation have been demonstrated in a spaceflight environment. Draft specifications are available for streaming over DTN and QoS approaches; however, prototype implementations are needed to perform proof-of-concept studies to refine the specifications.

Critical gaps between the state of the art and the technology need include:

- User policy management for QoS, security, and other service policy agreements.
- Analysis of security architectures and security key management.
- Applications to improve operations and network utility.
- Subnetting architectures and capabilities.
- Testing frameworks for deep-space interplanetary exploration, containerization, federated testbeds and cloud-based approaches.
- Small-scale lightweight DTN applications for radiation hardened processors, field programmable gate arrays, and embedded systems (Reduced Instruction Set Computer [RISC] and Advanced RISC Machine [ARM] processors, systems with 1 GB of RAM or less).
- Applications for automated configuration management, monitoring, and analyzing network performance.
- Technologies for interfacing and managing heterogenous networks, particularly between DTN and proposed space surface networks like the 3rd Generation Partnership Project (3GPP).
- DTN node autoconfiguration, parameter tuning, and discovery.
- Standardization of software-defined networking approaches, scheduling interfaces, and application programming interfaces.

Relevance / Science Traceability:

DTN has been identified as a key technology to enable the future lunar network, as well as deep-space missions from the Moon to Mars. Network policy management for QoS, video streaming, and security are needed for crewed missions. The majority of lunar and deep space operations will be run remotely from Earth, which could require substantial coordination and planning as NASA, foreign space agencies, and commercial interests all place assets on the Moon and beyond. As future communications and networks become more complex, automation and network management are essential to mitigate complexity and reduce operations costs. Management interfaces and protocols must be implemented in a standardized fashion. DTN can provide the basis for these protocols.

References:

1. LunaNet Interoperability Specification: https://www.nasa.gov/directorates/somd/space-communications-navigation-program/lunanet-interoperability-specification/
2. NASA Develops Advanced Space Communications Process: https://www.nasa.gov/humans-in-space/nasa-develops-advanced-space-communications-process/
3. DTN Mission Resources: https://www.nasa.gov/technology/space-comms/delay-disruption-tolerant-networking-mission-resources/
4. NASA's Lunar Communications and Navigation Architecture: https://ntrs.nasa.gov/api/citations/20230016359/downloads/Lunar%20Communications%20and%20Navigation%20Architecture.pdf

Implementations

1. https://github.com/nasa/DTNME
2. https://github.com/nasa/bp
3. https://github.com/nasa/HDTN
4. https://github.com/nasa-jpl/ION-DTN

Specifications

1. Licklider Transmission Protocol for CCSDS: https://public.ccsds.org/Pubs/734x1b1.pdf
2. CCSDS Bundle Protocol Specification: https://public.ccsds.org/review/CCSDS%20734.2-P-1.1/734x2p11e1.pdf
3. CCSDS Bundle Protocol Security Specification: https://public.ccsds.org/review/CCSDS%20734.5-R-2/734x5r2.pdf
4. Schedule Aware Bundle Routing: https://public.ccsds.org/Pubs/734x3b1.pdf
5. Specification for RTP as Transport for Audio and Video over DTN: https://public.ccsds.org/Lists/CCSDS%207663R2/766x3r2.pdf

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

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

Subtopic Introduction:

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

Future orbital and surface deep space habitats will require resilient and autonomous operations during times when crew are and are not on board. These new smart habitats will require a functional, hospitable, and safe environment for astronauts, necessitating advances in robotics and in automated and autonomous systems. New capabilities should address critical challenges faced by future deep space habitats.

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

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

Scope Description:

A critical focus for smart habitats is the appropriate and necessary balance between human and autonomous system intervention during anomalies. Onboard autonomous systems will be used to: (1) collect a wide array of sensor information, (2) integrate heterogeneous data from various vehicle subsystems, (3) identify and predict system/subsystem/hardware required maintenance, (4) diagnose subsystem faults, and (5) recommend resolutions after malfunctions. Humans will need to process all information and recommendations provided by the autonomous systems. While this is true for both onboard astronauts and on-Earth mission control flight controllers, astronauts will have a more challenging time as they may not have immediate access to on-Earth support. It will be essential to provide astronauts with the capability to respond to anomaly events in deep space missions.

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

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

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

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

Primary Technology Taxonomy:

- Level 1: TX 10 Autonomous Systems
- Level 2: TX 10.3 Collaboration and Interaction

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype

Desired Deliverables Description:

Phase I deliverables include use cases/scenarios, preliminary designs, etc., for anomaly responses in smart habitats.

Phase II deliverables include new technology or prototypes confirmed through integrated demonstrations as well as recommendations. Ideally, deliverables would be open-sourced and include algorithms, models, and/or software prototypes.

Three inter-related subsystems must be modeled (e.g., power, life support, thermal, food system, or payload) and interface with a smart habitat technology (e.g., prognostic algorithms, digital twin, and FDIR) to generate suggested fault recovery actions based on an inserted anomaly or malfunction. Wizard of Oz integration is not permissible—that is, a computer system being operated or partially operated by an unseen human does not meet success criteria. If applicable, human-in-the-loop evaluation is expected (e.g., designing and prototyping user interface).

State of the Art and Critical Gaps:

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

Shortfalls Addressed:

- 1523: Earth Independent Human Operations Within Habitat Elements
- 1532: Autonomous Planning, Scheduling, and Decision-Support to Enable Sustained Earth-Independent Missions
- 1535: Autonomous Vehicle, System, Habitat, and Infrastructure Health Monitoring and Management
- 1543: Multi-Agent Robotic Coordination and Interoperability for Cooperative Task Planning and Performance

Relevance / Science Traceability:

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

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T7.04: Lunar Surface Site Preparation (STTR)

Related Subtopic Pointers: Z-LIVE.05
Lead Center: KSC
Participating Center(s): GRC, MSFC

Subtopic Introduction:

It is envisioned that early lunar infrastructure will include prepared surfaces composed of bulk regolith, rocks, and other surface treatments. The intent of this subtopic is to develop (1) civil engineering designs of lunar prepared surfaces infrastructure, (2) technologies to build the infrastructure, and (3) construction concepts of operations (ConOps) for the south polar region of the Moon. Earth-based civil engineering materials, processes, and technologies are not adequate for lunar construction; therefore, lunar civil engineering designs and construction technologies must be developed. The fundamental robotic capabilities of interest are:

- High resolution topography mapping.

- Rock removal.
- Establishment of grade and desired ground features.
- Compaction.
- Verification of design parameters and geometry of built structures.
- Surface treatments to mitigate dust, improve trafficability, and provide safe and stable operational areas.
- Routines and sensors for autonomous operations.

Scope Title: Surface Preparation and Bulk Regolith Infrastructure

Scope Description:

The desired outcome of this effort is the robotic capability to build surfaces that reduce risk from hazards such as rocks, unlevel/unstable terrain, and dust, and to improve travel energy efficiency on the lunar surface. This includes engineered surface features/structures and the design, prototype, testing, analysis, modeling, and demonstration of prototype construction hardware and investigative instruments. These technologies are sought for initial ground demonstrations and follow-on sub-scaled lunar construction demonstration missions.

An example of this interest is Civil Space Shortfall 662: Robotic Regolith Manipulation and Site Preparation. The following lunar civil engineered structures are of particular interest to NASA. Proposers are welcome to suggest other regolith-based infrastructure concepts. Proposals targeting sintering and/or melting technologies to make regolith bricks/concrete are not of interest.

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

Other areas of significant interest include:

- Engineered surface treatments such as deployable surface covers and stabilizing agents to secure launch/landing pad surrounding areas (pad apron), improve surface conditions for vehicle traffic, control dust, and strengthen protective berms.
- Flame deflector design, analysis, simulation, and prototypes for HLS class landers that are intended to be brought from Earth and deployed on the Moon beneath landers to minimize plume surface interaction risks during the launch phase. Flame deflectors should be designed for single or multiple engine plumes and so they can eventually be constructed with in situ materials.
- Advanced geotechnical site investigation methods and systems, beyond cone penetrometer/shear vane measurements, that provide information on subsurface characteristics such as rock distributions, depth to bedrock, soil stratification, and caverns. This includes orbital remote sensing techniques such as Interferometric Synthetic Aperture Radar (InSAR) and Ground Penetrating Radar (GPR) or surface-based technologies that include surface wave techniques, automated robotic bore hole investigations,

and GPR, etc. Ground-based technologies should be suited for a small geotechnical mobility platform. A depth of at least 1 meter should be targeted with the potential to scale up.

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

Tests and validated models/simulations should be developed to characterize the system and regolith infrastructure performance in its intended environments/applications (for example, discrete element models of regolith behavior with compaction systems/processes).

ConOps should be developed to define the sequence of steps to complete construction tasks. ConOps should begin with the natural lunar surface including craters, hills, valleys, and surface/subsurface rocks, and end with the completed bulk regolith infrastructure verified to meet design criteria.

Concepts should be appropriate for a CLPS-scale demonstration mission on the lunar surface (e.g., <100 kg overall mass) 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 Artemis missions will be prioritized. Proposals that show promise for implementation by a single, compact, robotic regolith manipulation and surface preparation system will rank high. Concepts that employ or build upon higher Technology Readiness Level (TRL) systems will be prioritized. NASA is seeking systems that can build bulk regolith infrastructure that can be demonstrated by 2030.

Research institute partnering is anticipated to provide analytical, research, testing, and engineering support to proposers. Examples include (1) applying civil engineering principles and planning methods, (2) identifying and developing needed standards or specifications for lunar structures and operations, (3) modeling regolith interactions, (4) developing analytical models and simulations for verifying system performance, and (5) developing methods for designing and prototyping 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 deliverables must include the design and test of critical attributes associated with the proposed site preparation technology, operations, and achieved site characteristics. Civil engineered designs of regolith and prepared surface infrastructure must include associated testing, modeling, and simulations. Also required is a ConOps for constructing the infrastructure and verifying that 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 regolith and prepared surface infrastructure, including mobility. The infrastructure must be constructed using robotic systems and implements, and proof of critical functions of the infrastructure and systems must be demonstrated. Structures and systems must be developed to a minimum of TRL 5.

State of the Art and Critical Gaps:

While civil engineering and construction are well-established practices on Earth, lunar applications remain at low TRLs. The design requirements and functional capabilities of bulk regolith-based lunar infrastructure are not well defined. To date, very few studies have included civil engineering designs of bulk regolith and prepared surface 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 regolith and prepared surface infrastructure directly addresses shortfalls associated with the Space Technology Mission Directorate (STMD) strategic thrust LIVE: Sustainable Living and Working Farther from Earth, Advanced Materials, Structures, and Construction capability area.

References:

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2. Overview of the ASCE ASD Space Engineering and Construction Technical Committee: Lunar Infrastructure Engineering, Design, Analysis, and Construction Guidelines: Lunar Structural Loads Subgroup: http://dx.doi.org/10.13140/RG.2.2.28322.40645
3. Requirements Development Framework for Lunar In Situ Surface Construction of Infrastructure. ASCE, Earth and Space 2021. https://doi.org/10.1061/9780784483374.106
4. Design of an Excavation Robot: Regolith Advanced Surface Systems Operations Robot (RASSOR) 2.0. ASCE Earth & Space Conference, 2016. https://ntrs.nasa.gov/citations/20210011366
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T8.06: Quantum Sensing/Measurement and Communication (STTR)

Related Subtopic Pointers: S12.06, S16.08, T8.07
Lead Center: GSFC
Participating Center(s): GRC, 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 should apply to those specific subtopics and are not covered in this 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.

- Systems are needed for enhanced multiplexing factor, reading out arrays of cryogenic energy-resolving, single-photon detectors, including the supporting resonator circuits, amplifiers, room temperature readout electronics, GHz frequency division multiplexers, and enabling amplifiers including superconducting quantum interference device (SQUID) systems.
- Quantum light sources are needed that are capable of efficiently and reliably producing prescribed quantum states including entangled photons, squeezed states, photon number states, NOON states, Holland-Burnett states, and broadband correlated light pulses. Such entangled sources are sought for the visible infrared (vis-IR) and in the microwave entangled photons sources for quantum ranging and ground-penetrating radar.
- On-demand, single-photon sources with narrow spectral linewidth are needed for system calibration of single-photon counting detectors and energy-resolving single-photon detector arrays for 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. Narrow linewidth entangled pair sources compatible with atomic transitions are also needed for distributed quantum sensor networks and efficient usage with quantum memories.

Quantum sensing and measurement includes quantum metrology and radiometry (absolute radiometry without massive blackbody cryogenic radiometer or synchrotron), quantum sources (prescribed quantum states with high fidelity), quantum memories (storage and release of quantum states), and quantum absorbers and quantum amplifiers (efficient absorption and detection of quantum states).

We welcome proposals for quantum sensing modeling that address an identified NASA technology need and aim to advance the TRL. Successful proposals should:

1. Discuss the state-of-the-art performance of existing technologies, including their fundamental performance limitations.
2. Demonstrate how the proposed quantum sensing technique can offer enhanced performance.

Please note that the following areas are excluded from T8.06 this year:

- Atomic sensors and clocks and “atom-like” sensors (offerors are suggested to consider S16.08 “Quantum Sensing: Atomic sensors, optical atomic clocks, and solid-state systems").

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
- Hardware

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: This phase 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. This phase should include prototype delivery to the government. (It is understood that this is a research effort, and the prototype is a best-effort delivery with no penalty for missing performance goals.) The Phase II effort should target 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 are needed to generate quantum photon number states. Such sources would utilize high-detection-efficiency, photon energy-resolving, and single-photon detectors (where the energy resolution is used to detect the photon number) developed at NASA. Sources that fall in the wavelength range from 20 µm to 200 nm are of high interest. Photon number state generation anywhere within this spectral range is also highly desired including emerging photon-number quantum state methods providing advantages over existing techniques (Stobińska, et al., Sci. Adv. 5 (2019)). Proposal-generating Holland-Burnett states (Phy Rev. Let 71, 1355 (1993)) are also of interest.

Further advances are sought for 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]).

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

Higher brightness and multiple entanglement and heralded multiphoton entanglement and boson sampling sources are needed. 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. Advances in microwave superconducting quantum interference device (SQUID) are desired to enable increasing multiplexing 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, MIR, far infrared (FIR), and microwave.

Quantum memories with long coherence times (> 30 ms to several hours) and efficiency coupling are needed and should 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%. Further reduction in detection efficiency uncertainty is sought to characterize ultra-high-efficiency absorber structures. Combining the calibration method with the ability to tune over a range of different wavelengths is sought to characterize cryogenic single-photon detector 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 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 ultra-precise sensors with applications ranging from natural resource exploration and biomedical diagnostics to navigation.
- Exploration Systems Development Mission Directorate (ESDMD) and Space Operations Mission Directorate (SOMD)—Astronaut health monitoring.
- Science Mission Directorate (SMD)—Earth, planetary, and astrophysics including imaging spectrometers on a chip across the electromagnetic spectrum from X-ray through 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:

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2. 2019 NASA Fundamental Physics and Quantum Technology Workshop. Washington, DC (April 8-10, 2019).
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   http://kiss.caltech.edu/final_reports/Quantum_final_report.pdf
4. National Quantum Initiative Act:
   https://www.congress.gov/congressional-report/115th-congress/house-report/950/1
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https://www.lightourfuture.org/NPI/media/npi/Resources/NPI-Recommendations-to-HSC-for-National-Quantum-Initiative-062217.pdf?ext=.pdf
5. European Union Quantum Flagship Program:
https://qt.eu
6. UK National Quantum Technologies Programme:
http://uknqt.epsrc.ac.uk
7. DLR Institute of Quantum Technologies:
https://www.dlr.de/en/qt/
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9. Polyakov, Sergey V.: "Single Photon Detector Calibration in Single-Photon Generation and Detection," Elsevier Inc. Volume 45, 2013:
http://dx.doi.org/10.1016/B978-0-12-387695-9.00008-1
10. 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 interconnects, quantum repeaters, high-efficiency detectors, as well as integrated quantum photonics that integrate multiple components. A key need in all these areas is technologies with low SWaP that can be utilized in aerospace applications. Some examples (not all inclusive) of requested innovations include:

- Photonic waveguide integrated circuits for quantum information processing and manipulation of entangled quantum states with phase stability, low propagation loss (i.e., 100 MHz incidence rate), and 1-sigma time resolution of 50% at the highest incidence rate.
- Quantum memory with high buffering efficiency (> 50%), storage time (> 10 ms), and high fidelity (> 0.9), including heralding capability as well as scalability.
- Stable narrow-band filters for connecting to quantum memory and atomic interferometers. Narrow band (100 MHz or less for spectral bandwidth per channel) has > 50 dB extinction and > 90% coupling efficiency for either NIR or C-band.
- Very narrow wavelength division multiplexing (~30 GHz channels) with high coupling efficiency.
- High-efficiency and high-speed optical switches.
- High-rate and fidelity quantum entangled photon source. Source should produce entangled pairs of a rate > 1 MHz and a multi-pair down rate reduced by at least a factor of 1,000. This could be accomplished through a single source or array of sources.
- Integrated quantum spectrometer, which may utilize a wavelength-division multiplexing (WDM) architecture with high coupling efficiency to external sources.
- Narrow spectral linewidth entangled pair sources that can effectively interact with atomic systems and quantum memories.
- Quantum sensor with quantum photonic output for quantum sensor network.
- Quantum modeling to mature TRL of fundamentally secure quantum communication tolerant to large losses (uplink and downlink).

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: This research is highly encouraged to 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: For this phase, new technology development efforts shall deliver components at 4 to 6 TRL 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, or networks of quantum computers. Deliverables that substantiate technology efficacy include reports of key experimental demonstrations that show significant capabilities. In general, however, it is desired that the deliverable includes 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. There are a number of sensing applications that could benefit from dramatically improved sensitivity by using quantum sensing arrays.

References:

1. Katz, E.; Child, B.; Nemitz, I.; Vyhnalek, B.; Roberts, T.; Hohne, A.; Floyd, B.; Dietz, J.; and Lekki, J.: “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).
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T8.07: Photonic Integrated Circuits (STTR)

Related Subtopic Pointers: T8.06
Lead Center: GSFC
Participating Center(s): GRC, JPL, LaRC

Subtopic Introduction:

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

Scope Title: Photonic Integrated Circuit (PIC) technology development and infusion

Scope Description:

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

Additional Clarifications:

- Proposals to this subtopic should focus on development of one or more of the following:
  1. New PIC components.
  2. New PIC platforms/materials.
  3. New fabrication and/or packaging capabilities.
  4. Significant improvement in PIC performance.
- On-chip generation, manipulation, and detection of light in a single-material system may not be practical or offer the best performance, so heterogenous or hybrid integration and packaging of different material systems are also of interest. [Ref. 1]
- Often the full benefits of photonic integration are only realized when combined with integrated electronics. [Ref. 2] Proposals that leverage co-integrated electronics and/or new materials for new or improved PIC functionality are invited but should consider the ultimate space environment.
- There are advantages to the development of PIC technology in existing open access foundries (such as AIM [Ref. 3]) to enable low cost, continued support, commercialization, and cross-compatibility with other development efforts.

- Proposers are strongly recommended to consider the final use case of the proposed component/system and a route to integrate the new technology with NASA's existing instruments/PICs in a potential Phase II activity. For example, standalone PICs should discuss a planned approach for packaging suitable for lab tests without a probe station (TRL 4). Alternatively, proposals to develop a specific on-chip component should discuss how this new component could be incorporated into existing foundry processes or added as a back-end-of-line process.
- Proposers should clearly delineate what will be accomplished under the Phase I activities, what could be accomplished if a phase II was also awarded, and what the vision or end product is if additional work is needed after the phase II funding.
- Overlap with other topics: Proposers who are developing PIC-based subsystems for applications covered in other SBIR/STTR topics should consider which call is more applicable.
    1. Proposals in which more than 50% of the effort is focused on PIC development are encouraged to be submitted to this subtopic.
    2. Subtopics that often have overlap with this subtopic include:
        - Optical/laser communications
        - Lidar
        - Quantum sensors
        - Spectroscopy
        - Astronomy

Existing NASA needs for PIC technology include:

- Hybrid or heterogeneous integration of III-V gain elements on silicon for optical amplification.
    - Proposals responsive to this item should include evanescent couplers, photonic wire bonds, or similar structures/technologies to couple the III-V gain elements to silicon waveguides efficiently and optically.
    - Proposers are strongly encouraged to either work directly with, or ensure direct compatibility with, silicon photonic foundries in the U.S.
    - Proposers should seek to achieve performance comparable to low-noise, pre-amplifier erbium doped fiber amplifiers (EDFAs), i.e., > 20 dB small signal gain with < 5 dB noise figure at input power levels as low as -50 dBm across the optical C-band (1530 to 1565 nm).
- On-chip amplitude modulators capable of high extinction ratio, when compared with current foundry demonstrations [Ref. 9]
    - Explore technology compatible with handling higher power input levels on-chip
    - Continue to progress high-speed modulation in the design space of reduced dependence on active biasing
- On-chip high-speed avalanche photodiodes (APDs) operating at 1550 nm with GHz bandwidth compatible with at least one silicon photonic foundry in the U.S., targeting an eventual process design kit (PDK) element available in the foundry.
    - APDs may be fabricated in the process itself (i.e., using existing process materials such as Ge) or heterogeneous/hybrid integrated in a back-end-of-line process.
    - APD designs that require active cooling (e.g., thermoelectric coolers (TECs), cryogenic ≥ 77 K) are acceptable.
    - APD designs capable of single-photon sensitivity (SPADs) are strongly encouraged. Performance goals for integrated 1550 nm SPADs should target ~ 50% detection efficiency, < 5 kilo counts per second (kcps) dark count rates, and < 70 ps full width at half maximum (FWHM) timing jitter, similar to that in Ref. 8.
- PIC systems enabling mid-infrared (MIR) tunable laser spectrometers similar to those mentioned in [Refs. 5, 6]. Designs should nominally target the 4-5 um range and target PIC development including tunable lasers and/or high-frequency (2+ GHz) detectors on-chip.
- Packaging approaches and on-chip coupling components [Ref. 7] for coupling a multimode fiber directly to a PIC.
- PIC platforms with on-chip laser, amplifiers, modulators, phase shifters and/or detectors from 670 nm to 850 nm targeting eventual establishment of multi project wafer (MPW) runs supporting this wavelength range.

    - Proposers should include a notional roadmap towards establishing MPW capabilities for this platform.
    - Proposers should include at least one active element (e.g., laser/amplifier/modulator/phase shifter/detector) to be responsive.
    - Multiple active component designs can be used to address the full wavelength range.
    - Note that approaches that package on-chip waveguides to off-chip lasers/detectors using small-form-factor packaging techniques (e.g., direct edge coupling, flip-chip, photonic wire bonding, etc.) are also of interest.
    - Approaches demonstrated in, or compatible with, existing commercial foundries are of particular interest.

Proposals that do not target a specific use case from the list above may also target a NASA area of general interest. Proposals in this category are expected to make a clear connection between the proposed technology development and directly enhancing a NASA instrument or mission, as well as a comparison of the proposed technology to existing NASA instruments. Areas of general interest for PIC components and subsystems include, but are not limited to:

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

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

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: This phase 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: This work 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.

Proposers should clearly delineate what will be accomplished under the Phase I activities, what could be accomplished if Phase II is also awarded, and what the vision or end product is if additional work would be needed after the Phase II funding.

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.

References:

1. Komljenovic, T.; Huang, D.; Pintus, P.; Tran, M.A.; Davenport, M.L.; and Bowers, J.E. (2018): "Photonic Integrated Circuits Using Heterogeneous Integration on Silicon," Proceedings of the IEEE, 106(12), 2246-2257.
2. Stojanović, V.; Ram, R. J.; Popović, M.; Lin, S.; Moazeni, S.; Wade, M.; and Bhargava, P. (2018): "Monolithic Silicon-Photonic Platforms in State-of-the-Art CMOS SOI Processes," Optics Express, 26(10), 13106-13121.
3. AIM Foundry: http://www.aimphotonics.com
4. Gambacorta, A.; Stephen, M.; Gambini, F.; Santanello J.; Mohammed, P.; Sullivan, D.; and Piepmeier, J. (2022): "The Hyperspectral Microwave Photonic Instrument (HYMPI)-Advancing our Understanding of the Earth's Planetary Boundary Layer from Space," In IGARSS 2022-2022 IEEE (pp. 4468-4471).
5. Mahaffy, P.R.; Webster, C.R.; Cabane, M.; et al. (2012): "The Sample Analysis at Mars Investigation and Instrument Suite," Space Sci Rev, 170, 401-478.
6. Yu, A.W., et al. (2023): "Photonic Integrated Circuit Tuned for Reconnaissance and Exploration," 2023 IEEE Aerospace Conference, Big Sky, MT, USA (pp. 1-11).
7. Marchetti, Riccardo; et al. (2019): "Coupling Strategies for Silicon Photonics Integrated Chips," Photonics Research, 2, 201-239.
8. Signorelli, F.; et al.: "InGaAs/InP SPAD Detecting Single Photons at 1550 nm with up to 50% Efficiency and Low Noise," 2021 IEEE International Electron Devices Meeting (IEDM), San Francisco, CA, USA, 2021, pp. 20.3.1-20.3.4, doi: 10.1109/IEDM19574.2021.9720559.
9. Publications: https://www.aimphotonics.com/publications-2023-2024

T8.08: Lunar Imagery (STTR)

Related Subtopic Pointers: A2.01, H15.01
Lead Center: MSFC
Participating Center(s): N/A

Subtopic Introduction:

NASA needs to capture, process, and broadcast high-quality motion imagery from the surface of the Moon to answer science questions, monitor operations, guide automated activities, and inspire the public. The Moon presents numerous challenges for imagery such as withstanding the lunar environment (thermal, radiation, etc.), but this solicitation focuses on maximizing imagery quality with limited Size, Weight, and Power (SWaP), especially constrained bandwidth (bit rate), and a unique landscape including harsh and high-dynamic range lighting conditions. Ongoing research in adaptive compression, quality assessment algorithms, delay-tolerance, multivariable adjustment including resolution, frame rate, and bit depth, and automated camera operations could be adapted and combined to address lunar-specific challenges.

Scope Title: Lunar Imagery

Scope Description:
NASA needs to capture, process, and broadcast high-quality motion imagery from the Moon to answer science questions, monitor operations, guide automated activities, and inspire the public. The Moon presents numerous challenges for imagery such as withstanding the lunar environment (thermal, radiation, etc.), but this solicitation focuses on maximizing imagery quality with limited SWaP, especially constrained bandwidth (bit rate), and a unique lunar landscape including harsh and irregular lighting conditions. Ongoing research in adaptive compression, quality assessment algorithms, delay-tolerance, multivariable adjustment including resolution, frame rate, and bit depth, and automated camera operations could be adapted and combined to address lunar-specific challenges.

This solicitation seeks to support an approach to optimizing the quality of video from one or more cameras over a range of constrained bit rates (1 to 20 Mbps) and a range of landscapes in the field(s) of view. The solutions should address human space flight applications including addressing the desires of members of the public for high-quality, live video. Proposers may include advancing camera technology, although higher priority may be given to approaches that improve on or adapt existing commercial-off-the-shelf (COTS) hardware for lunar applications. Proposers should seek to create or combine multiple technologies and or techniques (e.g., communications protocols and image quality assessment algorithms) to make a solution uniquely adapted to the challenges of spaceflight and specifically the lunar environment (e.g., lighting, radiation, thermal). Desired solutions improve imagery without needing large increases in size, weight, mass, or cost at the point.

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

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:

- Software
- Hardware
- Prototype

Desired Deliverables Description:

The successful solution will develop and eventually demonstrate approaches and/or software that can be applied to a range of motion sensory imagery systems. The deliverables could include hardware or software improvements along any step in the acquisition, compression, communication, processing, and broadcast of live imagery from the lunar surface (this could involve improvements to technology that will be in space or on the ground). Desired solutions may include bespoke hardware solutions but should be supported by an underlying approach that could be applied to existing NASA hardware (e.g., the handheld universal lunar camera [HULC]).

Phase I research should include initial exploration, testing, and feasibility of the underlying approach. The testing can be done on non-lunar imagery with a test system.

Phase II research should deliver working hardware and/or software to the government. The approach should be demonstrated live in a simulated lunar environment, ideally using a system or hardware similar to what would be utilized on the lunar surface.

State of the Art and Critical Gaps:

The state of the art is COTS hardware designed for terrestrial applications hardened for the lunar environment. Live video streams (stream timing or changes in resolution) are designed before the missions or instructed manually by ground controllers.

A critical gap is improving video quality while fitting within a very small bandwidth allocation. This is made more challenging as the scenes being captured are less predictable than other live content (e.g., sporting events) and cannot be managed by a broadcast team on-site (i.e., before transmission). Finally, effectively solving these problems for the lunar surface may require solutions that currently do not exist.

Relevance / Science Traceability:

The work advances NASA's top-level strategic goals of conducting missions that forward inspiration and national posture. It also meets Exploration Systems Development Mission Directorate (ESDMD) requirements to provide motion imagery for internal applications (e.g., Human Exploration Requirements for Audio and Imagery – HEO-R-2) and to meet the agency's (e.g., NASA Communications) need for high-quality motion imagery.

References:

1. Artemis: https://www.nasa.gov/humans-in-space/artemis/
2. Lunar Terrain Vehicle (LTV): https://www.nasa.gov/extravehicular-activity-and-human-surface-mobility/lunar-terrain-vehicle/
3. STMD Shortfalls (1626: Advanced Sensor Components: Imaging): https://www.nasa.gov/spacetechpriorities/
4. Handheld Universal Lunar Camera: https://www.nasa.gov/humans-in-space/nasa-signs-agreement-with-nikon-to-develop-lunar-artemis-camera NASA Signs Agreement with Nikon to Develop Lunar Artemis Camera - NASA

T11.05: Model-Based Enterprise (STTR)

Related Subtopic Pointers: S17.02, S17.03, Z-ENABLE.05
Lead Center: LaRC
Participating Center(s): ARC, GSFC, HQ, MSFC, SSC

Subtopic Introduction:

MBE targets the use of models in any function, from engineering to safety to finance to facilities and more (i.e., model-based anything [MBx]). The goal is 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. This subtopic focuses on applying MBE approaches to analyze gaps in existing regulations and standards to enable approval and adoption of novel AAM vehicles for airspace operations.

Scope Title: Model-Based Systems Engineering, Digitally Interacting Comprehensive Frameworks and Models, and Decision-Making Capabilities for Agency Research Investments

Scope Description:

Novel technologies often promise unique benefits for transportation systems. The focus usually becomes one of advancing the state of the technology to demonstrate the concept in an operational environment or developing a prototype of the novel technology. While many novel technologies seem to be demonstrated, the challenge is characterizing the environment. Properly representing the operational environment can be done, in part, by assessing the technology's ability to meet standards and regulations associated with its design and operation. These standards and regulations are where society's expectation of safety, performance, and service are codified.

The dilemma is balancing the promise of the novel technology with the societal expectation of safety and performance. Disregarding the standards and regulations results in an irrelevant environment and diminishes the novel technology to the role of an interesting novelty. On the other hand, strictly interpreting the standards and regulations results in stifling the potential innovation of the novel technology.

This solicitation requests an integrated model-based enterprise (MBE) environment to assess the vehicle, operation, and airspace gaps in current regulations and standards to enable future vehicles. The innovation should provide a clear identification of gaps along with a means to prioritize the most critical gaps to be addressed.

The traditional solution uses subject matter experts to conduct a gap analysis to see where the novel technology fits within a given set of relevant regulations and standards and where gaps need to be addressed with new regulations and standards. Gaps are then identified and assessed to determine whether they are applicable or whether they need replacing with new relevant regulations and standards. Experts in both existing regulations and the novel technologies typically conduct this gap analysis in practice. Any change to the technology or the standards requires the gap analysis to be redone. This becomes time-consuming and inefficient, especially in an agile technology development effort (for example, during the concept development phase). NASA has previously examined the application of model-based systems engineering (MBSE) to a specific example of conducting the regulatory and standards gap analysis for an integrated megawatt (MW)-class powertrain system. This approach has demonstrated much promise by providing a means to identify gaps in the design and testing of vehicle regulations and standards for electrified aircraft (associated with 14 CFR Parts 25 and 33, in particular). The challenge of this subtopic is to apply this or a similar method to any variety of advanced air mobility (AAM) designs.

Proposals should present a use case and conceptual architecture of the proposed MBE innovation as it applies to modeling and gap analysis of airspace regulations and standards. The proposal should also address how the proposed innovation facilitates updates in response to changes in regulations, standards, or AAM technologies. Proposers should consider integration of the MBE model with NASA tools for AAM modeling, such as those developed and maintained by the Revolutionary Aviation Mobility Portfolio under NASA's Transformational Tools & Technologies Project (https://nari.arc.nasa.gov/ttt-ram/).

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

Primary Technology Taxonomy:

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

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Hardware
- Software

Desired Deliverables Description:

- Phase I: Delivery of reports identifying use cases, MBE architecture, proposed tool views, features and capabilities, identification of NASA or industry leveraging or integration opportunities, test data from proof-of-concept studies, partial-functionality software prototype, and designs for Phase II.

- Phase II: Delivery of MBE models/tools/platform that demonstrates capabilities for identified use cases. A 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 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. Real-time collaboration and refinement of these validated libraries into either “single source” or “authoritative sources” of truth provides 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 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 the 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, when 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:

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

References:

1. “An Overview of NASA’s AAM Mission and Select Partnerships,” NTRS - NASA Technical Reports Server, 2023: https://ntrs.nasa.gov/citations/20230008601
2. “Overview of NASA EPFD Regulations & Standards,” 8/24/2023: https://aam-cms.marqui.tech/uploads/aam-portal-cms/originals/4e6ec688-85e3-4efe-8787-8d20bb469f31.pdf
3. “An MBSE Framework to Identify Regulatory Gaps for Electrified Transport Aircraft,” NTRS - NASA Technical Reports Server, 2023: https://ntrs.nasa.gov/citations/20230003302
4. “Transformative Tools & Technologies Project,” Transformative Aeronautics Concepts Program (TACP): https://nari.arc.nasa.gov/ttt-ram/

5. “Quality Systems - Aerospace - Model for Quality Assurance in Design, Development, Production, Installation and Servicing,” SAE International, 11/1/1999: https://www.sae.org/standards/content/as9100/
6. OMG Technical Meeting, OMG Standards Development Organization, 2024: https://www.omg.org/
7. OpenMBEE: https://OpenMBEE.org
8. “Formal Methods in Resilient Systems Design using a Flexible Contract Approach,” Systems Engineering Research Center: https://sercuarc.org/project/?id=64&project=Formal+Methods+in+Resilient+Systems+Design+using+a+Flexible+Contract+Approach

T12.01: Additively Manufactured Electronics for Space Applications (STTR)

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

Subtopic Introduction:

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, atmosphere probes, and instruments/subcomponents of ocean world landers. Some of the electronics in these missions will likely need to perform below cold survival temperatures associated with warm electronics boxes (i.e., colder than -35 °C).

Scope Title: High-Temperature Additively Manufactured Electronics

Scope Description:

Electronics integration in extreme temperature applications is a challenging problem that often requires complex and specialized manufacturing technologies. This is specifically true for high-temperature applications where standard space-grade materials and processes in electronics can’t be easily applied. Several applications that require structural and electrical integration at high temperature include Venus missions, solar probes, and even propulsion applications. Continuous-use temperatures for these applications could be 500 ºC to 800 ºC. There is specific interest in developing AME approaches that can readily withstand these temperatures. Such an approach should address the following technical challenges:

1. AME method must be able to deposit conductor material on high-temperature, compatible insulating substrates.
2. Methods must exist to allow interconnectivity through the high-temperature substrate.
3. AME conductors must be able to withstand continuous exposure to temperatures between 500 ºC and 800 ºC for extended duration (≥ 1000 hours) without significant degradation.
4. AME conductors must support electrical attachment of sensors.
5. The high-temperature substrate may be part of the AME manufacturing process.

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 12.1 Materials

Desired Deliverables of Phase I and Phase II:

- Research
- Prototype

Desired Deliverables Description:

Effectiveness of material adhesion and material behavior at elevated temperatures should be understood given the extreme environment temperatures. Material sets and methodologies should be readily available for NASA centers to use on application-specific designs to meet future needs.

- Phase I: This phase should demonstrate that materials selected have the capability to have repeatable processing. Phase 1 should also demonstrate integration methods to the AME conductors.
- Phase II: The deliverables for Phase II should include the design, fabrication, and demonstration of incorporated elements in an application of interest for space use. 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 at extreme high temperatures.

Relevance / Science Traceability:

Use of AME is relevant to the 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 International Space Station (including major work from NASA centers on fabrication of circuits in space). Future AME missions that will encounter extreme high temperatures include Venus and solar probes as well as propulsion systems. These are relevant to SMD and STMD goals.

References:

1. Mohammed Alhendi, Firas Alshatnawi, El Mehdi Abbara, Rajesh Sivasubramony, Gurvinder Khinda, Ashraf I. Umar, Peter Borgesen, Mark D. Poliks, David Shaddock, Cathleen Hoel, Nancy Stoffel, and Tommyhing-K.H. Lam: "Printed Electronics for Extreme High Temperature Environments," Addit. Manuf., Vol. 54, 2022, 102709. https://doi.org/10.1016/j.addma.2022.102709
2. M. A. S. R. Saadi, Alianna Maguire, Neethu T. Pottackal, Md Shajedul Hoque Thakur, Maruf Md. Ikram, A. John Hart, Pulickel M. Ajayan, and Muhammad M. Rahman: “Direct Ink Writing: A 3D Printing Technology for Diverse Materials,” Adv. Mater., 2022, 34, 2108855. https://doi.org/10.1002/adma.202108855

Scope Title: Large-Scale Reflectarrays using Additively Manufactured Electronics

Scope Description:

Current methods of creating large format reflectarrays can require manual placement of conductive elements or coordinated measuring machine (CMM) assisted alignment and bonding of multiple elements. In part, this is due to limitations on panel sizes for traditional manufacturing processes that require lithography. These additional processes can reduce alignment, increase the necessary tooling, and require complex CMM to assemble. AME roll processing has been demonstrated using both aerosol and inkjet methods. These can be used to directly print large-scale patterns that could be used for future reflectarray applications. Applications for these arrays could include incorporating printed elements into a composite structure or the use of tensioned members in deployable reflectarray [Ref. 1] or metalens [Ref. 2] antenna. Such an approach should consider the following technical challenges:

1. Roll width needs to be at least 1 m of patterned surface.
2. Yield needs to be sufficient to print at least 2 m in length.
3. The material system needs to handle temperatures between -180 ºC and 125 ºC.
4. The printing technology should be compatible with multiple substrates including materials with improved RF performance.

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:

- Research
- Prototype

Desired Deliverables Description:

- Phase I: This phase should:
    - Demonstrate that materials selected have the capability to have repeatable processing.
    - Demonstrate material system compatibility substrate and inks to the desired temperature range.
    - Attempt to demonstrate full-scale fabrication and fully identify any gaps in materials and processes.
- Phase II: Deliverables in this phase should include full-scale fabrication (~1 m by 2 m) delivered to NASA for possible use. Phase II is expected to resolve any reproducibility issues as well as provide scaling and accuracy capabilities.

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. Current work shows the technology easily scales to large formats for use in commercial applications. The current work does not show this technology being tested for NASA relevant environments or meeting the print accuracy needed for the size of this application.

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 International Space Station (including major work from NASA centers on fabrication of circuits in space). There are many future missions where large reflectarrays or other large-format printed circuit needs would be of direct use. These are relevant to SMD and STMD goals.

References:

1. Manan Arya et al: "Large-Area Deployable Reflectarray Antenna for CubeSats," AIAA Scitech 2019 Forum, 2019.

2. Jung Eun Park et al: "Multilayer Tensioned Membrane Structures for Radio-Frequency Lenses," AIAA SCITECH 2024 Forum, 2024.

T12.10: Low-Cost Manufacturing and Integration of Reusable Thermal Protection Systems (TPS) (STTR)

Related Subtopic Pointers: S16.05, Z-LAND.02
Lead Center: JSC
Participating Center(s): ARC, KSC, LaRC

Subtopic Introduction:

Commercial space needs lower cost and robust thermal protection system (TPS) solutions for current and next-generation reusable transportation vehicles to support the formation of a sustainable low-Earth orbit (LEO) economy. The current state of the art for reusable TPS is largely derived from Space Shuttle heritage; however, these are constrained by high costs, long lead times, supply chain challenges, and performance limitations. Existing solutions include lightweight ceramic tiles and blankets, hot structures, and metallic TPS. Many competent high-temperature refractory materials with suitable manufacturing processes exist but have not yet been applied to the reusable entry vehicle problem.

This subtopic seeks to generate solutions for reusable TPS suitable for return from LEO with reduced costs and feasible, scalable paths for manufacturing and integration. Proposed cost reductions could be achieved through raw material selection, manufacturing and installation, and/or operations.

Examples include:
- Alternative compositions (e.g., alternate silica fibers for a Shuttle-like insulating tile).
- New materials entirely (e.g., carbide, boride, or nitride ceramics or metallic systems).
- Novel and efficient manufacturing processes (e.g., additive manufacturing, automation, microwave sintering, etc.).
- Streamlined operations (e.g., reduced or eliminated refurbishment between flights).

Proposers are requested to establish a clear potential for cost reduction over a comparable heritage solution. The ideal solution would represent an advancement in more than one, if not all, of the above areas (material selection, manufacturing and integration, and operations).

This subtopic seeks to develop solutions for several Civil Space Shortfalls identified by NASA's Space Technology Mission Directorate (STMD), including:
- 1624: Advanced Thermal Management Technologies for Diverse Applications.
- 1567: Entry Capabilities for Small-Scale and Commercial Spacecraft.
- 1572: Performance-Optimized Low-Cost Aeroshells for EDL Missions.

Furthermore, the subtopic addresses gaps in STMD mission thrusts EXPLORE (Advanced Manufacturing) and LAND (Entry, Descent, and Landing [EDL] Technology).

Scope Title: Low-Cost Manufacturing and Integration of Reusable Thermal Protection Systems (TPS)

Scope Description:

Material Characteristics:

Materials for use in reusable TPS must be capable of withstanding several high heat flux exposures associated with LEO reentry without severe degradation or deleterious changes to material properties. Oxide and non-oxide ceramics as well as metallic materials are primarily of interest for reusable TPS. Materials may be made resistant to oxidation or other forms of degradation via the application of coating systems. Coating systems can also modify the optical and catalytic properties of the surface to enable survival in more extreme conditions. The scope of this subtopic spans the bulk material, coatings (if applicable), and attachment system, as well as expected long-term operations of a vehicle equipped with such a TPS. All these areas must be considered together for a cohesive, effective TPS solution. The proposed solution—including the material system, manufacturing and integration approach, and operational processes—should offer a combined reduction in cost relative to heritage systems. The long-term operating cost, including the need for inspections or refurbishments between flights, should be considered. The robustness of the system to expected environments (e.g., the micrometeoroid and orbital debris [MMOD] environment) is an important driver of these operational considerations.

Desired Capabilities and Characteristics:

- Capable of reuse for LEO reentry at temperatures ≥ 815°C and 1,500°F, with higher temperature capability desired.
- Thermal properties such that all elements of the system, including any underlying structural components, maintain reasonable, survivable temperatures. Multiple layers may be used to limit thermal soak through the thickness (e.g., a dense ceramic outer layer backed by lightweight insulation).
- The material, its attachments, and interfaces must withstand anticipated loading without failure throughout launch, thermal cycling on-orbit, and hypersonic reentry.
- Constituent materials should be available in sufficient quantities and with adequate lead times to support manufacturing at scale for the foreseeable future.

The material must be designed with manufacturing and integration in mind. For Phase I, conceptual designs for manufacturing scale-up and integration onto a spacecraft structure must be considered. Small-scale manufacturing demonstration is expected in Phase I. For Phase II, the material should be manufactured in a form and scale suitable for integration onto a vehicle.

Phase I Proposal Expectations:

The proposal should include the following:

- A clear description of the TPS concept, including the material system, manufacturing approach, integration approach, and anticipated operational mode(s).
- A detailed description of the proposed materials and how they will be processed and tested.
- Evidence that the proposed material system and manufacturing and integration approaches are good candidates relative to heritage materials in terms of performance and cost.
- Test plan and schedule to evaluate the material against the provided desired material properties.
- Description of test articles to be delivered to NASA for testing.

Research institutions (RIs) are anticipated to contribute to areas of materials development and testing, though their work is certainly not limited to that. RIs are uniquely situated to pursue development and testing on novel high-temperature materials, including ceramics and metallic alloys, which are well suited as reusable TPS materials.

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 12.1 Materials

Desired Deliverables of Phase I and Phase II:

- Research
- Prototype
- Hardware

Desired Deliverables Description:

Phase I:

1. Develop conceptual design of the material system, manufacturing process, and integration process.
2. Demonstrate the capability to fabricate the material.
3. Establish evidence for cost reduction over comparable heritage solutions and robustness of the supply chain for future scale-up.
4. Conduct material property testing relevant to desired material properties.
5. Conduct high enthalpy tests of the manufactured material.
6. Deliver small-scale articles to NASA for testing.

Phase II:

1. Manufacture material in a form and scale suitable for integration onto a vehicle. If tiled, will include several sections or segments to capture seam and joint configurations.
2. Conduct material property testing for a greater range of temperature and pressure conditions.
3. Demonstrate capability to integrate the TPS material onto a structure.
4. Conduct tests on the integrated TPS/structure.
5. Perform analysis for manufacturing, integration, and operating cost to demonstrate cost reduction over comparable heritage solutions.

State of the Art and Critical Gaps:

State-of-the-art reusable TPS date back to the Space Shuttle Orbiter and have not seen significant advancement since the 1990s. Existing solutions are high-touch labor, high cost, and long lead time with weak supply chains. A push toward spacecraft reusability to reduce costs and establish a sustainable LEO economy has highlighted the need for reusable TPS solutions with lower cost, improved robustness, enhanced operability, and healthy supply chains. Novel manufacturing and integration approaches paired with readily available raw materials can reduce cost and schedule while ensuring a sustainable solution into the future. Health monitoring and inspection capability can ease operational overhead and enable rapid refurbishment of TPS. Together, such advances are aimed at making reusable TPS more accessible for the future of space transportation.

Relevance / Science Traceability:

All missions that return to Earth or enter a planetary atmosphere require TPS to protect the spacecraft from the high heating associated with hypersonic flight. TPS with increased temperature capability and improved reusability will benefit the development and operation of spacecraft, whether used for return of humans or cargo to Earth from LEO, return from the Moon, or landing on Mars. Although the scope of this subtopic focuses on LEO transportation systems, advancements in reusable TPS may find infusion in lunar, Martian, and other missions.

Benefits would have impacts across the agency, including the Exploration Systems Development Mission Directorate (ESDMD), Space Operations Mission Directorate (SOMD), Commercial Crew Program, and Commercial LEO Destinations Program. The science and technology generated also would benefit the Science Mission Directorate (SMD) and Space Technology Mission Directorate (STMD).

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T12.11: Biomanufacturing for Space Missions: Harnessing Microbial Communities for Sustainable Production in Moon and Mars Environments (STTR)

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

Subtopic Introduction:

This subtopic is intended to encourage and attract innovations that harness the efficiency of biofilm [Ref. 1] in the biomanufacturing of building materials, pharmaceuticals, food, clean soil, oxygen, and energy using available feedstock in Moon and Mars conditions. Biofilms present unique opportunities for developing sustainable biomanufacturing processes tailored for space missions by producing useful molecules [Refs. 2-4]. Current methods lack the necessary public data on growth rates, low feedstock requirements, stability, and productivity in simulated Moon and Mars environments [Ref. 5]. It is imperative to address gaps in the industry by conducting foundational research to balance microbial and feedstock requirements in key organisms. The goal is to develop robust, scalable systems that minimize waste, match performance of off-the-shelf products, and support long-duration human exploration of space.

Efforts shall focus on conceptualizing and assessing the feasibility of these processes, with an emphasis on using current Environmental Control and Life Support System (ECLSS)-related feedstock (CO^2, brine, fecal waste, methane), reduced use of water sources, supplemented only by regolith, to establish a closed-loop system, and deliver a prototype system. Biofilm shall be used in uniquely designed hardware with respective vessels, support structures, supplementary equipment (e.g., pumps and mixers), sensors, control systems, harvesting systems, and downstream processes. The successful development of these systems will reduce the need for resupply missions from Earth, thereby enhancing the sustainability of NASA's Moon and Mars missions.

Scope Title: Biofilm Cultivation and Optimization for Space Environments

Scope Description:

Groups at NASA and other entities have made significant advances in biomanufacturing [Ref. 6]. However, there remains a need to streamline optimized processes and extend shelf-life research to translate recent findings into high Technology Readiness Level (TRL) hardware applicable for Moon and Mars missions. This scope focuses on the foundational work required to balance microbial and feedstock requirements. Biological methods and guidelines are essential for developing a biomanufacturing process and streamlining a product suitable for missions beyond Earth's boundaries. Conducting preliminary experiments before scaling up to broader industrial processes is critical. By utilizing primarily ECLSS-related feedstock, as previously mentioned, the aim is to reduce waste in life support systems and close the loop on sustainable crew activities in the production of necessary byproducts [Ref. 6].

The preliminary data collected by the development team will provide essential insights into the growth rates, stability, and productivity of the biofilms, laying the groundwork for further optimization in Phase II. The optimization and eventual prototyping of the system process will demonstrate an isolated end product, surpassing current advances and state of the art in biomanufacturing, that is useful to astronauts such as meals, drugs, manufacturing items, and energy.

Furthermore, advances in biomanufacturing using biofilm relies on refining methods for production and developing areas of science gaps such as:

- Limited understanding of biofilm development dynamics and the lack of biological toolkits for controlling biofilm dynamics [Ref. 7].
- Scarce availability of streamlined gene expression tools in microbial organisms, restricting the use of synthetic biology applications [Ref. 8].
- Challenges in maintaining long-term robustness and continuous and stable interactions among species in an optimized process [Ref. 9].
- Lack of research on the spatial distribution of different species within multispecies biofilms and how this impacts community stability [Ref. 10].
- Evolutionary decay of genetic circuits in engineered microbial populations [Refs. 11,12] and the need for strategies to reduce mutation-prone designs and host mutation rates to prevent evolutionary decay of genetic circuits [Ref. 13].
- Limited knowledge on interactions within microbial communities and how they can be harnessed to engineer stable interactions or cell-free interactions [Refs. 14,15].

Expected TRL or TRL Range at completion of the Project: 1 to 4

Primary Technology Taxonomy:

- Level 1: TX 12 Materials, Structures, Mechanical Systems, and Manufacturing
- Level 2: TX 12.X Other Manufacturing, Materials, and Structures

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Hardware
- Prototype

Desired Deliverables Description:

Phase I Deliverables:

- Establish protocols for cultivating robust biofilms with existing feedstock relevant to space environments for the production of a chosen byproduct (construction materials, food, medicine, oxygen, energy). The deliverable shall define the feedstock, microbial organism(s), product, chemical reactions, and bioprocess architecture in a detailed report.
- Collect data on growth rates, stability, and productivity consistent with spaceflight and crew sustainability in Moon and Mars environments. Develop (at least 3) Key Performance Parameters (KPPs) that align with NASA Moon or Mars missions. Add experimental data and KPP formulation to a detailed final report.

Phase II Deliverables:

- Refine and optimize continuous biofilm cultivation systems in a bioreactor or equivalent system with the ability to produce the desired products under acceptable KPPs. A detailed response to one of the biomanufacturing knowledge gaps is required.
- Report and demonstrate scalable use of biofilm in the production processes that can be integrated into space mission operations. Scalability shall be proven via changes in hardware, feedstock, and increased performance of microbial organism. Deliver a working prototype.
- Report performance metrics showing efficiency, yield, and resilience of the biological systems.

State of the Art and Critical Gaps:

This scope addresses several critical gaps in the development of biofilm-based biomanufacturing processes for space missions. While synthetic biology has made strides in the development of optimized bacterial cells, the continuous production and stability of large-scale processes remain unclear in the space industry. One major gap is the limited understanding of optimal conditions and requirements for microbial growth and productivity to be used in scalable bioprocesses and specialized hardware using available feedstock in Moon and Mars environments. How these systems may travel long distances and continue to operate for long spans of time is also unknown.

Another gap is the lack of established biological methods and guidelines for biomanufacturing in the Moon and Mars environments. By conducting initial experiments, this project will develop and validate the biological methods and guidelines necessary for effective biofilm-based biomanufacturing in space conditions. Additionally, there is insufficient public preliminary data on the growth rates, stability, and productivity of biofilms under space-like conditions. The project scope will collect this essential data to inform further optimization and development of biomanufacturing processes.

Relevance / Science Traceability:

Mars Campaign Office (MCO)/Exploration Systems Development Mission Directorate (ESDMD)

This scope focuses on ESDMD's efforts to reduce frequency and volume of resupply missions from Earth, thereby lowering the cost and logistical complexity associated with supporting long-duration missions, while also being cognizant of the unused Life Support System (LSS) byproducts. Sustainable production of essential materials such as food, medicine, and construction materials directly within space habitats ensures that crew members have a reliable and continuous supply of necessary resources.

Developing robust biofilm cultivation systems and optimizing microbial growth for biomanufacturing represents a significant technological advancement, with innovations that can be adapted and scaled for various applications within space travel and Moon and Mars missions. These aims also help use knowledge of space biofilms in the field of manufacturing as well as tackle the gaps in other areas such as the Trash Compaction Processing System (TCPS). Collecting detailed performance metrics and demonstrating scalable production processes ensures that the technology may be practical for integration into mission operations.

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Scope Title: Biofilm-Driven Biomanufacturing Processes

Scope Description:

To evolve the technology readiness of potential in situ biomanufacturing, multidisciplinary work is required as scalable processes are troubleshooted [Refs. 1,2]. This scope focuses on critical early-stage work for small businesses to design and validate biofilm-driven biomanufacturing processes. Conceptualization and initial feasibility assessment are required with the goal of establishing an analysis-driven design to guide subsequent development and optimization efforts. Efforts must focus on the use of ECLSS feedstock (CO^2, brine, fecal waste, methane), minimal water and oxygen, potential Moon and Mars conditions, and regolith.

By creating detailed conceptual designs and conducting feasibility studies, the team shall establish a bioprocess-based foundation, which surpasses the state of the art and current advances in the field, for biomanufacturing systems that can produce essential bioproducts for crew sustainability (building materials, pharmaceuticals, food, clean soil, oxygen, or energy). This phase is crucial for identifying potential challenges and opportunities, ensuring that subsequent development is both technically feasible and economically viable.

Development teams should afterwards shift their efforts to the practical implementation and testing of these concepts. By developing and testing prototype systems, the development team shall demonstrate the functionality and scalability of matured biofilm-driven biomanufacturing processes. Production trials shall provide data on the efficiency and reliability of these systems with minimal crew time, while performance evaluations must ensure that necessary operational and safety standards are met. The development of operational guidelines provided by the development team shall facilitate the integration of these systems into NASA missions, providing clear protocols for their use.

Expected TRL or TRL Range at completion of the Project: 4 to 7

Primary Technology Taxonomy:

- Level 1: TX 12 Materials, Structures, Mechanical Systems, and Manufacturing
- Level 2: TX 12.X Other Manufacturing, Materials, and Structures

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Hardware

Desired Deliverables Description:

Phase I Deliverables:

- Report conceptual designs for biomanufacturing processes utilizing biofilms that produce specific bioproducts (building materials, pharmaceuticals, food, clean Moon or Mars soil, oxygen, or energy).
- Complete feasibility studies demonstrating the potential of biofilm-driven processes for targeted bioproducts and report results in detailed reports that include cost-benefit analyses, risk assessments, and technical feasibility reviews.

Phase II Deliverables:

- Develop, test, and deliver final prototype(s) of the biomanufacturing systems capable of operating with feedstock.
- Conduct and report production trials to validate the efficiency and scalability of the biomanufacturing processes.
- Report detailed evaluation of biomanufacturing system performance, including productivity, quality, and reliability of the bioproducts.

State of the Art and Critical Gaps:

Phase I focuses on small business conceptualization and data-driven design of a feasible system. Phase II utilizes outcomes of Phase I to demonstrate a higher TRL system operation with commercial feasibility and benefit to NASA gaps in scalable biological systems.

Relevance / Science Traceability:

Mars Campaign Office (MCO)/Exploration Systems Development Mission Directorate (ESDMD)

This scope is focused on advancing the capabilities of biofilm-driven biomanufacturing processes to support long-duration space missions. By emphasizing the initial design and feasibility assessment, we may establish a strong foundation for creating biomanufacturing systems that can produce critical bioproducts in situ. This effort is crucial for ensuring a consistent and reliable supply of essential resources, thereby reducing dependence on resupply missions from Earth and lowering overall mission costs and logistical challenges.

First, the project involves the development of conceptual designs for biomanufacturing processes utilizing biofilms, along with feasibility studies. These studies incorporate cost-benefit analyses, risk assessments, and technical feasibility reviews. This phase is essential for identifying the most promising bioproducts and ensuring that the proposed biomanufacturing methods are both economically viable and technically sound.

Next, businesses engage in practical implementation and testing of the developed concepts. This includes the creation and evaluation of prototype biomanufacturing systems capable of operating in NASA-targeted environments. Conducting production trials will validate the efficiency and scalability of these systems, while detailed performance evaluations will assess productivity, quality, and reliability. The development of operational guidelines and protocols will facilitate the integration of these systems into NASA missions. By focusing on TRL maturation and validation of biofilm-driven biomanufacturing processes, this scope directly supports the ESDMD's primary systems towards practical self-sufficiency. The successful implementation of these technologies will enable the MCO to achieve its long-term goals of human exploration and habitation on Mars by providing innovative solutions that address the challenges of resource management and production in space.

The concept-of-operations (CONOPS) aspect of off-world biomanufacturing, as well as the use of biofilms were topics of discussion in the current Decadal Survey on Biological and Physical Sciences Research in Space 2023-2032.

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T12.12: Spray Processing of Oxide Dispersion Strengthened (ODS) Alloy GRX-810 (STTR)

Lead Center: GRC
Participating Center(s): MSFC

Subtopic Introduction:

The need for metal alloys that can perform at extreme temperatures above 1,100 °C while remaining manufacturable has led to a resurgence of interest in printable oxide dispersion strengthened (ODS) alloys. Recently, NASA developed an ODS alloy designed for additive manufacturing, called GRX-810, which revealed exceptional tensile and creep performance at temperatures of 1,093 °C and above. While initial efforts have explored testing these ODS alloys made via powder bed fusion, additional processing techniques could expand the application space for these novel materials. Coating processing methods such as air plasma spray, vacuum plasma spray, high-velocity oxide fuel (HVOF), and cold spray are established industrial processes used to apply materials to substrates or components. Deposition of ODS alloys using the above processing techniques would provide an ideal method to incorporate novel materials with superior high-temperature properties into new applications using accepted industrial capabilities. Utilizing spray processing methods would allow ODS alloys to be deposited either as a coating or standalone material for machining into components. Combining these ODS alloys with new processing methods will provide a better understanding of the material limitations, overcome scaling issues, and provide new applications that cannot be achieved with laser-based fusion methods.

Scope Title: Spray Processing of Oxide Dispersion Strengthened (ODS) Alloy GRX-810

Scope Description:

Phase I should show feasibility and proof of concept for material consolidation and microstructural characterization of spray processed GRX-810 while Phase II should emphasize property evaluation and scalability.

- Evaluate optimal powder size distribution, oxide loading on powder, and ideal composition of base alloy to optimize high-density material consolidation.
    - Show high density of deposited material using Archimedes or optical microscopy methods.
- Processing via spray methods can change the composition due to high-energy processing, and composition in the deposited state can differ significantly from the ideal stoichiometry.
    - Deposition parameters need to be optimized for ideal manufacturing of the ODS alloys to achieve the ideal mechanical and thermal capabilities as well as the location of the oxide dopants.
- Industrial processes such as thermal spray and cold spray can achieve high deposition rates that are equivalent or faster than additive printing methods for both coatings and bulk manufacturing.
    - Determination whether these techniques can be used to deposit these materials as a coating or bulk material that could be machined later is critical to understanding future applications and impact.
- Mechanical, thermal, and oxidation properties and performance should be evaluated for the consolidated materials via established testing methodologies up to 1,300°C.
    - Variation of material composition and oxide dopant location will impact high-temperature properties, and processing methods are expected to provide additional challenges and opportunities with these systems.

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

Primary Technology Taxonomy:

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

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis

Desired Deliverables Description:

Phase I should show feasibility and proof of concept by showcasing a highly dense build of an ODS alloy using an additive spray process. Microstructural characterization will be expected to determine build density and oxide size distribution.

Phase II will be expected to deliver the following objectives:

- Determine optimized parameters needed for ideal manufacturing of ODS alloys for ideal mechanical and thermal capabilities. A focus should be given to understanding how process parameters affect the distribution of the oxides in the consolidated material.
- Optimized parameters need to possess deposition rates equivalent to or faster than currently utilized additive processes, such as laser powder bed fusion or directed energy deposition. In addition, if coating a substrate is a target of the investigation, it is expected that multiple materials are explored and an understanding is developed over how substrate composition affects the ODS coating.

- High-temperature material properties (mechanical, thermal, and oxidation) should be evaluated for the consolidated materials up to 1,300 °C.

State of the Art and Critical Gaps:

Rocket engine components must withstand some of the most challenging environments, including high pressure, extreme thermal loads, and dynamic stresses. Turbine engines, operating for hundreds or thousands of hours, face similar demands. Advanced materials are crucial for meeting these requirements to ensure operational efficiency and balance programmatic needs, economic factors, and acceptable risk levels. As additive manufacturing has evolved from prototyping to mainstream production, it has facilitated the development of new material classes, such as ODS alloys. NASA researchers have recently introduced the novel ODS alloy GRX-810 that has demonstrated significant advantages, including a two-fold increase in tensile strength, 1,000-fold improvement in creep properties, and a two-fold increase in oxidation resistance compared to standard nickel-based alloys at temperatures above 1,000 °C. Currently all efforts on scaling GRX-810 have pertained to the manufacturing process called laser powder bed fusion (L-PBF). Though this manufacturing process is considered mature within industry, it has scaling limitations that only can be overcome using different additive techniques.

Coating processing methods such as air plasma spray, vacuum plasma spray, high-velocity oxide fuel (HVOF), and cold spray are established industrial processes used to apply materials to substrates or to produce consolidated components. These manufacturing avenues are of high interest to produce alloys such as GRX-810 as they are not as limited to part size as is L-PBF. However, ODS alloys have not yet been produced using these techniques, and challenges may need to be overcome to provide builds with sufficient oxide distributions. Efforts also need to be made to better understand how the properties of ODS alloys produced using these methods compare to the current state-of-the-art L-PBF process. If these challenges can be overcome, the application space of ODS alloys will greatly increase.

Relevance / Science Traceability:

There has been significant interest in developing GRX-810 using these other additive processes both within NASA and outside government and industry partners. Potential advocates include:

- NASA Aeronautics Research Mission Directorate (ARMD): Transformational Tools and Technologies
- NASA ARMD: Hypersonics Technology Project
- NASA Space Technology Mission Directorate (STMD): Nuclear Thermal propulsion
- NASA STMD: Game Changing Development (Optimized and Repeatable Components in Additive-manufacturing [ORCA], Rotating Detonation Rocket Engine [RDRE])
- Air Force Research Laboratory
- Department of Defense
- Oil and gas industry
- Defense industry

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T13.02: High-Efficiency, Reliable Electrical Subsystems for Cryogenic Pumps (STTR)

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

Subtopic Introduction:

With advancements in power and electrical storage systems and electronics, electrically driven pumps are becoming more capable and are being used for more applications across the aerospace industry. There is potential for highly reliable electrical subsystems driving cryogenic pumps to significantly increase capabilities for lunar and Martian commodity surface transfer, while also reducing costs for propulsion test and ground cryogenic transfer systems. However, current power requirements are too costly, maintenance needs are too frequent, and the failure rates are too high for these systems to be a practical option for long-term missions and cost-effective operations.

Scope Title: High-Efficiency, Reliable Electrical Subsystems for Cryogenic Pumps

Scope Description:

Current high-performance, electrically driven cryogenic pumps require high power, significant infrastructure, frequent maintenance, significant cooling, and complex drive systems with unreliable components. This solicitation aims to identify advancements that can significantly improve performance of electrical and control subsystems for driving cryogenic pumps under challenging environmental conditions. Particular focus is on power and thermal management, switching devices, more robust components, and sealed systems that can reduce maintenance and power requirements while increasing mean time between failures:

- Electrical, control, and drive subsystems will be used to pump cryogenic fluids. Cryogenic fluids of interest are liquid nitrogen, liquid oxygen, liquid hydrogen, and liquid methane.
- Proposals should focus on advancements in electrical components such as power electronics, motor drives, sensors, and control systems. Innovations should aim to optimize power consumption, improve response to dynamic load variations, minimize heat dissipation, and enhance overall system efficiency and reliability. This includes innovative power management strategies that reduce losses and improve efficiency.
- Solutions should demonstrate robustness and resilience to extreme temperatures, ensuring long-term operational stability with minimal maintenance requirements. Proposals should include advancements in sealed systems and environmental protection to mitigate the impact of the environment and harsh operational conditions.
- Innovations in switching devices (e.g., transistors, switches) are critical for efficient power control and modulation in cryogenic pump applications. Proposals should address advancements in switching technology that enhance reliability, reduce losses, improve response times, and reduce potential transients.
- Considerations for seamless integration with existing and future surface systems and adaptability across different pump sizes requiring varying performance are crucial. Compatibility with industry standard interfaces, protocols, and communication networks to facilitate easy integration and interoperability is desirable.

- Considerations should be made to reduce footprint, size, and weight of systems to improve flexibility and efficiency of installations in harsh, remote environments and locations.

This topic is applicable to both NASA and the commercial aerospace industry. This level of performance is mainly of interest to aerospace propulsion applications, but improvements in cryogenic pump design could benefit the oil and gas industry, transportation sector, automotive industry, and industrial cryogenics handling by reducing operating costs and increasing reliability and performance.

Successful development of this technology will lead to electrical subsystems for pumps that can provide cryogenic commodities with lower power requirements and more reliability than currently available options. Testing can be conducted at Stennis Space Center (SSC) to verify performance. If successful, a pump could provide a new capability for long-duration, cost-effective operations that would be of interest for future test customers.

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:
- Analysis
- Prototype
- Hardware
- Software

Desired Deliverables Description:
During Phase I, research for all technologies should demonstrate technical feasibility, proposed technical specifications, performance metrics, and proof of concept and also show a pathway toward Phase II hardware prototype demonstration. Delivery of a demonstration unit for NASA testing should occur at the completion of the Phase II contract.

Successful Phase II technologies will be candidates for integration and demonstration in the ground test and support facilities at SSC and Kennedy Space Center (KSC), as well as other cryogenic fluid management, launch support, and propulsion system development centers.

State of the Art and Critical Gaps:

The state of the art for this subtopic includes brushless drives, servo drives, and variable frequency drives with power supplied by considerable facility infrastructure and utilizing large power encoders, standard insulated-gate bipolar transistors (IGBTs), capacitors, and forced air ventilation or water cooling. In addition to requiring significant power and infrastructure, there is currently a need for frequent maintenance to condition, inspect, clean, and replace electrical components. Pumps with increased efficiency and reduced mass are needed for lunar and Mars missions. Mass and power restrictions for lunar and Mars elements will require low mass, highly efficient and reliable, lower-power subsystems for commodity transfer pumps. In addition to being volume limited, transfers may also be time constrained, requiring higher flow rates that could be produced from highly efficient pumps rather than pressurant tanks.

Reducing failures is possible with the development of more robust components to improve reliability and smarter control schemes. Electrical components and improved designs to improve longevity in harsh environments are possible through improved thermal and power management schemes. Reduced power and maintenance requirements through innovative components and control schemes, combined with other innovations, not only support cost-effective ground operations and propulsion tests, but also surface transfer systems. Future cryogenic transfer operations will require autonomous processes that also can be enabled by these innovations.

A sustained lunar presence will rely on robust fluid management technologies to ensure on-demand availability of critical fluids. Capabilities to autonomously control flow will be desired. In addition, supervised autonomous commodities conditioning across a network of storage locations and transfer lines, including consumption monitoring along with production and delivery tracking, will be desired to ensure on-demand availability, which can be enabled by advanced electric pump systems.

The ability to transfer a cryogenic liquid (usually propellant) from one tank to another is a strategic technology that is not mature. At issue is performing the transfer with minimal commodity loss and waste (unusable propellant in the supply tank). There are many aspects to transfer operations, such as tank pressurization, liquid acquisition, line and tank chill down as well as cryo-couplers.

Mobility systems are needed that are capable of transferring commodities across a complex network of surface system assets to transfer commodities between elements. For example, excess commodity may need to be transferred back to storage from individual elements, and mobile refilling capability may be needed to increase the duration of elements away from a central logistics area. These areas can be better enabled by advanced, lower power, reliable electrical and control subsystems for driving cryogenic pumps.

Relevance / Science Traceability:

This subtopic is relevant to these areas:

- Development of liquid propulsion systems development and verification testing in support of the Moon to Mars architecture.
- Space Technology Mission Directorate (STMD) strategic thrusts GO: develop rapid, safe, and efficient space transportation and LIVE: sustainable living and working farther from Earth.
- Exploration Systems Development Mission Directorate (ESDMD) and Space Operations Mission Directorate (SOMD).
- Autonomous Systems Lab (ASL).
- Ground test and support facilities at SSC and KSC and cryogenic fluid management, launch support, and propulsion system development at other NASA centers.

This subtopic directly supports these Civil Space Shortfalls (while indirectly supporting others):

- 792: In-space and On-surface transfer of cryogenic fluids.
- 1612: Surface-based fluid management for near/mid-term missions.
- 1613: Surface-based fluid management for sustained lunar evolution.

References:

1.) Stennis Space Center Home Page: https://www.nasa.gov/centers/stennis/home/index.html
2.) NASA Moon to Mars Architecture: https://www.nasa.gov/moontomarsarchitecture/
3.) NASA STMD Strategic Framework: https://techport.nasa.gov/strategy
4.) Abebe, R. et al. “Integrated motor drives: state of the art and future trends.” IET Electric Power Applications, 2016. https://ietresearch.onlinelibrary.wiley.com/doi/full/10.1049/iet-epa.2015.0506
5.) Renken, F. “High-temperature electronics for future hybrid drive systems.” 13th European Conferences on Power Electronics and Applications, Barcelona, Spain, 2009. https://ieeexplore.ieee.org/abstract/document/5278978
6.) Jahns, T and Dai, H, “The past, present, and future of power electronics integration technology in motor drives,” CPSS Transactions on Power Electronics and Applications, Vol. 2, No. 3, September 2017. https://ieeexplore.ieee.org/document/8118375

7.) Santiago, W, et al. High Power Silicon Carbide (SiC) Power Processing Unit Development, Report presented at Electrochemical Society (ECS) Meeting, October 2015. https://ntrs.nasa.gov/citations/20150023084
8.) Wang, J. and Han, Y., "A class of modular multilevel motor drives with design flexibility and reduced components number," 2015 IEEE Applied Power Electronics Conference and Exposition (APEC), Charlotte, NC, 2015. https://ieeexplore.ieee.org/document/7104682
9.) Improving Motor and Drive System Performance, U.S. Department of Energy: https://www.energy.gov/sites/prod/files/2014/04/f15/amo_motors_sourcebook_web.pdf
10.) Civil Space Shortfall Ranking https://www.nasa.gov/spacetechpriorities/

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

Related Subtopic Pointers: A1.02, A1.04, A1.06, A2.01, A2.02, A3.05
Lead Center: AFRC
Participating Center(s): LaRC

Subtopic Introduction:

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

The subtopic is designed to accelerate the development timeline of full-scale electric vertical take-off and landing (eVTOL) aircraft. The main focus areas are aerodynamics, propulsion, flight dynamics, controls, scaling, and/or acoustics, with potential to address focus areas in combination. This solicitation seeks proposals for designs or experiments that address full-scale applications. Full-scale is defined as a payload capacity equivalent to two or more passengers or equivalent cargo. Although eVTOL is preferred, electric short takeoff and landing (eSTOL) vehicle configurations are acceptable.

Scope Title: Full-Scale (Passenger/Cargo) Electric Vertical Takeoff and Landing (eVTOL) Scaling, Propulsion, Aerodynamics, and Acoustics Investigations

Scope Description:

The subtopic scope is designed to accelerate the development timeline of full-scale eVTOL aircraft via flight test. The main focus areas are aerodynamics, propulsion, flight dynamics, controls, and/or acoustics, with the potential to address focus areas in combination. Proposals are sought to:

1. Design and execute experiments in order to gather research-quality data to validate aerodynamics, propulsion, flight dynamics, controls, and/or acoustics modeling of full-scale, multirotor eVTOL aircraft, with an emphasis on rotor interactions with airframe components and other rotors and propellers.
2. Develop and validate scaling methods for extending and applying results of the instrumented subscale model testing to full-scale applications (if the proposal includes testing of subscale models).

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

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

Proposals should address the following if applicable:

1. Clearly define the data that will be provided and how it will help NASA and the community accelerate the design cycle of full-scale eVTOL aircraft and/or address significant barriers to market penetration. Also, define the data to be collected, data that will be considered proprietary, and data that will be available for publication. Data includes vehicle specifications; component and subsystem specifications; and performance, geometries, models, results, flight test data, and any other information relative to the work proposed.
2. If the proposal cannot address the full topic, please state the reasoning/justification.
3. Clearly propose a path to commercialization and include details with regards to the expected products, data, stakeholders, and potential customers.

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

Primary Technology Taxonomy:

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

Desired Deliverables of Phase I and Phase II:

- Software
- Hardware
- Analysis
- Research
- Prototype

Desired Deliverables Description:

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

- Research and development objectives and requirements.
- Initial experiment test plans for gathering experimental results related to the aerodynamic, flight dynamic, control, and/or acoustic characteristics of a multirotor eVTOL aircraft, with an emphasis on interactions between rotors and between the rotors and the vehicle structure for either:
    - A full-scale flight vehicle.
    - A subscale vehicle with fully developed methods for scaling the results to full scale.
- Expected results for the flight experiment, using appropriate design and analysis tools.
- Design data and performance models for the vehicle and subsystems/components used to generate the expected results.
- Preliminary design of the instrumentation and data recording systems to be used for the experiment.
- Data that is expected to be collected including data that will be considered proprietary.

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

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

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

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

State of the Art and Critical Gaps:

Integration of distributed electric propulsion (DEP) (4+ rotors) systems into advanced air mobility eVTOL aircraft involves multidisciplinary design, analysis, and optimization (MDAO) of several disciplines in aircraft technologies. These disciplines include aerodynamics, propulsion, structures, acoustics, flight dynamics and/or control in traditional aeronautics-related subjects. Innovative approaches in designing and analyzing highly integrated DEP eVTOL aircraft are needed to reduce energy use, noise, emissions, and safety concerns. Such advances are needed to address ARMD's Strategic Thrusts #1 - Safe, Efficient Growth in Global Operations, #3 - Ultra-Efficient Subsonic Transports, and #4 - Safe, Quiet, and Affordable Vertical Lift Air Vehicles. Due to the rapid advances in DEP-enabling technologies, current state-of-the-art design and analysis tools lack sufficient validation against full-scale eVTOL flight vehicles, especially in the areas of aerodynamics, propulsion, and acoustics. Ultimately, the goal is to model and test multidisciplinary aeropropulsive flight dynamics, controls, and acoustics.

Relevance / Science Traceability:

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

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

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

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

References:

1.) ARMD/Advanced Air Transport Technology (AATT) Project: https://www.nasa.gov/directorates/armd/aavp/aatt-project/

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

Scope Title: Full-Scale (Passenger/Cargo) Electric Vertical Takeoff and Landing (eVTOL) Flight Dynamics Investigations

Scope Description:

The subtopic scope is designed to accelerate the development timeline of full-scale eVTOL aircraft via simulation or flight test. The main focus area is flight dynamics based on real world or intended real world full-scale vehicle built up from disciplines in aerodynamics, propulsion, and controls, with the potential to address focus areas in combination. Proposals are sought to design and execute experiments in order to utilize research-quality data to build up flight dynamics modeling and simulation of full-scale, multi-rotor eVTOL aircraft, with an emphasis on high/increased-fidelity real-time aerodynamics, flying qualities, handling qualities and ride quality.

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

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

Proposals should address the following if applicable:

1. Clearly define the data that will be provided and how it will help NASA and the community accelerate the design cycle of full-scale eVTOL aircraft and/or address significant barriers to market penetration. Also, define what data will be collected, data that will be considered proprietary, and data that will be available for publication. Data includes vehicle specifications; component and subsystem specifications; and performance, geometries, models, results, flight test data, and any other information relative to the work proposed.
2. If the proposal cannot address the full topic, please state the reasoning/justification.
3. Clearly propose a path to commercialization and include details with regards to the expected products, data, stakeholders, and potential customers.

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

Primary Technology Taxonomy:

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

Desired Deliverables of Phase I and Phase II:

- Research

- Analysis
- Prototype
- Hardware
- Software

Desired Deliverables Description:

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

- Research and development objectives and requirements.
- Initial experiment test plans for gathering experimental results related to the flight dynamic characteristics of a multirotor eVTOL aircraft, with an emphasis on interactions between rotors and between the rotors and the vehicle structure for a full-scale flight vehicle.
- Expected results for the experiment using appropriate design and analysis tools.
- Design data and performance models for the vehicle and subsystems/components used to generate the expected results.
- Preliminary design to be used for the experiment.
- Data that is expected to be collected including data that will be considered proprietary.

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

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

- Experimental results that capture flight dynamic characteristics of a multirotor eVTOL aircraft, with an emphasis on interactions between rotors and between the rotors and the vehicle structure for a full-scale flight vehicle.
- 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, flight dynamics, and/or control in traditional aeronautics-related subjects. Innovative approaches in designing and analyzing highly integrated DEP eVTOL aircraft are needed to reduce energy use, noise, emissions, and safety concerns. Such advances are needed to address ARMD's Strategic Thrusts #1 - Safe, Efficient Growth in Global Operations, #3 - Ultra-Efficient Subsonic Transports, and #4 - Safe, Quiet, and Affordable Vertical Lift Air Vehicles. Due to the rapid advances in DEP-enabling technologies, current state-of-the-art design and analysis tools lack sufficient validation against full-scale eVTOL flight vehicles, especially in the areas of aerodynamics, propulsion, flight dynamics, control, and acoustics. Ultimately, the goal is to model and test multidisciplinary aeropropulsive flight dynamics, controls, and acoustics.

Relevance / Science Traceability:

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

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

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

References:

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

Scope Title: Full-Scale (Passenger/Cargo) Electric Vertical Takeoff and Landing (eVTOL) Control Design and Implementation Investigations

Scope Description:

The subtopic scope is designed to accelerate the development timeline of full-scale eVTOL aircraft via flight test. The main focus area is control design and implementation based on real world or intended real world full-scale vehicle built-up aerodynamics, propulsion, and flight dynamics, with the potential to address focus areas in combination. Proposals are sought to design and execute experiments in order to validate controls modeling and development of full-scale, multi-rotor eVTOL aircraft, with an emphasis on flying qualities, handling qualities, ride qualities, and rotor-rotor/airframe component interactions.

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

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

Proposals should address the following if applicable:

1. Clearly define the data that will be provided and how it will help NASA and the community accelerate the design cycle of full-scale eVTOL aircraft and/or address significant barriers to market penetration. Also, define the data to be collected, data that will be considered proprietary, and data that will be available for publication. Data includes vehicle specifications; component and subsystem specifications; and performance, geometries, models, results, flight test data, and any other information relative to the work proposed.
2. If the proposal cannot address the full topic, please state the reasoning/justification.
3. Clearly propose a path to commercialization and include details with regards to the expected products, data, stakeholders, and potential customers.

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

Primary Technology Taxonomy:

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

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

Desired Deliverables Description:

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

- Research and development objectives and requirements.
- Initial experiment test plans for gathering experimental results related to the control characteristics of a multirotor eVTOL aircraft, with an emphasis on interactions between rotors and between the rotors and the vehicle structure for either:
    - A full-scale flight vehicle.
    - A subscale vehicle with fully developed methods for scaling the results to full scale.
- Expected results for the flight experiment using appropriate design and analysis tools.
- Design data and performance models for the vehicle and subsystems/components used to generate the expected results.
- Preliminary design of the instrumentation and data recording systems to be used for the experiment.
- Data that is expected to be collected including data that will be considered proprietary.

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

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

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

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

State of the Art and Critical Gaps:

Integration of distributed electric propulsion (DEP) (4+ rotors) systems into advanced air mobility eVTOL aircraft involves multidisciplinary design, analysis, and optimization (MDAO) of several disciplines in aircraft technologies. These disciplines include aerodynamics, propulsion, structures, acoustics, flight dynamics, and/or control in traditional aeronautics-related subjects. Innovative approaches in designing and analyzing highly integrated DEP eVTOL aircraft are needed to reduce energy use, noise, emissions, and safety concerns. Such advances are needed to address ARMD's Strategic Thrusts #1 - Safe, Efficient Growth in Global Operations, #3 - Ultra-Efficient Subsonic Transports, and #4 - Safe, Quiet, and Affordable Vertical Lift Air Vehicles. Due to the rapid advances in DEP-enabling technologies, current state-of-the-art design and analysis tools lack sufficient validation against full-scale eVTOL flight vehicles, especially in the areas of aerodynamics, propulsion, flight dynamics, control, and acoustics. Ultimately, the goal is to model and test multidisciplinary aeropropulsive flight dynamics, controls, and acoustics.

Relevance / Science Traceability:

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

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

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

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

References:

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

Appendix A: Evaluation Rubric

The evaluation rubric, including criteria that will be used to evaluate proposals, is provided so that you may prepare the highest quality proposals. Please review the definitions, weighting, and review criteria to understand how the subject matter experts will evaluate your proposal. Use the definitions to inform the content of each part of your technical proposal.

NASA STTR Phase I (v1.0) Evaluation Criteria Defined

		DEFINITION
NASA BENEFITS	TECHNOLOGY DESCRIPTION	Describe your technology and how it addresses this NASA subtopic's need. What is it? What are its benefits? What makes it unique?
	ALIGNMENT	Argue your technology innovation is aligned with this NASA STTR subtopic's priorities as defined in the solicitation.
weight 30%	IMPACT	If successful, describe your technology's expected impact on the described subtopic need.
ADVANCING THE STATE OF THE ART	*weight 10%*	Describe how your technology would improve the state of the art -- as described in the subtopic solicitation.
TECHNICAL RISK	TECHNICAL FEASIBILITY	Convince readers that your technology is built atop sound scientific and/or engineering principles.
	TECHNICAL RISKS AND MITIGATION PLANS	A key historical difference between success and failure in NASA's STTR program is offerors' understanding of the unknowns and challenges they are likely to face in maturing their technologies. Prove to the reader that your team is sophisticated and clear-eyed in analyzing the remaining risks your technology faces. Demonstrate that you have plans to mitigate those risks. In this section, your risk narrative (to include mitigation plans) should be focused on technical matters. Please point out which risk mitigation plans would take place during a Phase I effort, during a Phase II effort and which would be post-Phase II.
weight 20%	DATA QUALITY	Do your best to prove your technical claims with quality data attributed to credible sources (including relevant academic research.) These data should logically support your technical feasibility arguments and risk narrative.
STTR PROJECT PLAN	TIMELINES, MILESTONES, DELIVERABLES	Please share your execution plan with timeline, milestones and proposed deliverables.
	BUDGET	Provide a detailed breakdown of the base period of performance and the planned project costs to be incurred during the next period of performance.
weight 15%	TECHNICAL FACILITIES & RESOURCES	Briefly list and describe your technical facilities and resources. Do you have the resources and technical facilities you need to successfully complete your proposed project through a Phase II and beyond? If not, convince the reader you have a credible plan to attain the necessary facilities or resources to accomplish the proposed solution.
COMMERCIAL POTENTIAL	COMPETITIVE EDGE	Why will you win in the commercial marketplace? (This is inclusive of non-NASA-relevant markets you may address.) A small company needs to have a Competitive Edge in the market: Something you do better than anyone else. This might be intellectual property, unmatched expertise, a novel business model, channel partners, network effects, etc. What is your advantage and why will it last?
weight 5%	BUSINESS QUALIFICATIONS & EXPERIENCE	Briefly list and describe your business team. Please describe their qualifications and experience as it relates to successfully running commercial businesses. (Note: this is intentionally distinct from the "Technical Qualifications & Experience" metric below.)
TEAM ABILITY	TECHNICAL QUALIFICATIONS & EXPERIENCE	Briefly list and describe your core scientific and technical team with an emphasis on their past accomplishments and experiences. Why are these the right technologists for this particular NASA subtopic?
	GAPS IN TECHNICAL TEAM	Do you have the key technical people you need to get to through an eventual Phase II NASA award? If not, convince the reader you have a credible recruiting plan and can fill personnel gaps.
weight 15%	PARTNERSHIPS / SUBCONTRACTS	Describe any organizations with which you plan to partner as you mature the proposed technology. Emphasize any partnerships relevant through a Phase II award -- this is our main focus. Later partnerships (and plans) should be mentioned. Summarize the nature and timing of these partnerships. If partnering is not required to successfully mature your technology, please explain why.
SUBMISSION QUALITY	*weight 5%*	Prove to the evaluators that you are capable of delivering a professional, polished and thoughtful proposal. (Please note: The Submission Quality Dimension is holistically evaluated across the materials you submit.)

NASA STTR Phase I (v1.0) Evaluation Criteria

		UNSATISFACTORY	MARGINAL	SATISFACTORY	SUPERIOR
NASA BENEFITS	TECHNOLOGY DESCRIPTION	Fails to describe technology solution and beneficial features.	Partly describes technology solution and beneficial features.	Adequately describes technology solution and beneficial features.	Clearly and concisely describes technology solution and beneficial features.
	ALIGNMENT	Not aligned with this subtopic's priorities.	Somewhat aligned with this subtopic's priorities.	Aligned with this subtopic's priorities.	Highly aligned with this subtopic's priorities.
weight 30%	IMPACT	If successful, no improvement vs. existing technological approaches.	If successful, slight improvement vs. existing technological approaches.	If successful, significant improvement vs. existing technological approaches.	If successful, radical improvement vs. existing technological approaches.
ADVANCING THE STATE OF THE ART	*weight 10%*	No improvement of the state of the art.	Slightly improves the state of the art.	Improves the state of the art.	Significantly improves the state of the art.
TECHNICAL RISK	TECHNICAL FEASIBILITY	No scientific basis for presented approach.	Incomplete scientific basis for presented approach.	Credible scientific basis for presented approach.	Convincing scientific basis for presented approach.
	TECHNICAL RISKS AND MITIGATION PLANS	Failed to present any technical risks.	Inadequate risk analysis or mitigation plans.	Credible risk analysis and mitigation plans.	Convincing risk analysis and mitigation plans.
weight 20%	DATA QUALITY	Poorly supported by data. Little to no data attribution.	Partially supported by data. Some data attribution.	Credibly supported by data. Adequate data attribution.	Persuasively supported by meaningful data. Comprehensive data attribution.
STTR PROJECT PLAN	TIMELINES, MILESTONES, DELIVERABLES	Poor plan. Missing or badly flawed timelines, milestones, and deliverables.	Marginal plan. Insufficient support from timelines, milestones, and deliverables.	Satisfactory plan. Well supported with timelines, milestones, and deliverables.	Highly credible plan. Convincingly supported with timelines, milestones, and deliverables.
	BUDGET	Incomplete table of costs. Non-credible basis of estimate data.	Complete table of costs. Somewhat credible basis of estimate data.	Complete table of costs. Credible basis of estimate data.	Complete table of costs. Highly credible basis of estimate data.
weight 15%	TECHNICAL FACILITIES & RESOURCES	Existing facilities and resources insufficient. Gaps are high risk.	Existing facilities and resources partially sufficient. Evolving plan for gaps.	Existing facilities and resources mostly sufficient. Credible plan for gaps.	Existing facilities and resources certainly sufficient. No unresolved gaps.
COMMERCIAL POTENTIAL	COMPETITIVE EDGE	Undifferentiated firm. Fails to argue it has an advantage.	Weakly differentiated firm. Some evidence of an advantage.	Strongly differentiated firm. Credibly argues it has durable advantage.	Highly differentiated firm. Convincingly argues it has durable advantage.
weight 5%	BUSINESS QUALIFICATIONS & EXPERIENCE	Business people lack qualifications OR have no experience.	Business people are somewhat qualified and have some experience.	Business people are highly qualified OR have significant experience.	Business people are highly qualified AND have significant experience.
TEAM ABILITY	TECHNICAL QUALIFICATIONS & EXPERIENCE	Technical people lack qualifications OR have no experience.	Technical people are somewhat qualified and have some experience.	Technical people are highly qualified OR have significant experience.	Technical people are highly qualified AND have significant experience.
	GAPS IN TECHNICAL TEAM	Team requires new talent.	Team recognizes gaps in personnel, but presents no plan to address needs.	Team presents specific plan to address personnel needs.	Team with excellent composition. No near-term personnel gaps.
weight 15%	PARTNERSHIPS / SUBCONTRACTS	Partnership development not addressed.	Identified potential partners. No evidence of relationship building.	Identified required partners. Evidence of progressing relationships.	Partnerships formally in place. Or, the offeror's team is well positioned without partnering.
SUBMISSION QUALITY	*weight 5%*	Poorly written. Very difficult to impossible to follow. Several quality errors.	Moderately written. Sometimes difficult to follow. Some quality errors.	Effectively written. Convincing, easy to follow. No quality errors.	Clearly and persuasively written. Compelling arguments. No quality errors.

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 2024 NASA Technology Taxonomy is an evolution of the technology roadmaps developed in 2015 and 2020. The 2024 NASA Technology Taxonomy provides a structure for articulating the technology development disciplines needed to enable future space missions and support commercial air travel. The 2024 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 2024 NASA Technology Taxonomy can be found at: https://techport.nasa.gov/taxonomy

2024 TX Mapping Level 1	2024 TX Mapping Level 2	SBIR/STTR Subtopic Number	Subtopic Title
TX01 - Propulsion Systems	TX01.3 - Aero Propulsion	A1.04	Novel Aircraft Configurations for Electrified Aircraft Propulsion
		A1.09	Zero-Emissions Technologies for Aircraft
	TX01.4 - Advanced Propulsion	Z-GO.02	Space Nuclear Propulsion
		Z-GO.03	Solar Photon Sails Research and Technology Development
	TX01.X - Other Propulsion Systems	Z-EXPAND.01	Servicing and Assembly Applications
TX02 - Flight Computing and Avionics	TX02.1 - Avionics Component Technologies	Z-ENABLE.02	High-Performance Space Computing Technology
TX03 - Aerospace Power and Energy Storage	TX03.1 - Power Generation and Energy Conservation	S13.06	Dynamic Power Conversion
		Z-ENABLE.01	Enabling Power and Thermal Technologies
	TX03.2 - Energy Storage	Z-LIVE.01	Surface Power Technologies
	TX03.3 - Power Management and Distribution	Z-LIVE.01	Surface Power Technologies
		T3.05	Lunar Orbital Power Beaming Technology Development
TX04 - Robotics Systems	TX04.1 - Sensing and Perception	H15.01	Autonomous Capabilities for Lunar Surface Mobility Systems
		Z-ENABLE.04	Robotic Hardware for In-Space Manipulation
		Z-ENABLE.05	Extensible Perception, Manipulation, and Interoperability for Autonomous Robotic Systems
	TX04.2 - Mobility	H15.02	Simulation and Modeling of Lunar Mobility System Interaction with Lunar Regolith

	TX04.3 - Manipulation	S13.01	Robotic Mobility, Manipulation, and Sampling
		Z-ENABLE.04	Robotic Hardware for In-Space Manipulation
	TX04.4 - Human-Robot Interaction	H6.25	Trusted Autonomy in Space Systems
		H15.01	Autonomous Capabilities for Lunar Surface Mobility Systems
	TX04.6 - Robotics Integration	Z-EXPAND.01	Servicing and Assembly Applications
		Z-ENABLE.05	Extensible Perception, Manipulation, and Interoperability for Autonomous Robotic Systems
	TX04.X - Other Robotic Systems	Z-EXPAND.01	Servicing and Assembly Applications
TX05 - Communications, Navigation, and Orbital Debris Tracking and Characterization Systems	TX05.1 - Optical Communications	S16.04	Suborbital Platform Technologies
	TX05.3 - Internetworking	H9.08	Lunar 3GPP Technologies
		T5.07	Communications Quality of Service (QoS) Optimization Through Network Autonomy
	TX05.4 - Network Provided Position, Navigation, and Timing	Z-EXPAND.05	Beyond LEO Sustainability
	TX05.5 - Revolutionary Communications Technologies	T8.06	Quantum Sensing/Measurement and Communication
	TX05.6 - Networking and Ground Based Orbital Debris Tracking and Management	H9.03	Flight Dynamics and Navigation Technologies
		Z-EXPAND.04	Low Earth Orbit (LEO) Sustainability
		T5.06	Non-Earth Orbit Conjunction Risk Analysis
	TX05.X - Other Communications, Navigation, and Orbital Debris Tracking and Characterization Systems	Z-EXPAND.04	Low Earth Orbit (LEO) Sustainability
		Z-EXPAND.05	Beyond LEO Sustainability
TX06 - Human Health, Life Support, and Habitation Systems	TX06.1 - Environmental Control & Life Support Systems (ECLSS) and Habitation Systems	H3.13	Oxygen Compatible Habitation Solutions for Exploration Environments
		H3.14	Nanobubble Facilitated Hydrogen Peroxide Production In Space
	TX06.1 - Environmental Control & Life Support Systems (ECLSS) and Habitation Systems TX06.1 - Environmental Control & Life Support Systems (ECLSS) and Habitation Systems TX06.2 - Extravehicular Activity Systems	H4.09	Long-Duration Exploration Portable Life Support System (PLSS) Capabilities
		H4.11	Advanced Materials for Durable Space Suits for the Moon and Mars
		H12.09	In-Suit Detection of Venous Gas Emboli
TX07 - Exploration Destination Systems	TX07.1 - In-Situ Resource Utilization	Z-LIVE.03	Space Resource Processing for Consumables, Manufacturing, Construction, and Energy

		Z-LIVE.05	Regolith Excavation and Manipulation for Surface Operations and Infrastructure with Assembly and Outfitting of Lunar Surface Structures
	TX07.2 - Mission Infrastructure, Sustainability, and Supportability	Z-EXPAND.02	Orbital Infrastructure Assembly
		Z-LIVE.04	Components for Extreme Environments
		T7.04	Lunar Surface Site Preparation
	TX07.3 - Mission Operations and Safety	S13.04	Contamination Control and Planetary Protection
	TX07.X - Other Exploration Destination Systems	Z-LIVE.05	Regolith Excavation and Manipulation for Surface Operations and Infrastructure with Assembly and Outfitting of Lunar Surface Structures
TX08 - Sensors and Instruments	TX08.1 - Remote Sensing Instruments/Sensors	A2.01	Flight Test and Measurement Technologies
		S11.01	Lidar Remote-Sensing Technologies
		S11.02	Technologies for Active Microwave Remote Sensing
		S11.03	Technologies for Passive Microwave Remote Sensing
		S11.04	Sensor and Detector Technologies for Visible, Infrared (IR), Far-IR, and Submillimeter
		S12.06	Detector Technologies for Ultraviolet (UV), X-Ray, and Gamma-Ray Instruments
		S14.02	In Situ Particles and Fields and Remote-Sensing-Enabling Technologies for Heliophysics Instruments
		S16.04	Suborbital Platform Technologies
		S16.07	Cryogenic Systems for Sensors and Detectors
		S16.08	Quantum Sensing: Atomic sensors, optical atomic clocks, and solid-state systems
		T8.07	Photonic Integrated Circuits
		T8.08	Lunar Imagery
	TX08.2 - Observatories	S12.01	Exoplanet Detection and Characterization Technologies
		S12.02	Precision Deployable Optical Structures and Metrology
		S12.03	Advanced Optical Systems and Fabrication/Testing/Control Technologies for Extended-Ultraviolet/Optical to Mid-/Far-Infrared Telescopes
		S12.04	X-Ray Mirror Systems Technology, Coating Technology for X-Ray-UVOIR (Ultraviolet-Optical-Infrared), and Free-Form Optics
	TX08.3 - In-Situ Instruments/Sensor	S11.05	Suborbital Instruments and Sensor Systems for Earth Science Measurements
		S13.05	In Situ Instruments and Instrument Components for Lunar and Planetary Science

		S14.02	In Situ Particles and Fields and Remote-Sensing-Enabling Technologies for Heliophysics Instruments
		S15.02	In Situ Sample Preparation and Analysis for Biological and Physical Sciences in a Microgravity Environment
		S15.03	Environmental Monitoring for Micro-G and Partial-G Experiments
		S16.08	Quantum Sensing: Atomic sensors, optical atomic clocks, and solid-state systems
	TX08.X - Other Sensors and Instruments	A3.05	Advanced Air Mobility (AAM) Integration
		S11.02	Technologies for Active Microwave Remote Sensing
		S13.03	Extreme Environments Technology
		S14.01	Space Weather Research-to-Operations and Operations-to-Research (R2O2R)
		T8.06	Quantum Sensing/Measurement and Communication
TX09 - Entry, Descent, and Landing	TX09.1 - Aeroassist and Atmospheric Entry	Z-LAND.02	Entry and Descent System Technologies
	TX09.2 - Descent	Z-LAND.01	Parachute Systems for Maneuverability and Wireless Data Acquisition
	TX09.3 - Landing	Z-LAND.03	Plume-Surface Interaction (PSI) Technologies
	TX09.5 - Flight Mechanics and GN&C for Entry, Descent, and Safe Precise Landing	Z-LAND.01	Parachute Systems for Maneuverability and Wireless Data Acquisition
		Z-EXPAND.03	Space Debris Prevention for Small Spacecraft
TX10 - Autonomous Systems	TX10.1 - Situational and Self Awareness	H15.01	Autonomous Capabilities for Lunar Surface Mobility Systems
		A1.11	Health Management and Sensing Technologies For Sustainable Aviation Vehicles
	TX10.2 - Reasoning and Acting	H6.25	Trusted Autonomy in Space Systems
		S17.03	Fault Management Technologies
	TX10.3 - Collaboration and Interaction	T6.09	Human-Autonomous System Integration for Deep Space Tactical Anomaly Response in Smart Habitats
	TX10.4 - Engineering and Integrity	A2.04	Aviation Cybersecurity
	TX10.X - Other Autonomous Systems	A2.02	Enabling Aircraft Autonomy
		Z-ENABLE.05	Extensible Perception, Manipulation, and Interoperability for Autonomous Robotic Systems
		Z-ENABLE.02	High-Performance Space Computing Technology

TX11 - Software, Modeling, Simulation, and Information Processing	TX11.1 - Software Development, Engineering, and Integrity	Z-LIVE.05	Regolith Excavation and Manipulation for Surface Operations and Infrastructure with Assembly and Outfitting of Lunar Surface Structures
	TX11.2 - Modeling	A1.06	Vertical Takeoff and Landing (VTOL) Vehicle Technologies - Vehicle Design Tool & Electric Powertrain Test Capability
		S17.02	Integrated Campaign and System Modeling
	TX11.3 - Simulation	S17.02	Integrated Campaign and System Modeling
	TX11.5 - Mission Architecture, Systems Analysis and Concept Development	A3.05	Advanced Air Mobility (AAM) Integration
	TX11.6 - Ground Computing	S17.01	Technologies for Large-Scale Numerical Simulation
	TX11.X - Other Software, Modeling, Simulation, and Information Processing	S14.01	Space Weather Research-to-Operations and Operations-to-Research (R2O2R)
		T11.05	Model-Based Enterprise
TX12 - Materials, Structures, Mechanical Systems, and Manufacturing	TX12.1 - Materials	A1.03	Propulsion Efficiency - Propulsion Materials and Structures
		Z-ENABLE.03	Advanced In-Space Laser Welding and Nondestructive Evaluation
		Z-LIVE.04	Components for Extreme Environments
		Z-EXPAND.05	Beyond LEO Sustainability
		T12.01	Additively Manufactured Electronics for Space Applications
		T12.10	Low-Cost Manufacturing and Integration of Reusable Thermal Protection Systems (TPS)
		T12.12	Spray Processing of Oxide Dispersion Strengthened (ODS) Alloy GRX-810
	TX12.2 - Structures	H5.01	Modular, Multi-Use 50 kW Lunar Solar Array Structures
		S12.02	Precision Deployable Optical Structures and Metrology
	TX12.4 - Manufacturing	H8.01	In Space Production Applications (InSPA) Flight Development and Demonstrations on ISS
		Z-ENABLE.03	Advanced In-Space Laser Welding and Nondestructive Evaluation
		T12.01	Additively Manufactured Electronics for Space Applications
	TX12.X - Other Manufacturing, Materials, and Structures	T12.11	Biomanufacturing for Space Missions: Harnessing Microbial Communities for Sustainable Production in Moon and Mars Environments
TX13 - Ground, Test, and Surface Systems	TX13.1 - Infrastructure Optimization	H10.04	In-line Commodity Purity Analysis

		T13.02	High-Efficiency, Reliable Electrical Subsystems for Cryogenic Pumps
	TX13.2 - Test and Qualification	A1.06	Vertical Takeoff and Landing (VTOL) Vehicle Technologies - Vehicle Design Tool & Electric Powertrain Test Capability
		A1.08	Aeronautics Ground Test and Measurement Technologies: Diagnostic Systems for High-Speed Flows and Icing
	TX13.5 - Surface Systems Technologies	A1.08	Aeronautics Ground Test and Measurement Technologies: Diagnostic Systems for High-Speed Flows and Icing
TX14 - Thermal Management Systems	TX14.1 - Cryogenic Systems	Z-GO.01	Cryogenic Fluid Management
	TX14.2 - Thermal Control Components and Systems	S16.05	Thermal Control Systems
		Z-ENABLE.01	Enabling Power and Thermal Technologies
		Z-LIVE.02	Spacecraft Thermal Management
	TX14.3 - Thermal Protection Components and Systems	S16.05	Thermal Control Systems
	TX14.X - Other Thermal Management Systems	S16.04	Suborbital Platform Technologies
		S16.05	Thermal Control Systems
		Z-LIVE.02	Spacecraft Thermal Management
TX15 - Flight Vehicle Systems	TX15.1 - Aerosciences	A1.02	Quiet Performance - Airframe Noise
		T15.04	Full-Scale (Passenger/Cargo) Electric Vertical Takeoff and Landing (eVTOL) Scaling, Propulsion, Aerodynamics, and Acoustics Investigations
	TX15.2 - Flight Mechanics	H9.03	Flight Dynamics and Navigation Technologies
		T15.04	Full-Scale (Passenger/Cargo) Electric Vertical Takeoff and Landing (eVTOL) Scaling, Propulsion, Aerodynamics, and Acoustics Investigations
TX16 - Air Traffic Management and Range Tracking Systems	TX16.1 - Safe All Vehicle Access	A2.04	Aviation Cybersecurity
		A3.03	Future Aviation Systems Safety
	TX16.3 - Traffic Management Concepts	A3.02	Advanced Air Traffic Management for Nontraditional Airspace Missions
TX17 - Guidance, Navigation, and Control (GN&C)	TX17.2 - Navigation Technologies	H9.03	Flight Dynamics and Navigation Technologies
		Z-EXPAND.03	Space Debris Prevention for Small Spacecraft
	TX17.X - Other Guidance, Navigation, and Control	S16.03	Guidance, Navigation, and Control

Appendix C: Technology Readiness Level (TRL) Descriptions

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

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

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

Definitions

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

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

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

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

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

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

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

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

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

Appendix 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 as if they were given in full text. The full text for Federal Acquisition Regulation (FAR) and the NASA FAR Supplement (NSF) provisions and clauses can be accessed electronically here:

FAR: www.acquisition.gov
NASA FAR Supplement: www.hq.nasa.gov/office/procurement/regs/NFS.pdf

Note that 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

52.202-1 DEFINITIONS. (Jun 2020)
52.203-3 GRATUITIES. (Apr 1984)
52.203-5 COVENANT AGAINST CONTINGENT FEES. (May 2014)
52.203-6 RESTRICTIONS ON SUBCONTRACTOR SALES TO THE GOVERNMENT. (Jun 2020)
52.203-7 ANTI-KICKBACK PROCEDURES. (Jun 2020)
52.203-8 CANCELLATION, RESCISSION, AND RECOVERY OF FUNDS FOR ILLEGAL OR IMPROPER ACTIVITY (May 2014)
52.203-10 PRICE OR FEE ADJUSTMENT FOR ILLEGAL OR IMPROPER ACTIVITY (May 2014)
52.203-11 CERTIFICATION AND DISCLOSURE REGARDING PAYMENTS TO INFLUENCE CERTAIN FEDERAL TRANSACTIONS. (Sep 2024)
52.203-12 LIMITATION ON PAYMENTS TO INFLUENCE CERTAIN FEDERAL TRANSACTIONS. (Jun 2020)
52.203-18 PROHIBITION ON CONTRACTING WITH ENTITIES THAT REQUIRE CERTAIN INTERNAL CONFIDENTIALITY AGREEMENTS OR STATEMENTS-REPRESENTATION (Jun 2020)
52.203-19 PROHIBITION ON REQUIRING CERTAIN INTERNAL CONFIDENTIALITY AGREEMENTS OR STATEMENTS. (JAN 2017)
52.204-7 SYSTEM FOR AWARD MANAGEMENT. (NOV 2024)
52.204-8 ANNUAL REPRESENTATIONS AND CERTIFICATIONS (DEVIATION 20-02B) (May 2024)
52.204-10 REPORTING EXECUTIVE COMPENSATION AND FIRST-TIER SUBCONTRACT AWARDS. (Jun 2020)
52.204-13 SYSTEM FOR AWARD MANAGEMENT MAINTENANCE. (OCT 2018)
52.204-16 COMMERCIAL AND GOVERNMENT ENTITY CODE REPORTING. (AUG 2020)
52.204-18 COMMERCIAL AND GOVERNMENT ENTITY CODE MAINTENANCE. (AUG 2020)
52.204-19 INCORPORATION BY REFERENCE OF REPRESENTATIONS AND CERTIFICATIONS. (Dec 2014)
52.204-22 ALTERNATIVE LINE-ITEM PROPOSAL (JAN 2017)
52.204-23 PROHIBITION ON CONTRACTING FOR HARDWARE, SOFTWARE, AND SERVICES DEVELOPED OR PROVIDED BY KASPERSKY LAB AND OTHER COVERED ENTITIES. (DEC 2023)
52.204-24 REPRESENTATION REGARDING CERTAIN TELECOMMUNICATIONS AND VIDEO SURVEILLANCE SERVICES OR EQUIPMENT (NOV 2021)

52.204-25 PROHIBITION ON CONTRACTING FOR CERTAIN TELECOMMUNICATIONS AND VIDEO SURVEILANCE SERVICES OR EQUIPMENT. (NOV 2021)
52.204-26 COVERED TELECOMMUNICATIONS EQUIPMENT OR SERVICES - REPRESENTATION. (OCT 2020)
52.204-27 PROHIBITION ON A BYTEDANCE COVERED APPLICATION. (JUN 2023)
52.204-29 FEDERAL ACQUISITION SUPPLY CHAIN SECURITY ACT ORDERS—REPRESENTATION AND DISCLOSURES. (DEC 2023)
52.209-6 PROTECTING THE GOVERNMENT'S INTEREST WHEN SUBCONTRACTING WITH CONTRACTORS DEBARRED, SUSPENDED, OR PROPOSED FOR DEBARMENT. (NOV 2021)
52.213-4 TERMS AND CONDITIONS – SIMPLIFIED ACQUISITIONS (OTHER THAN COMMERCIAL PRODUCTS AND COMMERCIAL SERVICES (NOV 2024)
52.215-1 INSTRUCTIONS TO OFFERORS—COMPETITIVE ACQUISITION. (NOV 2021)
52.215-2 AUDIT AND RECORDS-NEGOTIATIONS (JUN 2020)
52.215-8 ORDER OF PRECEDENCE—UNIFORM CONTRACT FORMAT. (OCT 1997)
52.217-9 OPTION TO EXTEND THE TERM OF THE CONTRCT (MAR 2000)
52.219-6 NOTICE OF TOTAL SMALL BUSINESS SET-ASIDE (Nov 2020)
52.219-8 UTILIZATION OF SMALL BUSINESS CONCERNS. (Feb 2024)
52.219-28 POST-AWARD SMALL BUSINESS PROGRAM REREPRESENTATION. (Feb 2024)
52.222-3 CONVICT LABOR. (June 2003)
52.222-21 PROHIBITION OF SEGREGATED FACILITIES. (Apr 2015)
52.222-26 EQUAL OPPORTUNITY. (Sept 2016)
52.222-35 EQUAL OPPORTUNITY FOR VETERANS. (Jun 2020)
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52.222-54 EMPLOYMENT ELIGIBILITY VERIFICATION. (May 2022)
52.225-1 BUY AMERICAN-SUPPLIES (Oct 2022)
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52.227-2 NOTICE AND ASSISTANCE REGARDING PATENT AND COPYRIGHT INFRINGEMENT (Jun 2020)
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52.232-12 ADVANCE PAYMENTS. (MAY 2001) AS MODIFIED BY NFS 1852.232-70 ALTERNATE IV (APR 1984) ALTERNATE V (MAY 2001)
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52.232-39 UNENFORCEABILITY OF UNAUTHORIZED OBLIGATIONS. (Jun 2013)
52.232-40 PROVIDING ACCELERATED PAYMENTS TO SMALL BUSINESS SUBCONTRACTORS. (Mar 2023)
52.233-1 DISPUTES. (May 2014)
52.233-3 PROTEST AFTER AWARD. (Aug 1996)
52.233-4 APPLICABLE LAW FOR BREACH OF CONTRACT CLAIM. (Oct 2004)
52.242-13 BANKRUPTCY (July 1995)
52.242-15 STOP-WORK ORDER. (Aug 1989)
52.243-1 CHANGES—FIXED PRICE. (Aug 1987)
52.244-6 SUBCONTRACTS FOR COMMERCIAL PRODUCTS AND COMMERCIAL SERVICES (Nov 2024)

52.246-7 INSPECTION OF RESEARCH AND DEVELOPMENT—FIXED PRICE. (Aug 1996)
52.246-16 RESPONSIBILITY FOR SUPPLIES. (Apr 1984)
52.247-34 F.O.B. DESTINATION (Jan 1991)
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52.252-1 SOLICITATION PROVISIONS INCORPORATED BY REFERENCE. (Feb 1998)
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52.252-2 CLAUSES INCORPORATED BY REFERENCE. (Feb 1998)

NASA Provisions and Clauses

1852.203-71 REQUIREMENT TO INFORM EMPLOYEES OF WHISTLEBLOWER RIGHTS (Jul 2023)
1852.204-76 SECURITY REQUIREMENTS FOR UNCLASSIFIED INFORMATION TECHNOLOGY RESOURCES. (DEVIATION 21-01) (Jan 2011)
1852.211-70 PACKAGING, HANDLING, AND TRANSPORTATION CERTIFICATIONS—OTHER THAN COMMERCIAL ITEMS (Sep 2005)
1852.216-78 FIRM FIXED PRICE. (Dec 1988)
1852.219-80 LIMITATION ON SUBCONTRACTING – SBIR PHASE I PROGRAM. (Oct 2011)
1852.219-83 LIMITATION OF THE PRINCIPAL INVESTIGATOR – SBIR PROGRAM. (Oct 2006)
1852.219-85 CONDITIONS FOR FINAL PAYMENT – SBIR AND STTR CONTRACTS (Oct 2006)
1852.225-70 EXPORT LICENSES (Feb 2000)
1852.225-71 RESTRICTION ON FUNDING ACTIVITY WITH CHINA (Feb 2012)
1852.225-72 RESTRICTION ON FUNDING ACTIVITY WITH CHINA – REPRESENTATION. (DEVIATION 12-01A) (Feb 2012)
1852.215-81 PROPOSAL PAGE LIMITATIONS. (Apr 2015)
1852.223-75 MAJOR BREACH OF SAFETY OR SECURITY. (Feb 2002)
1852.227-11 PATENT RIGHTS – OWNERSHIP BY THE CONTRACTOR. (Apr 2015)
1852.227-72 DESIGNATION OF NEW TECHNOLOGY REPRESENTATIVE AND PATENT REPRESENTATIVE. (Apr 2015)
1852.232-80 SUBMISSION OF VOUCHERS FOR PAYMENT.(Apr 2018)
1852.233-70 PROTESTS TO NASA. (Apr 2015)
1852.235-70 CENTER FOR AEROSPACE INFORMATION. (Dec 2006)
1852.235-71 KEY PERSONNEL AND FACILITIES (Mar 1989)
1852.235-73 FINAL SCIENTIFIC AND TECHNICAL REPORTS. ALTERNATE III (Dec 2006)
1852.235-74 ADDITIONAL REPORTS OF WORK - RESEARCH AND DEVELOPMENT. (Feb 2003)
1852.237-72 ACCESS TO SENSITIVE INFORMATION. (Jun 2005)
1852.237-73 RELEASE OF SENSITIVE INFORMATION. (Jun 2005)
1852.239-73 REVIEW OF THE OFFEROR'S INFROMATION TECHNOLOGY SYSTEMS SUPPLY CHAIN (DEVIATION 15-03D) (Jan 2020)
1852.239-74 INFORMATION TECHNOLOGY SYSTEM SUPPLY CHAIN RISK ASSESSMENT. (DEVIATION 15-03D) (Jan 2020)
1852.244-70 GEOGRAPHIC PARTICIPATION IN THE AEROSPACE PROGRAM (Apr 1985)
1852.246-72 MATERIAL INSPECTION AND RECEIVING REPORT. (Apr 1985)
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 21-04A 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