# AMENDMENT OF SOLICITATION/MODIFICATION OF CONTRACT

| | | | | |
|---|---|---|---|---|
| 1. CONTRACT ID CODE | | PAGE 1 | OF | PAGES 1 |

| 2. AMENDMENT/MODIFICATION NUMBER | 3. EFFECTIVE DATE | 4. REQUISITION/PURCHASE REQUISITION NUMBER | 5. PROJECT NUMBER *(If applicable)* |
|---|---|---|---|
| P00001 | See Block 16C | | |

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

| 8. NAME AND ADDRESS OF CONTRACTOR *(Number, street, county, State and ZIP Code)* | (X) | |
|---|---|---|
| | [X] | 9A. AMENDMENT OF SOLICITATION NUMBER<br>80NSSC26R0007<br>9B. DATED *(SEE ITEM 11)* |
| | [ ] | 10A. MODIFICATION OF CONTRACT/ORDER NUMBER<br><br>10B. DATED *(SEE ITEM 13)* |
| CODE FACILITY CODE | | |

## 11. THIS ITEM ONLY APPLIES TO AMENDMENTS OF SOLICITATIONS

[X] The above numbered solicitation is amended as set forth in Item 14. The hour and date specified for receipt of Offers [ ] is extended. [X] 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. |
| [X] | 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 [X] 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.)*

FAR 52.222-90 Addressing DEI Discrimination by Federal Contractors (APR 2026) (DEVIATION APR 2026) is incorporated by reference as required by Executive Order (E.O.) 14398, “Addressing DEI Discrimination by Federal Contractors.”

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)*<br>Kenneth E. Albright | |
|---|---|---|---|
| 15B. CONTRACTOR/OFFEROR<br><br>*(Signature of person authorized to sign)* | 15C. DATE SIGNED | 16B. UNITED STATES OF AMERICA<br>KENNETH ALBRIGHT Digitally signed by KENNETH ALBRIGHT Date: 2026.04.29 10:10:59 -05'00'<br>*(Signature of Contracting Officer)* | 16C. DATE SIGNED |

# National Aeronautics and Space Administration

## Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs

## FY26-27 Broad Agency Announcement (BAA)

**Broad Agency Announcement 80NSSC26R0003**

## Appendix 26B:

## Small Business Technology Transfer (STTR) Phase I Funding Opportunity

Originally Issued: April 21, 2026

Proposals Due: May 21, 2026 by 5:00 PM ET

# FY26-27 BAA- Appendix 26B: Small Business Technology Transfer (STTR) Phase I

## Change Log

| Version | Description of Changes | Date |
|---|---|---|
| Original Release | ----- | April 21, 2026 |
| Amendment 1 | Added clause FAR 52.222-90 | April 28, 2026 |

# Contents

# Executive Summary

This is the third appendix to NASA SBIR/STTR Program FY2026-2027 Broad Agency Announcement (BAA) and solicits proposals for the Small Business Technology Transfer (STTR) Phase I funding opportunity.

Chapter 6 of this appendix contains the proposal submission instructions and Chapter 9 contains the technical research topics. Instructions for how to prepare your proposal can be found in the BAA (https://sam.gov/workspace/contract/opp/bf991b7587b1438ca7930a9b840635dc/view). The chapter numbers align to the chapters in the BAA and can be used to locate additional information within the BAA. In any instance where specific requirements in this appendix conflict with requirements in the BAA, the specific requirements in this appendix take precedence for this opportunity.

## Important Dates

Proposals Due: May 21, 2026 by 5:00 PM ET

Note that the submission open period is shorter than prior years.

Deadline for guaranteed response from the Help Desk: May 20, 2026 by 5:00 PM ET

## Multiple Submissions

NASA will not accept more than two (2) proposal packages from any one offeror for this funding opportunity. See sections 3.2 in this appendix and section 4 in the BAA.

# 1. Program Description

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

The Help Desk will not guarantee a timely answer to questions about this appendix after May 20, 2026, at 5:00pm ET.

# 2. Registrations, Certifications and Other Information

No additional content, requirements, or exceptions beyond information in BAA.

# 3. Proposal Preparation Instructions and Requirements

### 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. **You may not submit more than two (2) proposals to the funding opportunity in this appendix.** 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.

# 4. Method of Selection and Evaluation Criteria

The rubric containing all evaluation criteria is available in attachment 26B.1 STTR.

# 5. Considerations for Contracting and Additional Information

No additional content, requirements, or exceptions beyond information in BAA.

# 6. Submission of Proposals

## 6.1 How to Submit your Proposal Package

NASA uses electronically supported business processes for the SBIR/STTR program. You must have internet access and an email address. NASA will not accept paper submissions. NASA's electronic systems for submission and contract management are not document repositories. NASA follows federal regulations for records management and disposal (NPR 1441.1E).

### 6.1.1 Electronic Submission of Proposals

NASA will be using ProSAMS for the submission of these proposal packages. ProSAMS requires firm registration and login. To access ProSAMS, go to https://prosams.nasa.gov/. To submit proposals to this appendix, select "STTR 2026B-I" from the solicitation type dropdown as you start a new proposal.

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 Proposal Package Submission

**NASA must receive your proposal package for STTR Phase I no later than 5:00 p.m. ET on Thursday, May 21, 2026, 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.

If your proposal contains ITAR/EAR information, it may be submitted via ProSAMS.

**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 Acknowledgement 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:

Kenneth Albright
NASA Shared Services Center

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

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

### 6.2 Phase II Information

If you are awarded a Phase I contract, you will be eligible to submit a proposal for an SBIR/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 proposal due date stated in your contract.

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

No additional content, requirements, or exceptions beyond information in BAA.

## 8. Submissions 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 BAA 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 BAA section 3.1.5.5.
    - ☐ 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 (BAA section 3.1.4).
- ☐ All required letters/documentation are included.
    - ☐ A letter of commitment from the appropriate government official if the research effort requires use of government resources (BAA sections 3.1.5.4 and 5.13).
    - ☐ A letter from the Small Business Official explaining why the SBIR research project requires the use of government resources, if the effort requires government resources (BAA sections 3.1.5.4 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.
- ☐ Total proposed funding for the effort does not exceed $225,000 (BAA section 1.3), and if requesting TABA, the cost for TABA does not exceed $6,500 (BAA sections 1.8 and 3.1.5.9).
- ☐ Proposed project duration does not exceed thirteen (13) months (BAA section 1.3).
- ☐ Confirm you received an acknowledgement of submission email before 5:00 p.m. ET on May 21, 2026 (Appendix 26B STTR section 6.1.4).

## 9. Research Topics

The 11 STTR subtopics in this appendix are organized by topic based on technical theme and thus identify subtopics where your research and development capabilities may be a good match. There are 8 topics and 11 total subtopics in this appendix. This appendix only contains STTR subtopics.

You should be thoughtful in selecting a subtopic to ensure the proposal is responsive to the NASA need as defined by the subtopic. The NASA SBIR/STTR program will NOT move a completed proposal package between STTR subtopics.

**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.

**NASA has changed the subtopic numbering convention for the SBIR/STTR program this year:**

Subtopics are organized and numbered according to their topic alignment and appendix. Prior subtopics numbers are listed in the subtopic title as appropriate to help you locate returning subtopics.

## Research Subtopics

# Aeronautics Research (AERO)

## AERO.9.T26B: Full-Scale (Passenger/Cargo) Advanced Air Mobility (AAM) and Vertical Takeoff and Landing (VTOL) Interdisciplinary Investigations (STTR) (previously T15.04)

**Lead Center:** AFRC

**Participating Center(s):** LaRC

**Subtopic Problem Statement/Description:**

This subtopic addresses enabling technologies, state-of-the-art design, and analysis tools needed for the Advanced Air Mobility Pathfinders (AAMP) as well as the cutting-edge concepts of urban air mobility (UAM), distributed electric propulsion (DEP), and propulsion-airframe interaction (PAI).

The subtopic closes a large gap in full-scale Advanced Air Mobility (AAM) and Vertical Takeoff and Landing (eVTOL) flight vehicle support data. The main focus areas are aerodynamics, propulsion, flight dynamics, controls, and/or acoustics, with potential to address focus areas in combination. Further development, validation and verification of helicopter design and analysis codes and practices are expected for eVTOL vehicles. Proposals should be focused in the areas of full-scale multirotor AAM and eVTOL aircraft design, execution of experiments, and development and validation of scaling methods. In the case of subscale testing, at the completion of Phase II the outcomes are expected to enable and extend the results to all full-scale applications. In the case of full-scale testing and at the completion of Phase II the outcomes are expected to enable future eVTOL testing, provide valuable validation data for design codes, analysis codes, as well as benefits outlined below.

The purpose of the subtopic is to facilitate and accelerate the primary discipline research areas on full-scale vehicles. Additionally, the subtopic expects to utilize developmental testing of full-scale vehicles by partnering with universities, small business and start-up AAM and VTOL companies. The benefits could include enabling subcomponent testing, providing better decision-making processes, providing lessons learned and best practices, and potentially enabling test beds for future flight and testing experiments.

Full-scale vehicle testing data is still highly sought after for the purposes outlined above, and the modeling and testing is essential for AAM, UAM, DEP, and PAI. Historically, relevant-environment test data are very difficult to obtain due to the challenges associated with planning, executing, and obtaining quality data from testing as well as sensitive/proprietary data issues for companies doing this work. Ultimately, the goal is to model and test multidisciplinary aerodynamics, propulsion, flight dynamics, controls, and/or acoustics.

This subtopic also includes the option for data/testing on subscale vehicles and scaling methods to extend the data to full-scale applications. Scaling methods for flight vehicles have been developed for many decades across the technical areas considered in this subtopic. Subscale testing is often less difficult for various reasons, and it is expected that such proposal may include more expanded test programs and data collection than would be possible at full-scale.

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 (2) develop and validate scaling methods to extend and apply the results of instrumented subscale model testing to full-scale applications.

This subtopic is highly relevant and facilitates further research and opportunities to small businesses and research institutions. Under the umbrella of air taxis, Full scale AAM and VTOL vehicles 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 areas of this subtopic, facilitating flight testing of these vehicles provides many other benefits. A few are providing opportunities for many small businesses to develop and market subsystems and support infrastructure such as batteries, electric motors, propellers, rotors, instrumentation, sensors, manufacturing, vehicle support, vehicle operations, and more.

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

**Primary Technology Taxonomy:**

- Level 1: TX15 Flight Vehicle Systems
- Level 2: TX15.1 Aerosciences

**Desired Deliverables of Phase I:**

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

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

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

**Desired Deliverables of Phase II:**

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

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

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

**Desired Deliverable Types of Phase II:**

- Analysis
- Test Results
- Research (STTR Only)
- Software
- Digital Models
- Hardware
- Prototype

**State of the Art:**

Integration of distributed electric propulsion (DEP) (4+ rotors) systems into Advanced Air Mobility (AAM) and Vertical Takeoff and Landing (VTOL) aircraft involves multidisciplinary design, analysis, and optimization (MDAO) of several disciplines in aircraft technologies. These disciplines include aerodynamics, propulsion, structures, acoustics, and/or control in traditional aeronautics-related subjects.

AAM and VTOL technology is forefront to today's aeronautical innovation and driven by stakeholders in the government, academia and industry. Further innovation within NASA and ARMD will require continued research, facilitation and support.

**Critical Gaps:**

Innovative approaches in designing and analyzing highly integrated DEP AAM and VTOL 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 AAM and VTOL flight vehicles, especially in the areas of aerodynamics, propulsion, flight dynamics, controls, and acoustics. Ultimately, the goal is to model and test multidisciplinary aero-propulsive flight dynamics, controls, and acoustics.

**Shortfalls And Decadal Surveys:**

As an Aeronautics Research Mission Directorate (ARMD) topic it does not tie well into the Civil Space Shortfalls or Decadal Surveys. It appears from a key word search the document has declined to include ARMD topics. However, if interplanetary exploration using autonomous helicopters or other aero vehicles is underlying any of these shortfalls, this subtopic area would be directly applicable to advancing those technologies.

This subtopic aligns with NASA aeronautics legacy mission to make subtle low cost and low risk improvements through research and testing. Reference the critical gaps section.

**Need Horizon:** Mid-Term (5-10 years)

**References:**

- NASA/ARMD/Advanced Air Vehicles Program (AAVP): Nateri Madavan
  - Subsonic Vehicle Technologies and Tools (SVTT) project: Tony Nerone.
    - ARMD/Advanced Air Transport Technology (AATT) Project: Dr. Dale Van Zante https://www.nasa.gov/aeroresearch/programs/aavp/aatt

    - ARMD/Revolutionary Vertical Lift Technology (RVLT) Project: Noah Schiller https://www.nasa.gov/aeroresearch/programs/aavp/rvlt
- ARMD/Transformative Aeronautics Concepts Program (TACP):Dr. John Cavolowsky
    - ARMD/Transformational Tools and Technologies (TTT) Project: Azlin Biaggi-Labiosa https://www.nasa.gov/aeroresearch/programs/tacp/ttt
    - ARMD/University Innovation (UI) Project: Gelsomina (Mina) Cappuccio https://www.nasa.gov/aeroresearch/programs/tacp/ui
- ARMD Strategic Implementation Plan:
- AOSP/Airspace and Operations Safety Program: Akbar Sultan
    - Advanced Capabilities for Emergency Response Operations Project: Dr. Min Xue

## AERO.10.T26B: Hybrid Powertrain Technologies (STTR)

**Lead Center:** GRC

**Subtopic Problem Statement/Description:**

Hybrid powertrain technologies comprise all of the major pieces of electrified vehicles that enable multiple energy sources to combine to propel the aircraft forward. A common example would be a system where batteries, though an electric powertrain system, assist in turning the shaft of a gas turbine engine, but there are many other topologies as well. This subtopic in general is intended to cover the range of hybridization for commercial aircraft. This year, the subtopic is focused on the subset which is described as "high power electrified aircraft propulsion (EAP)" or "high power EAP".

High Power EAP technologies are aimed at enabling high percentage electrification of propulsion systems for regional and single aisle aircraft. These require power dense, components and systems that can handle 10 MW of total power or more depending on the airframe and mission design requirements. Such systems range from electric machines (motors and generators) to power electronics and devices (inverters, converters, circuit breakers etc.) to cables and connectors.

Superconducting systems are of particular interest for high power EAP due to their potential for extremely high specific power and efficiencies. While significant progress has been made to date in this area, there is a need for further development in order to address the final gaps for application in the field (entry into service). Of specific interest for this subtopic call are technologies for superconducting electric machines and the cryo-compatible power electronics that support them.

In the area of power electronics that work with superconducting systems, there is a specific need for optoelectronics solutions to operate at or near the operational temperatures of both the electric machines and the superconducting cabling which connect them to the rest of the system (temperature ranges from 20K-40K).

Cryo-compatible power electronics solutions are sought with the following as a reference design:

A total power inverter solution for a multi-megawatt devices operating at the stated cryogenic temperatures with application to a superconducting motor spinning at a steady fundamental frequency of 500 Hz to 1000 Hz, 2-5 MW total output power (can be modular) at 1.5-2.5 kV, and with ultra-low total harmonics distortion (nearly a pure sine wave).

Proposed inverters are welcome, and also enabling subcomponents and technologies such as:

- Cryo-compatible gate drives for Gallium Nitride (GaN) High Electron Mobility Transistors (HEMT) based power electronics
- Hermetic connectors for high power, high voltage (1-3kV, 75-500A) , cryogenic motor drives (a solution here may include the entire power electronics enclosure and heat sink(s)
- Active EMI filtering specific to GaN HEMT based systems to reduce filtering weight

Other areas of where proposal are sought under this subtopic are:

- Cryo-compatible partial discharge measurement capabilities (hardware and integrated detection system)
- Light weight cryo fans for gaseous helium (possible helium/hydrogen combination) for high flow rates (50+ m^3/hr or greater)

**Note**: This subtopic is for electric powertrain components between the electric energy source (i.e. battery or fuel cell) and the shaft (as in the case of turboprop or turbine engine shaft), focusing on superconducting or other high power but extremely power dense and efficient solutions.

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

**Primary Technology Taxonomy:**

- Level 1: TX15 Flight Vehicle Systems
- Level 2: TX15.1 Aerosciences
- Level 3: TX15.1.1 Aerodynamics

**Desired Deliverables of Phase I:**

**Phase I Deliverables**:

- Design of an initial protype and proof of principal in the form of a study or test (or both) that support the initial designs to meet the stated goals in a reverent environment
- Report describing the design, test and analysis results and recommendations for work beyond Phase I.

**Desired Deliverables of Phase II:**

**Phase II Deliverables**:

- Prototype(s) capable of being integrated into a larger system. The prototype(s) should be accompanied by test data showing the device working in conditions like those in the final applications
- Report describing final design, test and analysis results, analysis of ability to integrate into a reference system such as NASA's multi-megawatt high power motor and drive system or similar (NASA will work with awardee to help define this).
- Estimation of technology gaps remaining for the given approach
- Delivery of prototype hardware as an option

**Desired Deliverable Types of Phase II:** Analysis, Test Results, Prototype, Hardware

**State of the Art:**

The state-of-the-art for aircraft with 5-10 Megawatt (MW) or greater onboard power is defined by ground demonstration for subscale systems alongside aircraft studies and work on cryogenic fuel systems. Systems providing up to 1 Megawatt of power are beginning to see flight demonstration and much progress has been made toward understanding how to derive benefits from electrified propulsion while meeting flight safety standards.

Larger planes with higher power levels require another step change in performance for the components themselves, and more highly integrated. The treatment of the thermal interactions on an airplane level is of particular importance as designers strive to extract more benefit. Work in this area is laying a foundation for future airplanes and future airspaces which can adapt to alternate fuels such as liquid hydrogen.

**Critical Gaps:**

NASA is pushing power levels, voltages and cooling system requirements to reduce weight while increasing power. For this application there are solutions that work at ambient temperatures but are either unproven or known to not work at cryogenic temperatures that are required for superconducting systems.

Significant progress has been made over the past decade in the area a of electrified aircraft propulsion. Prototype aircraft, major ground tests and flight demonstrators have succeeded with systems ranging from 100s of kilowatts to a megawatt. These power levels allow full electrification of urban air mobility vehicles (2-6 passengers) or mild hybridization of single aisle aircraft propulsion systems. While these prototypes and demonstrators are a significant step in the electrification of propulsion systems for aviation, it still falls short of the 2016 National Academies Decadal Survey, “Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions Recommendations.” This survey recommended the investigation of fully turboelectric single aisle aircraft. To do this requires developing systems that are capable of handling more than 10 megawatts alongside more radical changes to the airframe and more highly integrated designs.

The ultra-high efficiencies offered by superconducting systems are attractive for such applications, but there are a number of supporting technologies that must be more fully developed before the superconducting motors and distributions systems can be realized in an aircraft propulsion system. This subtopic is meant to address targeted technologies that need immediate action in order to drive this technological area forward.

**Shortfalls And Decadal Surveys:**

https://www.nationalacademies.org/projects/DEPS-ASEB-14-03/publication/23490

https://www.icao.int/Meetings/a41/Documents/WP/wp_368_en.pdf

https://www.faa.gov/sites/faa.gov/files/2021-11/Aviation_Climate_Action_Plan.pdf

https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/future-air-mobility-blog/fuel-efficiency-why-airlines-need-to-switch-to-more-ambitious-measures

**Need Horizon:** Long Term (Greater than 10 years)

**References:**

1. Megawatt and Beyond, NASA's Electrified Aircraft Propulsion, Dr. Andrew Woodworth https://ntrs.nasa.gov/api/citations/20250006231/downloads/PEASA2025%20-STI.pdf
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# GO – Space Transportation (GO)

## GO.4.T26B: Modernization of CFD Tools for Advanced Propulsion Applications (STTR)

**Lead Center:** MSFC

**Participating Center(s):** GRC

**Subtopic Problem Statement/Description:**

Predictive, analytical modeling of subcritical combustion physics is a challenge that bridges several state-of-the-art and state-of-the-practice limitations of currently available models. Practically all spacecraft propulsion systems operate in a subcritical propellant injection regime during nominal operations. The maturation of advanced chemical propulsion systems with high efficiency and reliability is critical to NASA's missions for human exploration on the Moon and Mars. Development of these systems requires robust and accurate computational fluid dynamics (CFD) models to help guide design decisions and understand combustion dynamics and performance observed in testing or operation.

Rotating Detonation Rocket Engines (RDREs) operate by injecting liquid fuel and/or oxidizer into an annular combustion chamber. These propellants are initially in a liquid state and undergo liquid break-up and atomization once introduced into the combustion chamber as dictated by their fluid properties and injection dynamics. In an RDRE application, a supersonic combustion wave impacts the injected propellent stream, further atomizing the injected fuel and oxidizer streams to enhance combustion in an unsteady combustion environment. The potential advantages of RDREs have led to great interest in development of flight-scale RDREs, but with limited success to date due in part to a lack of understanding of the complex multiphase fluid injection and combustion physics.

In traditional, subsonic combustion rocket engines, the initial start-up operation of the engine requires that the fuel and oxidizer are injected in a subcritical fluid regime. The success of the rocket engine performance relies on characterization of ignition and combustion dynamics. In the case of liquid hypergolic rocket engines, liquid fuel and oxidizer are injected, break up and atomize, undergo extremely energetic liquid-liquid chemical reactions and simultaneous vaporization followed by gas-phase chemical reactions, with a range of timescales from microseconds to tens of milliseconds. Hypergolic engines have been plagued with damaging transient combustion events throughout the history of their development, with mitigations typically resulting from extensive test campaigns to develop operational keep out zones, with significant residual risk due to a lack of physical understanding of these transient combustion events.

Predictive analytical models could potentially avoid engine development issues and ensure reliable, predictable combustion dynamics across the range of liquid rocket engines from traditional chemical, hypergolic, to RDRE. There are currently no validated or even pragmatic analytical tools that can predictively model the physics of subcritical propellant injection, break-up, phase change and combustion. Model development in these areas of subcritical liquid injection and break-up, interface tracking, phase change, and multiphase combustion kinetics mechanisms are needed in order to develop predictive analytical tools that can be used in the design of advanced chemical propulsion systems. Particular focus should be placed on coupling subcritical approaches to existing methodologies used for trans- and supercritical regime flows.

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

**Primary Technology Taxonomy:**

- Level 1: TX11 Software, Modeling, Simulation, and Information Processing
- Level 2: TX11.3 Simulation
- Level 3: TX11.3.7 Multiscale, Multiphysics, and Multifidelity Simulation

**Desired Deliverables of Phase I:**

Development of an analytical model capable of simulating injection of multiple liquid species into a highly turbulent gaseous region representative of a combustion chamber. The model should be able to capture the physics of liquid break-up, initially modeled using a sharp-interface method (e.g., volume of fluid or phase field), into droplets that then evaporate into the background gas while conserving mass, momentum and energy. Demonstration of a proof-of-concept simulation for a lab-scale combustion chamber at relevant conditions.

**Desired Deliverables of Phase II:**

Development of an analytical model that captures the fully coupled physics between propellant injection at subcritical conditions through liquid break-up and finally coupled with a gas-phase combustion model. The analytical model shall be extended to model liquid-liquid hypergolic reactions prior to gas-phase hypergolic reactions as a secondary objective. The final analytical model must be validated to the best degree possible with available combustion chamber test data and demonstrated on a 3-D, realistic combustion application that is relevant to NASA. The final model must also be scalable to full-sized space flight engines and efficient enough to justify the value of the analytical model as a tool for propulsion system development. The model should be formulated to accommodate implementation in a graphics processing unit (GPU)-accelerated finite-volume framework.

**Desired Deliverable Types of Phase II:**

- Analysis
- Software

**State of the Art:**

The current state-of-the-art (SOA) for CFD modeling of subcritical liquid injection and combustion involves the use of an interface-tracking method to represent the gas-liquid interface of the injector spray, transitioning to an Eulerian or Lagrangian representation of the droplet field once the length scales of individual droplets can no longer be resolved by the computational mesh. Heat transfer to the droplets is modeled stochastically, resulting in evaporation, mixing, and combustion of the gas phase.

**Critical Gaps:**

In practice, the SOA models are computationally expensive, requiring extremely high spatial resolution, and are not numerically robust enough to conduct simulations of realistic many-element injector designs in a useful timeframe without enormous computational resources. Droplet breakup and heat transfer models are based on data from experiments relevant to traditional subsonic combustion chambers, which may not be appropriate for evolving engine technologies such as RDREs. Currently, no practical models exist for simulation of liquid-liquid reactions as found in the combustion of hypergolic fuels.

**Shortfalls And Decadal Surveys:**

NASA Civil Space Shortfall 1511 - Advance Computational Fluid Dynamics Tools/Capabilities

**Need Horizon:** Near-Term (Less than 5 years)

**References:**

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## GO.5.T26B: Very Low Earth Orbits (VLEO) Control Surfaces (STTR)

**Lead Center:** GRC

**Participating Center(s):** MSFC, AFRC

**Subtopic Problem Statement/Description:**

Very low Earth orbits (VLEOs), defined as 80 – 400 km (ref.), are becoming of interest due to uncertainties in their composition, ionization levels, and movement patterns[1]. In particular, The altitude ranges from ~80 to ~160 km—that is, the D- and E-regions of the ionosphere—is a critical region where key aspects of the energy and momentum transport between the M-I-T (Mesosphere/Ionosphere/Thermosphere) system take place. While previous LEO missions have provided information on the magnetospheric input into the upper atmosphere and ionosphere—as well as preliminary insight into its response—these missions have been unable to probe the mechanisms of coupling. Concepts for orbital “dipper” missions that regularly dip into very low Earth orbit (VLEO; i.e., the E-region ionosphere) have been circulating in the community for several decades, no such mission has yet been implemented to answer these questions.[2]

Orbits at low altitudes will be defined by high relative spacecraft speeds: circular orbits are on the order of 7-8 km/s, equivalent to an approximate Mach number of 25. This is therefore a regime of rarefied gases and hypersonic flow. In this regime, spacecraft will encounter aerodynamic forces, particularly at the lowest altitudes, that will influence spacecraft orbits through drag. Also, in the regimes between 80 and 200 km, propellant efficient electric propulsion will not be possible due to the magnitude of the drag and composition and density of the atmosphere at those altitudes. Extended missions passing through lowest altitudes will therefore need to address some combination of

1. minimizing drag,
2. countering drag with propulsion using either on board or ambient propellant,

3. and/or possibly adapting the spacecraft to take advantage of the available aerodynamic forces to maintain orbit and/or change orbits.

One successful example of maneuvering in this regime is the USSF X37b spaceplane, which has demonstrated aerobraking to change orbits aerodynamically[3]. To date, civil satellite missions or designs in the VLEO regime (ASTRE[2], SOAR[4]) have not used control surfaces on their spacecraft to maintain orbit. For example, the proposed ASTRE mission would use hydrazine propulsion to remain on orbit; SOAR started at ~400 km and reentered within 8 months.

To date, open tests of satellites in the VLEO regime (ASTRE[2], SOAR[4]) have not used control surfaces on their spacecraft. Additional lift/steering forces from such surfaces would allow longer satellite durations and greater data collection. The desired products of this subtopic are therefore the design of either aerodynamic components, or a combination of such components with a viable propulsion system, to maintain orbit, or perform orbital maneuvers, at orbital altitudes that are not just VLEO, but particularly in the 80 km – 120 km region.

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

**Primary Technology Taxonomy:**

- Level 1: TX15 Flight Vehicle Systems
- Level 2: TX15.X Other Flight Vehicle Systems
- Level 3: TX15.1.6 Advanced Atmospheric Flight Vehicles

**Desired Deliverables of Phase I:**

Phase 1 Products would be:

1. VLEO environmental model
2. Aerodynamic spacecraft surface design
4. Propulsion system design if needed
5. Identification of potential maneuvers, or mission durations, that could be expected with the systems
6. Identification of possible test facilities validation in Phase 2

**Desired Deliverables of Phase II:**

Phase 2 Products would be:

1. Test article (aerodynamic system to be tested)
2. Test design
3. First experimental test results demonstrating lift, drag, and moments

**Desired Deliverable Types of Phase II:**

- Analysis,
- Test Results
- Hardware
- Prototype

**State of the Art:**

The altitude ranges from ~80 to ~160 km—that is, the D- and E-regions of the ionosphere—is a critical region where key aspects of the energy and momentum transport between the M-I-T system take place. This region is immensely important because it is the altitudinal crossroads where ionospheric electrodynamics (e.g., Joule heating and current closure) occur in concert with significant neutral densities and thermospheric processes (e.g., neutral winds). Unfortunately, despite the importance of this region in understanding the intricacies of the coupled near-Earth space system, it remains woefully underexplored with most focused investigations coming from the sounding rocket program. The paucity of measurements in this region stems from the general inability to investigate these altitudes using orbital spacecraft owing to substantial atmospheric drag that arises from the combination of required high orbital velocities and relatively large plasma and neutral densities at altitudes below ~400 km.

**Critical Gaps:**

Aerodynamic maneuvering designs for 80 to 160 km

Efficient propulsion at 80 to 160 km

**Shortfalls And Decadal Surveys:**

Perform advanced remote sensing and science measurements with improved sensing capabilities and autonomy.

Provide space technology demonstration environments.

**Need Horizon:** Mid-Term (5-10 years)

**References:**

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# LIVE – Surface Infrastructure (LIVEI)

## LIVEI.2.T26B: Bulk Regolith Manipulation and Site Preparation (STTR)

**Lead Center:** KSC

**Participating Center(s):** LaRC, ARC, GRC

**Subtopic Problem Statement/Description:**

Some of the first possible lunar infrastructure will be prepared surfaces composed of bulk regolith, rocks and other surface treatments. This subtopic will develop civil engineering designs of prepared lunar surface infrastructure, technologies to build the infrastructure, and construction concepts of operations (ConOps) for the South Polar region of the Moon. The intention of this subtopic is to prepare the systems that can stimulate commercial space resource based economic activity through robotic regolith manipulation and site preparation. Products and services that can be offered to the market by the proposed technologies should be specified along with realistic pricing. Development of financial engineering constructs to facilitate the exchange of goods and services are also desired. Proposals should be compatible with the Lunar Innovation Park (Park) concept described in the references and with Fission Surface

Power (FSP) emplacement and radiation protection applications. Park and FSP missions are the infusion path for this subtopic.

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.
- Geotechnical measurement.
- Rock removal and management.
- Establishing grade and forming desired ground features (e.g., berms, ramps, and level surfaces).
- Compaction.
- Anchoring for foundations and stabilizing structures (e.g., guy-wires)
- Verification of infrastructure design parameters and geometry of built structures.
- Surface treatments to mitigate PSI ejecta and dust.
- Routines, sensors, and ultrawideband beacons for autonomous construction operations and localization.
- Radiation sensors for space and FSP radiation measurements to assess radiation protection characteristics of built structures.

The desired outcome of this effort is the robotic capability to perform site preparation and regolith manipulation tasks that are applicable to the Park and FSP. These technologies are sought for initial ground demonstrations with follow on lunar construction missions. The following lunar civil engineered structures are of particular interest to NASA:

- Bulk regolith-based landing zones designed to minimize risks associated with landing on regolith surfaces for medium to large scale Commercial Lunar Payload Services (CLPS) class vehicles with extensibility to Human Landing System (HLS) vehicles.
- Bulk regolith berms for PSI ejecta and FSP radiation mitigation.
- Foundations for reusable Launch/Landing Pads, FSP installations, and shelters
- Sloped access ramps.
- Bulk regolith overburden on unpressurized shelters for thermal stability, space radiation attenuation, and meteoroid impact mitigation (<u>shelter structures are not within subtopic scope unless composed primarily of bulk regolith</u>).
- Structures for access to subgrade (e.g., trenches and pits) for utilities and science.

Proposers are welcome to suggest other regolith-based infrastructure concepts. In-situ resource utilization technologies for applications like oxygen production and construction (e.g., regolith sintering and/or melting to make bricks/paved areas) are desired for Park service customer demonstration missions, and potentially to construct a reusable Launch/Landing Pad, but <u>they are not within scope of this subtopic.</u> Other areas of significant interest include:

- Non-regolith-based surface treatments such as Class II deployable or assemble-able surface covers, stabilizing agents, or other solutions to improve regolith surfaces for purposes such as reusable launch/landing pad surfaces (including flame deflectors), improving berms as PSI ejecta barriers, improving regolith berms and overburden for radiation protection, improving trafficability, and dust mitigation.
- Holistic designs that improve upon the Lunar Innovation Park concept and/or regolith features of FSP emplacements.

- Financial engineering development to facilitate the emergence of space resource based economic activity within the context of the Lunar Innovation Park with extensibility beyond. For example, development of a space commodities exchange, board of trade, or other banking, finance or market innovation that kickstarts the space resource economy. A core tenet of the Lunar Innovation Park concept is to transition from a "go study" posture to "go do". Therefore, proposed financial engineering activities must go beyond completing research and making recommendations. Rather, proposals in this area must create and test the financial tools and technologies that enable space resource based economic activity. Development activities should be commensurate in time/scale with initiating commodity exchange the Park in the early 2030s.

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

**Primary Technology Taxonomy:**

- Level 1: TX07 Exploration Destination Systems
- Level 2: TX07.2 Mission Infrastructure, Sustainability, and Supportability
- Level 3: TX07.2.3 Surface Construction and Assembly

**Desired Deliverables of Phase I:**

Phase I must include tests and validated models/simulations should be developed to characterize the system and regolith infrastructure performance in its intended environments/applications. For example, performance of berms when exposed to plume gases and PSI ejecta and prediction of secondary ejecta trajectories.

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

Concepts should be appropriate for eventual medium scale CLPS demonstration missions on the lunar surface (e.g., <100 kg overall mass). Assume that implements to perform the above-mentioned robotic capabilities will attach to a modular interface (mechanical, power, communications) on an existing construction mobility platform. <u>Development of construction mobility platforms are not within scope of this subtopic.</u> The construction mobility platform scale and capabilities should be assumed to be consistent with the Infrastructure Pilot Excavator (IPEx) (previously ISRU Pilot Excavator) with interfaces at the forward and aft position after the rotary "shoulder" actuators. In the Lunar Innovation Park concept, the modular construction mobility platform is notionally called Construction Pilot Excavator (CPEx). Assumption of other commercial planned or available construction mobility platforms is welcome as long as it is consistent with the scale and capability of IPEx/CPEx.

Proposers may select one or more systems/structures of interest to develop. Concepts that employ or build upon higher Technology Readiness Level (TRL) systems will be prioritized. It should be assumed that the technology/infrastructure will be infused into a lunar demonstration mission flight at the end of 2030.

**Desired Deliverables of Phase II:**

Phase II deliverables must be built on Phase I and include ground demonstration of infrastructure construction including the use of a mobility platform. The infrastructure must be constructed using robotic systems and implements. Critical functions of the infrastructure and systems must be demonstrated in relevant environments. Structures and systems must be developed to a minimum of TRL 5. It is anticipated that follow on work will quickly transition to flight hardware, so Phase II systems should be as flight-like as possible.

**Desired Deliverable Types of Phase II:**

- Analysis
- Test Results
- Hardware
- Prototype
- Software
- Digital Models

**State of the Art:**

While civil engineering and construction are well-established practices on Earth, lunar methods remain at low TRLs. Robotic construction on Earth is still in its infancy. The design requirements and functional capabilities of bulk regolith-based and Class II lunar infrastructure are based on the Lunar Innovation Park and FSP applications. To date, very few studies have performed civil engineering designs of bulk regolith infrastructure for these applications. Tests have been performed on Earth but only for short periods of time and with limited environmental and operational fidelity.

IPEx is the state-of-the-art lunar robotic excavation platform. The only existing lunar construction demonstration is planting the United States flag on the Moon.

**Critical Gaps:**

The following robotic capabilities gaps exist:

- High resolution topography mapping.
- Geotechnical measurement.
- Rock removal and management.
- Establishing grade and forming desired ground features (e.g., berms, ramps, and level surfaces).
- Compaction.
- Anchoring for foundations and stabilizing structures (e.g., guy-wires)
- Verification of infrastructure design parameters and geometry of built structures.
- Surface treatments to mitigate PSI ejecta and dust.
- Routines, sensors, and ultrawideband beacons for autonomous construction operations and localization.
- Radiation sensors for space and FSP radiation measurements to assess radiation protection characteristics of built structures.

The design of the following lunar civil engineered structures and robotic ability to construct them are gaps:

- Bulk regolith-based landing zones designed to minimize risks associated with landing on regolith surfaces for medium to large scale Commercial Lunar Payload Services (CLPS) class vehicles with extensibility to Human Landing System (HLS) vehicles.
- Bulk regolith berms for PSI ejecta and FSP radiation mitigation.
- Foundations for reusable Launch/Landing Pads, FSP installations, and shelters
- Sloped access ramps.
- Bulk regolith overburden on unpressurized shelters for thermal stability, space radiation attenuation, and meteoroid impact mitigation.
- Structures for access to subgrade (e.g., trenches and pits) for utilities and science.

Other significant gaps include:

- Non-regolith-based surface treatments such as Class II deployable or assemble-able surface covers, stabilizing agents, or other solutions to improve regolith surfaces for purposes such as reusable launch/landing pad surfaces (including flame deflectors), improving berms as PSI ejecta barriers, improving regolith berms and overburden for radiation protection, improving trafficability, and dust mitigation.
- Holistic designs that improve upon the Lunar Innovation Park concept and/or regolith features of FSP emplacements.
- Financial engineering development to facilitate the emergence of space resource based economic activity within the context of the Lunar Innovation Park with extensibility beyond.

**Shortfalls And Decadal Surveys:**

2024 Civil Space Shortfall

Integrated Rank - Shortfall ID - Name

1 - 1618 - Survive and operate through the lunar night

2 - 1596 - High power energy demonstration on the Moon and Mars Surfaces

4 - 1557 - Position, navigation, and timing for in-orbit and surface applications

5 - 1545 - Robotic actuation, subsystem components, and system architectures for long-duration and extreme environment operations

6 - 1552 - Extreme environment avionics

9 - 1304 - Robust, high-progress rate, and long-distance autonomous surface mobility

12 - 1591 - Power management systems for long duration Lunar and Martian Missions

18 - 1548 - Sensing for autonomous robotic operations in challenging environmental conditions

19 - 1558 - High-rate communications across the Lunar surface

20 - 1626 - Advanced sensor components: imaging

24 - 1571 - Navigation sensors for precision landing

25 - 1573 - Terrain mapping capabilities for precision landing and hazard avoidance

**Need Horizon:** Near-Term (Less than 5 years)

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# Science Instruments and Computing to Study Planetary Bodies (INSTALG)

## INSTALG.6.T26B: Quantum Computing (STTR) (previously S17.05)

**Lead Center:** ARC

**Participating Center(s):** JPL

**Subtopic Problem Statement/Description:**

Quantum computing offers the possibility of strong computational advantage that can influence a wide range of computational fields, but that advantage requires scoping out and determining the abilities of quantum hardware for specific use cases. The goal of this subtopic is to develop and improve quantum, quantum-inspired, and hybrid quantum-classical workflows and work towards showing (or disproving) utility or advantage over existing classical state-of-the-art algorithms. Specifically, these methods should be deployed for solving high utility Science Mission Directorate (SMD) problems, such as those related to: how Earth’s climate and environment function and interact; how Earth and human systems impact each other; how and why the Sun varies and affects Earth and the rest of the solar system; how planets and life originate; and how the universe works?

The subtopic scope is focused on near-to-mid-term technology needs that are designed to jump start leveraging quantum computing advances made in industry for NASA SMD objectives. SMD sees this as a priority area in which engaging the commercial sector and academia is essential. NASA SMD seeks to remain at the forefront in terms of high-performance computing capabilities for science where advancing high-fidelity modeling and simulation with large data sets is a priority. In particular, SMD seeks quantum methods and techniques tailored to specific problems of scientific interest that are ready and deployable on utility-scale quantum hardware as it develops as well as quantum and physics inspired methods that are deployable on classical supercomputers.

This scope is not just about developing quantum and quantum-inspired algorithms, but more so applying and tailoring existing techniques to a high-utility science problem. There is a large gap between an academic/theoretical algorithm and one that has been tailored and scoped to a specific problem and deployable on hardware. In addition, we need to know what hardware advancements are needed to support the proposed methods.

Examples of applications of interest include the following, but are not limited to:

- Improving on image-to-image translation, noise filtering, data fusion and other data pre-processing tasks (see for example, Ref. [9]).
- Identifying actionable extreme weather event triggers.
- Optimizing data acquisition tasking and scheduling.
- Leveraging quantum computing for 2D and 3D phase unwrapping of synthetic aperture radar (SAR) data.
- Improving atmospheric and climatology modeling.
- Solutions for inverse problems (e.g., retrievals, data fusion, etc).
- Improving modeling of stellar evolution and its effect on our solar system.

Expertise in the following areas may be useful in responding to this solicitation:

- Familiarity with high utility problems of interest to SMD in areas such as climatology, astrophysics, and heliophysics.
- Quantum algorithms and software engineering.
- Classical high-performance computing.
- Quantum circuit simulators.
- Classical state-of-the-art techniques for solving the high-utility SMD problems of interest.
- Quantum hardware: it is within scope, but not required, to solve small test instances the problems of interest on current Noisy Intermediate Scale Quantum (NISQ) or Logical Intermediate Scale Quantum (LISQ) hardware, but this hardware does not need to be provided by the proposing business. Agreements with hardware manufacturers or publicly purchasable quantum compute time is acceptable. Some familiarity with state-of-the-art quantum hardware is warranted for all aspects of the call to ensure the quantum amenability of all parts of the computational workflow.

Successful proposers are likely to include experts from all the identified areas of expertise above in order to be able to design approaches that leverage quantum computing to solving high utility problems related to SMD's mission.

**Expected TRL or TRL Range at completion of the Project:** 3 - 4

**Primary Technology Taxonomy:**

- Level 1: TX11 Software, Modeling, Simulation, and Information Processing
- Level 2: TX11.X Other Software, Modeling, Simulation, and Information Processing

**Desired Deliverables of Phase I:**

Technical feasibility demonstration with supporting research results demonstrating advancement over state of the art and NASA relevance. Documentation of a path toward a Phase II deliverable.

While work aimed exclusively toward deliverables is acceptable, opportunities and desire to collaborate with NASA's existing quantum computing workforce on topics of mutual interest will be considered and can be created.

**Desired Deliverables of Phase II:**

Prototype demonstration and software delivery along with documentation of development and capabilities, including operating instructions. Plan scaling upwards to commercialization or infusion into NASA programs. For quantum-inspired algorithms, these methods should be directly deployable; for quantum methods, small test cases should be deployable, but full utility-scale employment must come with hardware conditions and specifications necessary to run the solution.

**Desired Deliverable Types of Phase II:**

- Analysis
- Test Results
- Software

**State of the Art:**

Quantum computing hardware has advanced rapidly from tiny laboratory experiments to quantum chips that can outperform even the largest supercomputers on specialized computational tasks. However, these NISQ and LISQ processors are still too small and non-robust to be able to solve practical problems of interest to SMD that are intractable on classical computers. As these devices scale up and become more reliable, we have an unprecedented opportunity to invent, explore, and evaluate quantum algorithms and methods empirically [Ref 2]. Quantum algorithms have been developed and demonstrated on small test cases for a variety of mathematical problems, but often these techniques lack full resource estimates or the last-mile adjustments that make them amenable to real world problems. Quantum and physics-inspired algorithms often stand as state of the art among classical techniques, but again, they often need to be tailored to be useable in practice.

**Critical Gaps:**

Critical gaps include the ability to encapsulate and describe in software high-utility problem instances of interest to SMD in areas including but not limited to remote sensing, climatology, astrophysics, and heliophysics. Additional gaps include software for estimating the classical and quantum resources for solving these problems; software for estimating the utility (in dollars) to SMD for solving these problems; and software for lowering the barrier for solving SMD problems of interest with quantum and hybrid quantum-classical tool chains.

Specific objectives are to:

- Identify problems of interest to SMD in areas, such as climatology, astrophysics, heliophysics [Ref. 3], which are amenable to acceleration or solution by a quantum computer and providing clear end-to-end classical and quantum resource estimates for solving the problem (i.e. exact qubit and gate counts and all classical resources, such as those found in [Ref. 1] using existing and novel algorithms.
- Develop and create test implementations of new quantum, quantum-inspired, or hybrid quantum-classical methods with well substantiated and significant improvements to existing state of that art quantum/hybrid methods for problems of interest to SMD, especially methods tailored to those problems rather than abstracted problem classes. Provide updated resource estimates as these new methods are developed.
- Reference and clearly articulate the comparison between developed quantum/hybrid algorithms and state of the art classical algorithms for solving the same problems.
- Clearly articulate the utility of solving the selected problems to SMD with a clear description of how utility is assessed and how current and future quantum workflow developments and their associated costs interact with that utility. This utility should reference existing state of the art classical algorithms and discuss the utility in excess of what is already provided by those algorithms.
- Develop new or augment existing resource estimation software (see for example, Zapata's Bench-Q [Ref. 4] tool for hardware resource estimates and the Rigetti Resource Estimation Software [Refs. 5,6]) to create open-source software for estimating the classical and quantum resources needed for solving the identified SMD problems of interest that provide features or specialization not currently available.

- Develop and demonstrate the effectiveness of novel methods to ingest large NASA datasets into networked quantum, quantum-inspired, or hybrid quantum-classical computers along with well substantiated and non-trivial quantum algorithms and/or hardware to enable such networked computations.
- Create test sets/instances for the chosen problem class of varying levels of complexity and size with associated utility metrics for each set/instance. For tests that are amenable in terms of size and complexity, run the specified test sets with the developed quantum/hybrid methodologies on current generation quantum hardware.

**Shortfalls And Decadal Surveys:**

"Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space," National Academies:https://www.nationalacademies.org/our-work/decadal-survey-for-earth-science-and-applications-from-space

“Solar and Space Physics: A Science for a Technological Society," National Academies: http://nap.edu/13060

This subtopic addresses the following shortfall(s) identified in the 2026 Civil Space Shortfall list:

- Provide a ground support infrastructure capable of supporting a launch cadence sufficient for continuous lunar access and missions to Mars

**Need Horizon:** Mid-Term (5-10 years)

**References:**

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8. Guillaume, A.; Goh, E. Y.; Johnston, M. D.; Wilson, B. D.; Ramanan, A.; Tibble, F.; Lackey, B., “Deep space network scheduling using quantum annealing,” IEEE Transactions on Quantum Engineering. 2022, Vol. 3, pp. 1-13: https://ieeexplore.ieee.org/iel7/8924785/8961200/09863923.pdf

9. Akbari Asanjan, A.; Memarzadeh, M.; Lott, P. A.; Rieffel, E.; Grabbe, S., "Probabilistic wildfire segmentation using supervised deep generative model from satellite imagery," Remote Sensing, 2023. Vol. 15, No. 11, pp. 2718: https://www.mdpi.com/2072-4292/15/11/2718

# Space Precision Components: Galaxies to Atoms (COSMO)

## COSMO.6.T26B: Fundamental Physics Test Apparatus (STTR) (previously S16.08)

**Lead Center:** JPL

**Participating Center(s):** GSFC

**Subtopic Problem Statement/Description:**

The next generation of space science and exploration will rely on exploiting quantum phenomena to push sensing precision beyond current limits. This subtopic seeks to advance technologies for ultra-precise measurements of fundamental constants and forces, gravity, inertia, electromagnetic fields, and time, which are essential to the search for new laws of physics and for deep-space navigation and exploration. The need is driven by NASA's unique requirements for rugged and low-Size, Weight, and Power (SWaP) systems leveraging quantum properties, including optical atomic clocks for next-level timekeeping and cold atom interferometers for precision inertial and gravitational sensing in microgravity. These technologies could also benefit from entanglement-enhanced measurement techniques and quantum memories to achieve precision beyond the standard quantum limit and to incorporate instruments into quantum-networks.

Recent developments of laser control and manipulation of atoms have led to new types of quantum sensors and clocks. Atomic systems, being intrinsically quantum mechanical, have demonstrated their unique advantages in metrology and sensing. Perhaps the most celebrated atomic metrology tool is the atomic clock. Recently, atomic clocks in the optical frequency domain (i.e., optical primary frequency standards) have been matured to achieve frequency uncertainty beyond 1 part in $10^{18}$, far exceeding that of the primary Cesium standards. Similarly, Doppler-sensitive quantum measurements of atomic particles lead to exquisite inertial sensors, exemplified by atom interferometers. Because the center of mass motion is involved, atom interferometers use atomic particles as test masses and quantum matter-wave interferometry for motional and force measurements.

Indeed, optical clocks and atom interferometers are two sides of the same coin, sharing many common physical processes, technologies, and salient performance features. For many measurements, the sensitivity scales strongly with the interaction time with an atom. As the atomic free fall time can be dramatically longer in microgravity, coupled with advanced cooling techniques which are optimized in the absence of gravity, these technologies are a natural fit for space exploration. Improved spaceborne quantum systems could enable spaceborne apparatuses to perform important fundamental physics experiments, including searching for local signatures of dark matter and dark energy, searching for time variations of fundamental constants, and precision tests of the foundational theories of modern physics including general relativity and quantum mechanics. However, maturing the technologies of spaceborne optical clocks and atom interferometers will also be impactful for application including timing and inertial navigation, planetary sciences, and gravity, atmosphere, and mass-change sensing. Maturing entanglement-enhanced sensors and quantum memories for space will also be important to realize quantum-networked sensors for exploring fundamental physics in space. With this broad range of possible applications and missions, the purpose of this proposal calls to specifically solicit the development of compact, space qualifiable subsystems common to atom interferometers, atomic clocks, and quantum gas systems including high-flux cold atom sources, lasers and optical distribution systems, highly stable current sources for rapidly switching inductive loads, and optical frequency combs.

Proposals are expected to address specific critical gaps identified.

Note that Rydberg-atom based sensors should go to INSTALG.5.S26B.

Note that quantum sensing for space weather should go to SPWX.3.T26B.

Note that superconducting detectors should go to INSTALG.4.S26B or COSMO.1.S26A depending on wavelength.

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

**Primary Technology Taxonomy:**

- Level 1: TX08 Sensors and Instruments
- Level 2: TX08.X Other Sensors and Instruments

**Desired Deliverables of Phase I:**

Phase I must deliver relevant studies, quantitative analysis, and a preliminary laboratory demonstration or bench scale experiment of the proposed quantum sensing or metrology technique. Deliverables must include a quantitative theoretical analysis of the proposed technology and a discussion of the technological maturation required to develop a prototype system with a path to space qualification, directly informing the plan for Phase II.

**Desired Deliverables of Phase II:**

Phase II must deliver a prototype system or demonstration hardware to a relevant NASA research center, along with a summary of performance analysis and applicable supporting documentation, data, and/or test reports. The deliverables must also include a clear delineation of any further work that would be required to bring the technologies to full operational and/or commercial use.

**Desired Deliverable Types of Phase II:**

- Research (STTR Only)
- Analysis
- Prototype
- Hardware
- Software

**State of the Art:**

For atomic clocks and interferometers to realize the many potential benefits of operating in space, key systems successfully demonstrated in a laboratory setting must be further matured for flight. It is therefore useful to distinguish the State of the Art (SOA) capabilities of spaceborne atomic clocks and interferometers from the SOA versions operating on the ground. The difference in performance between these two groups then naturally identifies the components and techniques which require development on a path to flight.

The current SOA for spaceborne clocks is represented by the Deep Space Atomic Clock (DSAC) mission, which successfully flew a space-qualified microwave ion clock demonstrating a long-term stability of $10^{-15}$, and the Atomic Clock Ensemble in Space (ACES) mission, which operates a Cesium Fountain Clock with target accuracy of $10^{-16}$ and a Hydrogen Maser on the ISS. On the ground, optical atomic clocks have been matured to achieve frequency uncertainty beyond 1 part in $10^{18}$ and have utilized quantum entanglement to achieve a metrological improvement of 2 beyond the standard quantum limit.

The current SOA for spaceborne atom interferometry is the proof-of-principle atom interferometer operating in the Cold Atom Lab on the ISS, which has demonstrated dual-species (rubidium-potassium) interferometry and single-species (rubidium) interferometry-based sensing at interrogation times below 20 milliseconds. The cold atom source for this interferometer is a compact atom chip-based system producing BECs on the order of $10^5$ atoms in a standard "pulsed configuration". On the ground, BECs sources have been produced with up to $10^8$ atoms per run, while more recent continuous BEC sources have been produced with $10^5$ atoms in steady state.

Many technology gaps exist in the development state of atomic sensors and clocks intended for NASA space applications. These gaps are mainly in the areas of reducing size, mass, and power, while increasing their performance and advancing them towards space qualification. These gaps may pertain to components, subsystems, instruments/devices, novel approaches, and/or theoretical analysis tools. Most of the needed improvements are elements that are beyond the current state of the art. These needed improvements include high-flux ultra-cold atom sources and atomic physics packages, including atomic vacuum cell technologies, low-power coils, and high-performance drivers specific to clock and atom interferometer applications, lasers and laser-optics system approaches with a high degree of integration and robustness that are suitable for spaceborne atomic devices, small ultra-stabilized laser systems, and miniature self-referenced optical frequency combs.

**Critical Gaps:**

The gaps to be filled and technologies to be matured for space include, but are not limited to, the following:

- Subsystem and components for high-performance and high accuracy optical clocks (e.g., Sr and Yb lattice or ion clocks), including low SWaP clock lasers, optical frequency combs, and advanced control electronics, with a path to a flight system.
- Space-qualifiable high-flux and low SWaP ultracold atom sources (e.g., greater than $1x10^6$ total atoms near less than 5 nK) for Rb, K, Cs, Yb, and Sr and ultra-high vacuum technologies (less than $1\ x10^{-9}$ Torr).
- Beyond the state-of-the-art photonic components at wavelengths for atomic species of interest, particularly visible, near infrared (NIR), and ultraviolet (UV), including:
    - Efficient acousto-optic modulators: e.g., low radiofrequency (RF) power ~200 mW, low thermal distortion, ~80% or greater diffraction efficiency.
    - Efficient electro-optic modulators: e.g., low bias drift, residual AM, and return loss; fiber-coupled preferred.
    - Integrated micro-optical assemblies and highly efficient photonic components (e.g., miniature optical isolators, high-speed high-extinction shutters, etc.) for quantum sensor applications.
- Flight qualifiable: i.e., rugged and long-life lasers or laser systems of high efficiency, narrow linewidth, high tunability, and/or higher power for clocks, atom interferometers, and optical dipole traps. Also, cooling and trapping lasers of 10 kHz linewidth and ~1 W or greater total optical power are generally needed, but offerors may define and justify their own performance specifications.
- Quantitative analysis and simulation tool of a cold atom system in trapped and free-fall states relevant to atom interferometer and clock measurements in space.
- Technical approaches and methods for beyond-state-of-the-art compact and miniature space-based clocks or atom interferometers, space-Earth optical time transfer, entanglement-enhanced measurements, or quantum memories, with emphasis on the performance per size, power, and mass.
- High-performance, rugged, and low SWaP octive-spanning optical frequency combs.

- Other innovative atomic quantum sensors for high-fidelity field measurements that have space applications and can be developed into a space-quantifiable instrument.

Because of the breath and diversity of the portfolio, performers are expected to be aware of specific gaps for specific application scenarios. All proposed system performances may be defined by offeror with clear justifications. Subsystem technology development proposals should clearly state the relevance to the anticipated system-level implementation and performance; define requirements, relevant atomic species, and working laser wavelengths; and indicate its path to a space-borne instrument.

**Shortfalls And Decadal Surveys:**

"Thriving in Space: Ensuring the Future of Biological and Physical Sciences Research: A Decadal Survey for 2023-2032," National Academies: https://doi.org/10.17226/26750

"Planetary Science and Astrobiology Decadal Survey 2023-2032,"
National Academies: https://www.nationalacademies.org/our-work/planetary-science-and-astrobiology-decadal-survey-2023-2032

This subtopic addresses the following shortfall(s) identified in the 2026 Civil Space Shortfall list:

- Perform advanced remote sensing and science measurements with improved sensing capabilities and autonomy.
- Provide tracking and navigation of crew and assets in space.

**Need Horizon:** Mid-Term (5-10 years)

**References:**

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- "National Quantum Initiative Act," Public Law. No. 115-368, 132 Stat. 5092, 2018: https://www.congress.gov/115/plaws/publ368/PLAW-115publ368.pdf
- "Quantum sensing for NASA science missions," Mercer, C.R., Montbach, E.N., Christe, S.D. *et al.,EPJ Quantum Technol.* **12**, 56 (2025). https://doi.org/10.1140/epjqt/s40507-025-00360-3
- Mark Clampin, Deputy Assoc. Admin., Sci. Mission Directorate, Nat'l Aeronautics & Space Admin., *Statement Before the H. Comm. on Sci., Space & Tech., Regarding "Assessing U.S. Leadership in Quantum Science and Technology"*, 119th Cong. (Jan. 22, 2026), https://docs.house.gov/meetings/SY/SY00/20260122/118878/HHRG-119-SY00-Wstate-ClampinM-20260122.pdf

# Space Weather (SPWX)

## SPWX.3.T26B: Quantum Sensing Components for Space Environment Measurements (STTR) (previously S14.04)

**Lead Center:** GSFC

**Subtopic Problem Statement/Description:**

The most recent Heliophysics decadal survey, The Next Decade in Solar and Space Physics: Exploring and Safeguarding Humanity's Home in Space (2025), emphasized the critical need for "a robust and sustained technology development program [that] ensures advancement of measurement capabilities across the full range of maturity, from inception of a novel concept that may or may not work, to mass production of hundreds of instrument copies." This call reflects a growing, and accelerating, shift in Heliophysics mission architectures from traditional single large spacecraft to novel distributed networks of small satellites that can provide simultaneous multi-point measurements of dynamic solar, magnetospheric, and ionospheric processes. The proliferation of fundamental space environment properties can be accomplished through rides of opportunity and/or targeted constellation missions. Such constellations, and particularly small satellites, can be enabled by sensors with dramatically reduced size, weight, and power, while maintaining or exceeding measurement performance compared to current state of the art.

NASA's Space Technology Mission Directorate has identified quantum sensing as a transformative technology that can be a means of addressing such needs. Quantum sensors leverage fundamental quantum mechanical phenomena such as superposition, entanglement, and the discrete energy levels of atoms and solid-state defects to achieve measurement sensitivities approaching or exceeding fundamental physical limits. For Heliophysics applications, fundamental properties include in-situ or remote measurements of magnetic fields – weak as in the solar wind and strong as in the Earth's environment-, electric fields, neutral and charged particle properties (including but not limited to densities, and velocity and energy distributions), and photon fluxes in relevant remote sensing frequency domains. Quantum sensing offers the potential to measure many of these properties in tenuous plasma environments with sensing techniques tied to fundamental physical constants rather than engineered components subject to drift.

This STTR subtopic solicits development of quantum sensing technologies at stages from early concept to flight-like prototype for in-situ or remote space environment measurements supporting solar and Geospace science, Moon to Mars operations, and space weather applications. Examples of application targets include but are not limited to (1) low B-field magnetometers that could operate in lunar temperature extremes (-100 to +120C), (2) quantum E-field sensors that can measure solar wind type of E-fields, i.e. few mV/m; (3) trace charged and neutral gas sensing, including noble gases, water, methane, ammonia, hydrogen and more. It is important to demonstrate innovation in design of both sensing components, control electronics and/or other instrument components in a low SWAP package.

Proposals must include partnerships with research institutions, indicate the targeted improvement over state of the art, and address pathways toward space qualification. Technologies should demonstrate concepts suitable for eventual operation in space environments, including relevant pressure and radiation levels, launch and impact stresses, and mission-specific temperature ranges. This subtopic targets advancement of quantum sensing concepts from early research stages (TRL 2-4) with clear paths toward flight demonstration.

Please note that quantum atomic clocks and atomic interferometry should go to COSMO.6.T26B.

Rydberg atom-based sensors should go to INSTALG.5.S26B.

Superconducting detectors should go to INSTALG.4.S26B or COSMO.1.S26A based on wavelength.

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

**Primary Technology Taxonomy:**

- Level 1: TX08 Sensors and Instruments
- Level 2: TX08.3 In Situ Instruments and Sensors

**Desired Deliverables of Phase I:**

Phase I shall deliver a feasibility study demonstrating proof-of-concept for the proposed quantum sensing technology. For lower TRL technology, the study must include theoretical analysis and modeling documenting quantum mechanical principles, expected performance metrics, and comparisons to classical sensing approaches. A preliminary sensor design shall identify critical components, key technical risks, and mitigation strategies. For higher TRL technology (including magnetometers), the study must conduct analysis and/or modeling demonstrating performance over state-of-the-art utilizing quantum principles lending to a future flight-like prototype. Space environment compatibility assessment shall analyze feasibility of operation under relevant conditions with preliminary SWaP estimates. A technology maturation roadmap shall detail Phase II demonstration objectives, required testing facilities, environmental test requirements, and timeline for TRL advancement. Final deliverables include a comprehensive report with specific recommendations for Phase II hardware development and assessment of potential impact on Heliophysics science objectives.

**Desired Deliverables of Phase II:**

The desired Phase II deliverable is a representative prototype demonstrating the quantum sensing technology in a relevant laboratory environment with hardware and specifications to be delivered to a NASA field center. The prototype or critical subcomponents should be fabricated and assembled with complete documentation of design, materials, and fabrication processes. Comprehensive testing and characterization should document sensor performance under controlled laboratory conditions, including sensitivity, accuracy, stability, and noise characteristics compared to Phase I predictions and state-of-the-art capabilities. Environmental testing should assess sensor response to temperature variations, electromagnetic interference, and other relevant factors. A detailed technology transition plan shall delineate specific steps required to advance the technology to flight readiness, including additional environmental testing needs, integration requirements, potential mission opportunities, and estimated timeline and resources. Final deliverables include a comprehensive report and test data package including steps for commercialization or NASA flight project infusion.

**Desired Deliverable Types of Phase II:**

- Analysis
- Research (STTR Only)
- Hardware
- Prototype
- Test Results

**State of the Art:**

NASA has significant heritage in quantum sensing for space, dating back to 1964 when Mariner IV flew an optically pumped helium vector magnetometer, one of the earliest quantum sensors deployed in space. Since then, quantum magnetometers have been flown on multiple planetary missions including subsequent Mariner missions to measure magnetic fields in interplanetary space and at Jupiter.

1. Transition-Edge Sensors (TES): TES bolometers provide 100 times better energy resolution than traditional detectors and have been demonstrated on multiple suborbital flights (BETTII, PIPER) and airborne

platforms (SOFIA/HIRMES). TES quantum calorimeters arrays provide ultra-high throughput spectroscopy (each pixel is a spectrometer, and array is an IFS on a chip). By changing the absorber for the specific bandpass are used from IR to X-ray photons for a range of applications including solar physics, astrophysics, and quantum information science.

2. Atomic Clocks: Space-qualified atomic clocks have been operational since 1974, with rubidium and cesium clocks providing precision timing for navigation and radio science experiments.
3. Cold Atom Lab (CAL): Operational on the ISS since 2018, CAL has demonstrated Rubidium-87 matter-wave interferometry as a quantum sensor to measure vibrations on the space station, though primarily for fundamental physics rather than operational sensing.

Most advanced quantum sensors (TES, MKIDs, SNSPDs, SQUIDs) require cryogenic cooling, adding significant mass, power, and complexity. While quantum magnetometers have space heritage, modern quantum sensing modalities for in-situ measurement of electric fields, particle distributions, and plasma diagnostics in space environments remain at low TRL (typically TRL 2-4). Quantum sensors also face challenges with radiation tolerance, electromagnetic noise from spacecraft systems, temperature extremes, and mechanical stresses during launch and operations. Quantum magnetometers are seen as particularly promising for Heliophysics missions studying solar corona dynamics, providing increased sensitivity together with self-calibration capabilities. NASA is activity pursuing magnetometers with target sensitivity of tens of pT/√Hz that offer self-calibration and robust performance in noisy spacecraft electromagnetic environments.

**Critical Gaps:**

For this subtopic, the following critical gaps identified between the state of the art and needed capabilities include:

- Quantum magnetometers (e.g., atomic vapor cells, nitrogen-vacancy centers, silicon carbide defect centers) for high-sensitivity magnetic field measurements in the solar wind, magnetosphere, and planetary environments, with emphasis on advancing beyond classical fluxgate and optically pumped heritage systems through improved SWaP, self-calibration, and multi-sensor architectures that reduce or eliminate boom requirements.
- Quantum electric field sensors for measuring fields in plasma environments with quantum-enhanced sensitivity exceeding classical double-probe techniques, reduced spacecraft interference, and operation in tenuous plasma regimes.
- Quantum-enhanced particle detectors leveraging quantum states (e.g., quantum dots, quantum wells, superconducting tunnel junctions) for improved sensitivity and energy resolution for charged particles and neutrals, particularly in the <10 keV energy range critical for solar wind and magnetospheric physics.
- Quantum plasma diagnostics using novel sensing modalities such as quantum defect centers or entangled photon techniques for measuring plasma density, temperature, composition, and wave properties in space environments.
- Room-temperature or reduced-cryogenic quantum sensors that eliminate or minimize cooling requirements while maintaining quantum-enhanced measurement performance, enabling deployment on CubeSats and resource-constrained platforms.
- Multi-parameter quantum sensing platforms capable of simultaneous, co-located measurements of multiple space environment parameters (fields, particles, waves) using integrated quantum sensor architectures.
- Quantum sensing components and subsystems including compact laser sources, quantum state preparation and readout electronics, magnetic shielding materials compatible with quantum sensors, and low-noise amplification for quantum signals.

**Shortfalls And Decadal Surveys:**

National Academies of Sciences, Engineering, and Medicine. 2025. The Next Decade of Discovery in Solar and Space Physics: Exploring and Safeguarding Humanity's Home in Space. Washington, DC: The National Academies Press. https://doi.org/10.17226/27938

This subtopic addresses the following shortfall(s) identified in the 2026 Civil Space Shortfall list:

- Perform advanced remote sensing and science measurements with improved sensing capabilities and autonomy.

**Need Horizon:** Mid-Term (5-10 years)

**References:**

"Quantum sensing for NASA science missions," Mercer, C.R., Montbach, E.N., Christe, S.D. *et al. EPJ Quantum Technol.* **12**, 56 (2025). https://doi.org/10.1140/epjqt/s40507-025-00360-3
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# Technology for In Situ Science Operations on Planetary Bodies (INSITU)

## **INSITU.7.T26B: Combustion and Fluids Experiments (STTR)** (previously S15.03)

**Lead Center:** GRC

**Subtopic Problem Statement/Description:**

The Biological and Physical Sciences Division (BPS) within NASA’s SMD sponsors long-duration microgravity physical sciences research aboard the International Space Station (ISS) in several disciplines including fluid physics, (liquids and soft matter) and combustion/fire safety. With the pending retirement of the ISS, other means of conducting low gravity research in the space environment need to be considered.

Several Commercial LEO Destinations (CLD) space stations are in development. In addition, over the last several years, 2860 smallsats, those having a mass of less than 1200 kg, compromised 97% of all spacecraft launched in 2023. Payload opportunities also exist on Commercial Lunar Payload Services (CLPS) and Artemis landers. Research on any of these platforms needs to provide different levels of power, data acquisition and control, telemetry, and the actual experiment and its instrumentation.

NASA's exploration mission is currently focused on lunar and Martian exploration. Fundamental research is needed to provide and develop effective solutions to the engineering challenges associated with a sustained human presence on the lunar surface. Many of these issues can be addressed effectively in the low-gravity environment found in LEO.

Proposals should identify a science research capability for physical science (combustion, fluid physics, or soft matter) research and develop a prototype design of the test facility designed for use in a CLD, lunar lander, or smallsat. Proposals must demonstrate the relevance of the hardware capabilities to measuring the desired phenomena and identify the potential size, weight, and power envelope and benefits of this technique over other existing methods. They must also identify one or more target platforms among the following: Commercial Lunar Payload Services (CLPS) lunar lander, Lunar Gateway, free-flyer, Artemis, ISS, Commercial Low Earth Orbit Destinations (CLD).

Proposals should address issues in NASA's Low Earth Orbit Microgravity Strategy, the Moon to Mars Architecture Definition Document or the STMD 2026 Civil Space Shortfalls.

**Expected TRL or TRL Range at completion of the Project:** 1 – 5

**Primary Technology Taxonomy:**

- Level 1: TX08 Sensors and Instruments
- Level 2: TX08.3 In Situ Instruments and Sensors
- Level 3: TX08.1.6 Cryogenic/Thermal Systems

**Desired Deliverables of Phase I:**

Phase I must deliver a Feasibility study detailing evidence with a proof of concepts that outlines the future path towards hardware autonomous prototype demonstration in space as well as comparison against existing current diagnostic and measurement methods. Depending on the scope of the proposal, development and test of bench-top prototype components may be included. A preliminary assessment of the technology business case (cost and revenue forecast, market size, potential customers, etc.) is also required.

**Desired Deliverables of Phase II:**

Phase II must deliver a Preliminary design and concept of operations, and the development and test of an engineering development unit in a relevant environment (ground or space). A report containing detailed interface requirements, performance envelopes, supporting test results, and an updated business case analysis and/or application plan with tentative business partners and/or endorsements by principal investigators is also required. Concepts that can achieve flight demonstration on a suborbital flight or on the ISS during Phase II are especially valuable. Phase II deliverables must also delineate any further work that would be required to bring the technologies to full operational and/or commercial use.

**Desired Deliverable Types of Phase II:**

- Analysis
- Test Results
- Hardware
- Prototype

**State of the Art:**

The current State of the Art for physical science research hardware in space shows two main limitations: Many existing experimental hardware suites designed for use on the ISS meet the functional and integration requirements for life support, measurement and telemetry, but do not meet the requirement for fully autonomous operation. Conversely, many biological CubeSats meet the autonomy requirement but lack the diverse experimental capabilities needed for complex science measurement.

**Critical Gaps:**

Facilities that are modular and extensible (allow easy addition of new capabilities) are strongly desired.

Proposed instruments should address all of the following gaps (requirements):

- Autonomous operation: control system enabling full experiment execution and data storage without user intervention once it is activated. Systems that can also accommodate "on-the-fly" remote modification of execution scripts, modification between individual experiments, and/or real-time control for troubleshooting are encouraged; at minimum, the system must be capable of fully autonomous operation for one experiment.

    - Tolerant of environmental conditions including the following: temperature, lighting, humidity, and pressure. Proposals must specify the target platform. Concepts must not fully depend on environmental control to be provided by the platform.
    - Measurement of parameters in real time, appropriate to the science being conducted.
    - Autonomy may be enabled/enhanced by artificial intelligence (AI)/machine learning (ML) methods.
- Independent operation from the gravity environment: full function at any gravitational level from micro-g up to terrestrial gravity as appropriate.
    - Storage and control, including metering or dilution series of appropriate media and experimental reagents such as dyes.
    - Mitigation of bubble formation in fluidic systems.

The instrument must also be capable of one or more of the following (additional desired features):

- Feedback control: ability for growth and motion measurements to feed back into control parameters for the experimental payload.
- Systems that support statistical robustness through replicate experiments as well as predictive capability to adjust test parameter.
- Both real-time telemetry as well as data storage for later downlink.

**Shortfalls And Decadal Surveys:**

Recapturing a Future for Space Exploration: Life and Physical Sciences Research for a New Era," National Academies: https://nap.nationalacademies.org/catalog/13048/recapturing-a-future-for-space-exploration-life-and-physical-sciences

This subtopic addresses the following shortfall(s) identified in the 2026 Civil Space Shortfall list:

- Provide Earth-independent safety and crew health and performance countermeasures during long duration missions.
- Transport crew and cargo from Earth to the Moon and Mars and back

**Need Horizon:** Near-Term (Less than 5 years)

**References:**

1. "NASA’s Low Earth Orbit Microgravity Strategy," National Aeronautics and Space Administration: https://www.nasa.gov/wp-content/uploads/2024/12/2024-12-lms-final-goals-and-objectives.pdf
2. "Exploration Systems Development Mission Directorate: Moon to Mars Architecture Definition Document," National Aeronautics and Space Administration: https://ntrs.nasa.gov/citations/20240015571
3. “Smallsats by the numbers 2025” https://brycetech.com/reports/report-documents/smallsats-2025/BryceTech_Smallsats-by-the-Numbers-2025.pdf
4. "Space Station Research & Technology: ISS Researcher's Guide Series," National Aeronautics and Space Administration: https://www.nasa.gov/international-space-station/space-station-research-and-technology/opportunities-%20information-for-researchers/iss-researchers-guide-series/
5. "Biological research and self- driving labs in deep space supported by artificial intelligence," Nature Machine Intelligence. 2023: https://www.nature.com/articles/s42256-023-00618-

# Unlocking the Orbital Economy (ORBECON)

## ORBECON.2.T26B: Biotechnology Applications from Space for Earth (STTR)

**Lead Center:** ARC

**Subtopic Problem Statement/Description:**

The National Aeronautics and Space Administration (NASA) In Space Production Application (InSPA) Portfolio seeks proposals under the Small Business Technology Transfer (STTR) Program to accelerate commercial scale production in space of superior biotechnology materials and products for important Earth applications that meet FDA standards. A special focus of this STTR is on projects that use space to accelerate solutions to intractable childhood diseases. Proposers should plan to implement projects in Low Earth Orbit (LEO). Sponsored by the International Space Station (ISS) Program, InSPA is a flight development program that supports innovative US companies to use microgravity and other space assets to deliver superior products for Earth, rather than space, applications. Most companies in the InSPA Portfolio are small businesses.

Over the past five years, InSPA and ISS National Lab sponsored projects delivered exceptional results from microgravity research and manufacturing development on ISS focused on medical applications for patients on Earth. They demonstrated the value of microgravity to accelerate and enable medically important advances in ways that are not possible in terrestrial gravity.

The major areas where microgravity has proven effective are the initial focus of this activity and include improving the speed and accuracy of diagnoses for critical diseases; improving and accelerating better treatment options and therapeutics; and enabling new medical devices and pharmaceuticals to a quality not possible on Earth. The results, which are available in numerous peer reviewed publications, are expected to help inform potential proposers of the kinds of processes and projects that require scaleup.

Several InSPA biomedical projects are ready to begin developing spaceflight manufacturing technologies to commercial scales. However, current equipment, which was designed for small batch research and not manufacturing on ISS, requires new technologies to enable the automation, quality control, FDA Good Manufacturing Processes, and repeatability needed for FDA approval of products. The goal of this STTR is to help enable, accelerate, and demonstrate repeatable, scalable biotechnology production in orbit for medical applications on Earth.

New assistive devices added to or incorporated in proven technologies are needed to enable 10X or higher throughput from each flight opportunity that efficiently uses the accommodations and constraints of the ISS and/or commercial vehicles and delivers the quality and quantity necessary to make in-space manufacturing profitable.

These include but are not limited to:

- Artificial Intelligence (AI)/Machine Learning (ML) Analyses and Modeling of microgravity dynamics are important to medical applications that inform scaleup designs and commercial scale processing.
- AI/ML Analyses of biomedical spaceflight results combined from multiple projects to obtain new knowledge from existing data important for developing new medical applications for Earth. Focus should be on results obtained over the past decade, but especially over the past five years, on ISS.
- Better inflight imaging, sensors and analytics for monitoring, process management, metrology and quality control inflight.
- Robotics to automate and ensure precision in exchanging feedstock for finished products; precisely injecting biomarkers, fixatives, and other chemicals at intervals through the growth processes of cells and tissues, including stem cells; moving samples from an incubator to refrigerator/freezer; enabling imaging of

biomaterials as they develop in space; and many other functions that enable repeatability, precision, and ability to hold cells, tissues, and organoids in the "sweet spot" where the best results are obtained in space.

- Identify and flight qualify relevant commercial off the shelf terrestrial medical research and manufacturing hardware to leverage standardized systems used on Earth. This enables effective comparisons between flight and ground processing and/or significantly reducse development time and cost of high throughput systems.

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

**Primary Technology Taxonomy:**

- Level 1: TX06 Human Health, Life Support, and Habitation Systems
- Level 2: TX06.3 Human Health and Performance

**Desired Deliverables of Phase I:**

Phase I Products include an Interim Report at Award + 3 months and a Final Report, but are not limited to:

- Technologies that enable FDA approval of space manufactured products.
- AI/ML Analyses and Models predicting microgravity dynamics to produce superior medical applications in space that inform inspace manufacturing hardware scaleup designs.
- AI/ML Analyses of biomedical spaceflight results combined from multiple projects to obtain new knowledge from existing data important for developing new medical applications for Earth. Focus should be on results obtained over the past decade, but especially over the past five years, on ISS.
- Better imaging, sensors and analytics devices and strategies for monitoring, process management, metrology and quality control inflight designed to be integrated into high throughput inspace productions systems for autonomous operation and monitoring.
- Robotics proofs of concept to automate and ensure precision and quality for inspace operations including: exchange of feedstock for finished products; precisely injecting biomarkers, fixatives, and other chemicals at intervals through the growth processes of cells and tissues, including stem cells; moving samples from an incubator to refrigerator/freezer; enabling imaging of biomaterials as they develop in space; and many other functions that enable repeatability, precision, and ability to hold cells, tissues, and organoids in the "sweet spot" where the best results are obtained in microgravity.
- Identify and describe the path for flight qualification of commercial off the shelf terrestrial medical research and manufacturing hardware that can be flight qualified with minimal changes to leverage standardized systems used on Earth. This enables effective comparisons between flight and ground processing and/or significantly reduce development time and cost of high throughput systems.

**Desired Deliverables of Phase II:**

Phase II Products are expected to result in prototypes for spaceflight implementation. These include:

- Model based control dynamics to enable commercial scaleup of high value products in space.
- Hardware designs, matured through at least a Preliminary Design Review milestone.
- Terrestrial prototypes and Engineering Development Units (EDU).
- Implementation of proofs of concepts on parabolic, suborbital, ISS or other LEO spacecraft. Applicants may seek matching NASA funding for flight demonstrations from the STMD Flight Opportunities Program via a Phase IIE application.
- Implementation concepts and concepts of operation for scaleup manufacturing of new products identified through AI/ML analyses in Phase I that can accelerate important medical solutions on Earth.

- Robotics incorporated into flight hardware prototypes.
- Flight qualification procedures for terrestrial commercial off the shelf medical research and manufacturing hardware.
- Hardware designs and implementation strategies designed for FDA approval of the space manufactured product.

**Desired Deliverable Types of Phase II:**

- Analysis
- Test Results
- Hardware
- Prototype
- Software
- Digital Models

**State of the Art:**

Today, no project has achieved commercial scale production in space for biologicals. This effort pioneers an important new industry for the US in space, with both high humanitarian value and high potential for wealth generation.

To date, one firm in 2024 on ISS, achieved commercial scale production of a high value product in space.

**Critical Gaps:**

Commercial scale manufacturing and manufacturing to FDA Good Manufacturing Practices has not yet been achieved or attempted in space, although work has begun through InSPA projects in collaboration with NIH and the FDA.

**Shortfalls And Decadal Surveys:**

This subtopic opens a new arena for US manufacturing: Inspace manufacturing for terrestrial markets. Despite its potential, this area has not been a subject for Decadal Surveys or NASA Space Technology Priorities except it could be considered under the broad topic of In-Space Manufacturing and Assembly. However, because the application focus is on Earth, this is a new area.

**Need Horizon:** Near-Term (Less than 5 years)

**References:**

Exceptional Results Reported by US Innovators on ISS 2024. This contains references to other publications.

https://docs.google.com/presentation/d/19qy1UE32hZvSglITBvFD0hTFfVr7EHj3/edit?slide=id.p1#slide=id.p1

Marotta D, Ward N, Bauer SR, Hunsberger J, Stoudemire J, Savin K, Giulianotti M, JamiesonCHM, Roberts D, Roberts M. Biomanufacturing in low Earth orbit: A paradigm shift. *Stem CellReports*. 2025

## ORBECON.3.T26B: Advanced Materials Manufacturing Applications from Space for Earth (STTR)

**Lead Center:** LaRC

**Participating Center(s):** ARC, MSFC

**Subtopic Problem Statement/Description:**

The National Aeronautics and Space Administration In Space Production Application (InSPA) Portfolio seeks proposals under the Small Business Technology Transfer (STTR) Program to produce superior and advanced materials applications at commercial scales via microgravity processing and manufacturing in low-Earth orbit (LEO).

Over the past five years, exceptional results from the International Space Station (ISS) InSPA and ISS National Lab projects clearly demonstrated the value of microgravity to accelerate and enable important materials advances in ways not possible on Earth.

InSPA is a flight development program that supports innovative US companies to use microgravity to deliver superior products for Earth applications, rather than space.

Most InSPA organizations are small, fast-moving high-tech businesses who are delivering superior materials and products from space. Most InSPA proposals begin at TRL 5, so the SBIR/STTR program is an essential player for initiating and maturing critical technologies. Many past InSPA SBIR proposals have received SBIR Phase III funding from InSPA to conduct demonstrations of space manufactured products on the ISS that exhibit superior quality and yield. A select few achieve in-space demonstrations during SBIR Phase II.

The intent of this STTR is to accelerate the development of a thriving space economy through commercial scale-up of the most promising microgravity assisted advanced materials for terrestrial applications important to sensors, electronics and communication, and US competitiveness in partnership with America's leading universities and research institutions.

Microgravity fundamentally alters physical processes by suppressing buoyancy-driven convection, sedimentation, and gravity-induced shear. These conditions enable significantly reduced material defects that cannot be reliably achieved on Earth. Research conducted aboard the ISS has demonstrated that microgravity can yield superior outcomes in Quantum Materials (QM) & Quantum Technologies, Semiconductors and Microelectronics, Artificial Intelligence (AI) and Digital Technologies to Support In-Space Manufacturing, and High-Performance Materials

NASA's InSPA Portfolio is focused on transitioning microgravity research from TRL 3 – TRL 5 to achieve repeatable, scalable, and economically relevant production pathways that benefit life on Earth and US competitiveness.

Priority will be given to advanced material manufacturing concepts that are designed from the outset to support commercial-scale production in orbit, including sustained operations aboard the ISS and future commercial space stations as well as appropriate autonomous commercial space platforms.

Proposed efforts should address technologies that support commercial scaleup of advanced materials manufacturing applications that measurably benefit from microgravity and demonstrate a credible pathway toward terrestrial impact and commercialization, or mission relevance.

Proposals must clearly articulate why the proposed advanced materials manufacturing can only be developed in space environments, such as microgravity in Low Earth Orbit (LEO) and cannot achieve equivalent outcomes using terrestrial methods alone or where terrestrial approaches need to be adapted for commercial scale orbital manufacturing or production.

Relevant areas of interest include, but are not limited to:

- Quantum Materials (QM) & Quantum Technologies: Novel materials and systems with unique quantum mechanical properties for applications in quantum devices, quantum sensors and quantum computing semimetals, and the development of hybrid systems combining QMs with other established technologies.
- Semiconductors and Microelectronics: Accelerating groundbreaking development in semiconductors materials and microelectronics systems produced in space including but not limited to leading-edge semiconductor materials (e.g., diamond-based semiconductors, wide band gap semiconductors, 2-D materials).
- Artificial Intelligence (AI) and Digital Technologies to Support In-Space Manufacturing: Development and testing of advanced algorithms (including quantum algorithms) for autonomous systems, intelligent operations, and (quantum) secure communications; complex simulations (e.g., microgravity environment, quantum simulations), digital twins, and human machine interfaces to enable remote R&D and smart manufacturing activities in space.
- High-Performance Materials: Advanced materials with enhanced properties that may include high-strength, high-temperature performance, high optical quality, and thermal and electrical conductivities.
- Cutting edge quantum applications: Exploring exotic techniques such as the use of DNA in materials for memory storage and AI coupled robotics for in-space processes of advanced materials.
- Computer Modelling: Multi-scale computer modelling of crystal growth processes in microgravity and Earth gravity to optimize process and protocols for flight experiments.

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

**Primary Technology Taxonomy:**

- Level 1: TX12 Materials, Structures, Mechanical Systems, and Manufacturing
- Level 2: TX12.X Other Manufacturing, Materials, and Structures
- Level 3: TX12.1.7 Special Materials

**Desired Deliverables of Phase I:**

Phase I Objectives and Deliverables:

The Phase I efforts should focus on feasibility demonstration and risk reduction, including:

- Establishing the technical rationale for microgravity-enabled advanced materials outcomes.
- Demonstrating initial proof-of-concept through ground-based analogs, modeling, or prior flight data.
- Defining measurable performance metrics comparing microgravity and terrestrial results.
- Developing an initial experimental or production prototype compatible with future on-orbit scale-up.
- Identifying pathways to Phase II maturation and potential end users, including NIST approval where relevant.

Phase I proposals are expected to define clear success criteria and produce data sufficient to justify continued development. The Phase 1 products include quarterly progress reports and a final report that discusses performed tasks and project milestones that may include, but not limited to:

- Performance and simulation models.

- CAD designs and computational models.
- Validated technologies and protocols or production workflows suitable for scale-up.
- Performance modeling software.

**Desired Deliverables of Phase II:**

Phase II Objectives and Deliverables:

The Phase II efforts should focus on technology maturation, validation, and transition, including:

- Execution of microgravity experiments or early production demonstrations in orbit.
- Quantitative validation of improved outcomes enabled by microgravity.
- Refinement of hardware, protocols, or processes for repeatability, automation, and scalability.
- Demonstration of compatibility with ISS systems and/or commercial LEO platforms.
- Engagement with commercial, medical, or governmental end users.
- Preparation for terrestrial translation, regulatory pathways, or mission infusion.

Phase II awards should position successful technologies for commercial deployment, licensing, sustained on-orbit production, or follow-on private investment. Phase II efforts are expected to result in production of ground prototypes of future spaceflight payloads. These include:

- Automation and robotics devices for commercial scaleup of existing flight proven systems.
- Sensors and imaging systems for inflight monitor and quality control.
- Identification of commercial partners, customers, and orbital production pathways.
- Material samples and functional devices.
- Terrestrial prototypes and Engineering Development Units (EDU).
- Implementation of proofs of concepts on parabolic, suborbital, ISS or other LEO spacecraft.
- Implementation concepts and concepts of operation for scaleup manufacturing of new products identified through AI/ML analyses in Phase I that can accelerate important medical solutions on Earth.

**Desired Deliverable Types of Phase II:**

- Analysis,
- Test Results,
- Hardware,
- Prototype,
- Software,
- Digital Models,
- Research (STTR Only)

**State of the Art:**

This effort pioneers an important new microgravity manufacturing industry for the US in space, with highly innovative products, US space industry leadership, development of new skills, and high potential for stimulating economic growth.

NASA supports the national plan to drive research and development (R&D) of next-generation technologies needed to increase U.S. industrial competitiveness and to drive national independence and security.

**Critical Gaps:**

This effort addresses the need for highly efficient quantum devices for communications, sensing, and computing, as well as next-gen microelectronics, communication segments, and potentially aircraft or spacecraft structural materials of very low weight or high performance.

**Shortfalls And Decadal Surveys:**

This subtopic opens a new arena for US manufacturing: In-space manufacturing for terrestrial markets. Despite its potential, this area has not been a subject for Decadal Surveys or NASA Space Technology Priorities except it could be considered under the broad topic of In-Space Manufacturing and Assembly. However, because the application focus is on Earth, this is a new area.

**Need Horizon:** Near-Term (Less than 5 years)

**References:**

1. https://www.nasa.gov/Inspa
2. The White House- The President's Council of Advisors on Science and Technology (PCAST) to spearhead American innovation and competitiveness in critical and emerging technologies. https://www.whitehouse.gov/presidential-actions/2025/01/presidents-council-of-advisors-on-science-and-technology/
2. ENSURING AMERICAN SPACE SUPERIORITY – The White House
3. Fiscal Year (FY) 2027 Administration Research and Development Budget
4. Department of Defense- DoD Critical Technology Areas. https://www.cto.mil/osc/critical-technologies/
5. Department of Energy- Office of Critical and Emerging Technologies. https://www.energy.gov/cet/office-critical-and-emerging-technologies
6. Digital Twin Consortium. https://www.digitaltwinconsortium.org/
7. Materials Genome Initiative. https://www.mgi.gov/
8. Department of Energy- Advanced Materials and Manufacturing Technologies Office https://www.energy.gov/eere/ammto/advanced-materials-and-manufacturing-technologies-office; https://www.energy.gov/eere/ammto/ammto-funding-opportunities
9. U.S. National Science Foundation's Directorate for Technology, Innovation and Partnerships- National Science Foundation.
10. Manufacturing USA- https://www.manufacturingusa.com/opportunities

## 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 references 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/view/taxonomy

| 2024 TX Mapping Level 1 | 2024 TX Mapping Level 2 | STTR Subtopic Number | Subtopic Title |
|---|---|---|---|
| TX06 - Human Health, Life Support, and Habitation Systems | TX06.3 – Human Health and Performance | ORBECON.2.T26B | Biotechnology Applications from Space for Earth |
| TX07 - Exploration Destination Systems | TX07.2 - Mission Infrastructure, Sustainability, and Supportability | LIVEI.2.T26B | Bulk Regolith Manipulation and Site Preparation |
| TX08 - Sensors and Instruments | TX08.3 - In-Situ Instruments/Sensor | INSITU.7.T26B | Combustion and Fluids Experiments |
| | | SPWX.3.T26B | Quantum Sensing Components for Space Environment Measurements |
| | TX08.X - Other Sensors and Instruments | COSMO.6.T26B | Fundamental Physics Test Apparatus |
| TX11 - Software, Modeling, Simulation, and Information Processing | TX11.1 - Software Development, Engineering, and Integrity | INSTALG.6.T26B | Quantum Computing |
| | TX11.3 - Simulation | GO.4.T26B | Modernization of CFD Tools for Advanced Propulsion Applications |
| TX12 - Materials, Structures, Mechanical Systems, and Manufacturing | TX12.X - Other Manufacturing, Materials, and Structures | ORBECON.3.T26B | Advanced Materials Manufacturing Applications from Space for Earth |
| TX15 - Flight Vehicle Systems | TX15.1 - Aerosciences | AERO.9.T26B | Full-Scale (Passenger/Cargo) Advanced Air Mobility (AAM) and Vertical Takeoff and Landing (VTOL) Interdisciplinary Investigations |
| | | AERO.10.T26B | Hybrid Powertrain Technologies |
| | TX15.X – Other Flight Vehicle Systems | GO.5.T26B | Very Low Earth Orbits (VLEO) Control Surfaces |

## Attachment 26B.1 STTR Phase I Evaluation Rubric

Subject matter experts will determine the most promising technical and scientific approaches, based on the following criteria:

**Factor 1: Scientific/Technical Merit and Feasibility**
NASA will evaluate the proposed effort on:

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

**Factor 2: Experience, Qualifications, and Facilities**
The qualifications of the proposed principal investigator/project manager, supporting staff and consultants and subcontractors, if any, will be evaluated for consistency with the research effort and their degree of commitment and availability.

The proposed necessary equipment or facilities required to accomplish the proposed technical approach will be evaluated to determine if they are adequate. In addition, any proposed reliance on external sources, such as government-furnished equipment or facilities (section 3.1.3.4 and part 8 of the technical proposal), will be evaluated for reasonableness.

**Factor 3: Effectiveness of the Proposed Work Plan**
The work plan will be evaluated for comprehensiveness, its proposed effective use of available resources, and approach to labor distribution. In addition, the work plan's proposed schedule for meeting the Phase I objectives will be evaluated to make sure they are reasonable and consistent with the proposed technical approach.

**Factor 4: Commercial Potential**
This evaluation factor will consider whether the offeror's proposal has demonstrated a knowledge of the potential economic benefits of the innovation, potential customers including NASA mission programs, other government agency programs, and/or non-government markets and strategies to reach them, as well as risks associated with this approach. If known, offerors may indicate if there are any existing and projected commitments for funding of the innovation beyond Phase I and II (this can include investment, sales, licensing, and other indicators of commercial potential).

## Attachment 26B.2 STTR List of Clauses, Regulations and Certifications

**Introduction**
Offerors who submit a 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 understand these rules and requirements before submitting a proposal package.

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

"RFO Deviation" indicates Revolutionary FAR Overhaul
Note that additional contract clauses may apply at time of award.

**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 (Jan 2017)
52.203-19 PROHIBITION ON REQUIRING CERTAIN INTERNAL CONFIDENTIALITY AGREEMENTS OR STATEMENTS.(JAN 2017)
52.204-7 SYSTEM FOR AWARD MANAGEMENT. (RFO DEVIATION SEP 2025)
52.204-10 REPORTING EXECUTIVE COMPENSATION AND FIRST-TIER SUBCONTRACT AWARDS. (RFO DEVIATION Sep 2025)
52.204-13 SYSTEM FOR AWARD MANAGEMENT MAINTENANCE. (RFO DEVIATION SEP 2025)
52.204-19 INCORPORATION BY REFERENCE OF REPRESENTATIONS AND CERTIFICATIONS. (Dec 2014)
52.209-6 PROTECTING THE GOVERNMENT'S INTEREST WHEN SUBCONTRACTING WITH CONTRACTORS DEBARRED, SUSPENDED, OR PROPOSED FOR DEBARMENT. (RFO DEVIATION Dec 2025)
52.213-4 TERMS AND CONDITIONS – SIMPLIFIED ACQUISITIONS (OTHER THAN COMMERCIAL PRODUCTS AND COMMERCIAL SERVICES (RFO DEVIATION DEC 2025)
52.215-1 INSTRUCTIONS TO OFFERORS—COMPETITIVE ACQUISITION. (RFO DEVIATION DEC 2025)
52.215-2 AUDIT AND RECORDS-NEGOTIATIONS (RFO DEVIATION DEC 2025)
52.215-8 ORDER OF PRECEDENCE—UNIFORM CONTRACT FORMAT. (RFO DEVIATION DEC 2025)
52.217-9 OPTION TO EXTEND THE TERM OF THE CONTRCT (MAR 2000)
52.219-6 NOTICE OF TOTAL SMALL BUSINESS SET-ASIDE (RFO DEVIATION Dec 2025)
52.219-8 UTILIZATION OF SMALL BUSINESS CONCERNS. (RFO DEVIATION Dec 2025)
52.219-28 POST-AWARD SMALL BUSINESS PROGRAM REREPRESENTATION. (RFO DEVIATION Dec 2025)

52.222-3 CONVICT LABOR. (RFO DEVIATION Dec 2025)
52.222-35 EQUAL OPPORTUNITY FOR VETERANS. (RFO DEVIATION Dec 2025)
52.222-36 EQUAL OPPORTUNITY FOR WORKERS WITH DISABILITIES. (RFO DEVIATION Dec 2025)
52.222-50 COMBATING TRAFFICKING IN PERSONS. (RFO DEVIATION Dec 2025)
52.222-54 EMPLOYMENT ELIGIBILITY VERIFICATION. (RFO DEVIATION Dec 2025)
52.225-1 BUY AMERICAN-SUPPLIES (RFO DEVIATION Dec 2025)
52.226-7 DRUG FREE WORKPLACE (May 2024)
52.226-8 ENCOURAGING CONTRACTOR POLICIES TO BAN TEXT MESSAGING WHILE DRIVING. (MAY 2024)
52.227-1 AUTHORIZATION AND CONSENT. (Jun 2020)
52.227-2 NOTICE AND ASSISTANCE REGARDING PATENT AND COPYRIGHT INFRINGEMENT (Jun 2020)
52.227-11 PATENT RIGHTS—OWNERSHIP BY THE CONTRACTOR (May 2014) as Modified by NFS 1852.227-11.
52.227-20 RIGHTS IN DATA—SBIR PROGRAM. (May 2014)
52.229-3 FEDERAL, STATE, AND LOCAL TAXES. (RFO DEVIATION Aug 2025)
52.232-2 PAYMENTS UNDER FIXED-PRICE RESEARCH AND DEVELOPMENT CONTRACTS. (Apr 1984)
52.232-9 LIMITATION ON WITHHOLDING OF PAYMENTS. (Apr 1984)
52.232-12 ADVANCE PAYMENTS. (RFO DEVIATION Dec 2025) AS MODIFIED BY NFS 1852.232-70 ALTERNATE IV (APR 1984) ALTERNATE V (MAY 2001)
52.232-23 ASSIGNMENT OF CLAIMS. (May 2014)
52.232-25 PROMPT PAYMENT. (Jan 2017)
52.232-33 PAYMENT BY ELECTRONIC FUNDS TRANSFER—SYSTEM FOR AWARD MANAGEMENT. (Oct 2018)
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. (RFO DEVIATION Sep 2025)
52.233-3 PROTEST AFTER AWARD. (RFO DEVIATION Sep 2025)
52.233-4 APPLICABLE LAW FOR BREACH OF CONTRACT CLAIM. (Oct 2004)
52.240-90 SECURITY PROHIBITIONS AND EXCLUSIONS REPRESENTATIONS AND CERTIFICATIONS (RFO DEVIATION Sep 2025)
52.240-91 SECURITY PROHIBITIONS AND EXCLUSIONS (RFO DEVIATION Sep 2025)
52.240-93 BASIC SAFEGUARDING OF COVERED CONTRACTOR INFORMATION SYSTEMS (RFO DEVIATION Sep 2025)
52.242-13 BANKRUPTCY (July 1995)
52.242-15 STOP-WORK ORDER. (Aug 1989)
52.243-1 CHANGES—FIXED PRICE. (RFO DEVIATION Jul 2025)
52.244-6 SUBCONTRACTS FOR COMMERCIAL PRODUCTS AND COMMERCIAL SERVICES (RFO DEVIATION Dec 2025)
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)
52.249-1 TERMINATION FOR CONVENIENCE OF THE GOVERNMENT (FIXED-PRICE) (SHORT FORM). (APR 1984)
52.252-1 SOLICITATION PROVISIONS INCORPORATED BY REFERENCE. (Feb 1998)
52.253-1 COMPUTER GENERATED FORMS. (RFO DEVIATION Nov 2025)
52.252-2 CLAUSES INCORPORATED BY REFERENCE. (Feb 1998)

**NASA Provisions and Clauses**

1852.203-71 REQUIREMENT TO INFORM EMPLOYEES OF WHISTLEBLOWER RIGHTS (Sep 2025) (DEVIATION)
1852.211-70 PACKAGING, HANDLING, AND TRANSPORTATION CERTIFICATIONS—OTHER THAN COMMERCIAL ITEMS (Sep 2005)
1852.215.84 OMBUDSMAN (Nov 2023)
1852.216-78 FIRM FIXED PRICE. (Dec 2025) (DEVIATION)
1852.219-80 LIMITATION ON SUBCONTRACTING – SBIR PHASE I PROGRAM. (Oct 2011)
1852.219-81 LIMITATION ON SUBCONTRACTING – SBIR PHASE II PROGRAM (Oct 2006)
1852.219-82 LIMITATION ON SUBCONTRACTING – STTR PROGRAM (Oct 2006)
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 (Dec 2025) (DEVIATION)
1852.225-72 RESTRICTION ON FUNDING ACTIVITY WITH CHINA – REPRESENTATION. (Dec 2025)(DEVIATION)
1852.215-81 PROPOSAL PAGE LIMITATIONS. (Apr 2015)
1852.226-73 MAJOR BREACH OF SAFETY OR SECURITY (Feb 2026)
1852.227-11 PATENT RIGHTS – OWNERSHIP BY THE CONTRACTOR. (Apr 2015)
1852.227-72 DESIGNATION OF NEW TECHNOLOGY REPRESENTATIVE AND PATENT REPRESENTATIVE. (Jan 2025) (DEVIATION)1852.232-80 SUBMISSION OF VOUCHERS FOR PAYMENT.(Apr 2018)
1852.233-70 PROTESTS TO NASA. (Sep 2025)(DEVIATION)
1852.235-70 NASA STI COMPLIANCE AND DISTRIBUTION SERVICES(Aug 2025)(DEVIATION)
1852.235-71 ESSENTIAL PERSONNEL AND FACILITIES (Aug 2025)(DEVIATION)
1852.235-73 FINAL SCIENTIFIC AND TECHNICAL REPORTS. ALTERNATE III (Aug 2025)(DEVIATION)
1852.235-74 ADDITIONAL REPORTS OF WORK - RESEARCH AND DEVELOPMENT. (Aug 2025)(DEVIATION)
1852.237-72 ACCESS TO SENSITIVE INFORMATION. (Dec 2025)(DEVIATION)
1852.237-73 RELEASE OF SENSITIVE INFORMATION. (Dec 2025)(DEVIATION)
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)
1852.240-76 SECURITY REQUIREMENTS FOR UNCLASSIFED INFORMATION TECHNOLOGY RESOURCES (Dec 2025)(DEVIATION)
1852.246-72 MATERIAL INSPECTION AND RECEIVING REPORT (Sep 2025)(DEVIATION)
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**

**SBA Certifications required for Phase I**