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) Building 1111, Jerry Hlass Road Stennis Space Center MS 39529-0001	NASA/Shared Services Center (NSSC) Building 1111, Jerry Hlass Road Stennis Space Center MS 39529-0001

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

CODE | FACILITY CODE

(X)

[X] 9A. AMENDMENT OF SOLICITATION NUMBER: 80NSSC26R0006

9B. DATED *(SEE ITEM 11)*

[ ] 10A. MODIFICATION OF CONTRACT/ORDER NUMBER

10B. DATED *(SEE ITEM 13)*

11. THIS ITEM ONLY APPLIES TO AMENDMENTS OF SOLICITATIONS

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

Updated link to 2024 Civil Space Shortfall Ranking on page 98.

(https://www.nasa.gov/wp-content/uploads/2024/07/civil-space-shortfall-ranking-july-2024.pdf?emrc=7dbadc https://techport.nasa.gov/file/314645)

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)*	
15B. CONTRACTOR/OFFEROR *(Signature of person authorized to sign)*	15C. DATE SIGNED	16B. UNITED STATES OF AMERICA KENNETH ALBRIGHT *(Signature of Contracting Officer)*	16C. DATE SIGNED Digitally signed by KENNETH ALBRIGHT Date: 2026.04.29 10:03:29 -05'00'

Previous edition unusable

STANDARD FORM 30 (REV. 11/2016)
Prescribed by GSA FAR (48 CFR) 53.243

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 Innovation Research (SBIR) 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 Innovation Research (SBIR) Phase I

Change Log

Version	Description of Changes	Date
Original Release	-----	April 21, 2026
Amendment 1	Updated link on page 98 for 2024 Shortfalls ranking and added clause FAR 52.222-90	April 28, 2026

Contents

Executive Summary

This is the second appendix to NASA SBIR/STTR Program FY2026-2027 Broad Agency Announcement (BAA) and solicits proposals for the Small Business Innovation Research (SBIR) 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.

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 "SBIR 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 SBIR 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.
- ☐ Proposed funding for the technical 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 six (6) 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 SBIR section 6.1.4).

9. Research Topics

The 37 SBIR subtopics are organized by topic based on technical theme. There are 14 topics and 37 total subtopics in this appendix. This appendix only contains SBIR 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 SBIR 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.1.S26B: Health Management and Sensing Technologies for Sustainable Aviation Fuel Systems (SBIR) (previously A1.11)

Lead Center: GRC

Participating Center(s): LaRC, AFRC, ARC

Subtopic Problem Statement/Description:

NASA is leading federal agencies and industry to accelerate the development of sustainable aviation technologies. This includes deploying new vehicle designs and architectures, as well as enabling use of sustainable aviation fuels. Hybrid Electric or All Electric vehicle concepts are in active development as are new Alternative Fuel/Hydrogen Vehicles. However, these aircraft concepts introduce new hardware systems along with new health management challenges. For example, fault detection and diagnostics of hybrid electric or all electric propulsion systems require an understanding of the operation, performance, degradation, and failure mechanisms of electric machines, converters (inverters/rectifiers), and power cables along with the operation of these devices in increasingly complex flight environments. Introduction of new vehicle types and integrated vehicle systems (power, structure, avionic, and propulsion systems) requires increasingly intelligent vehicle systems with capability to detect, diagnose, and predict system degradation, faults, and failures in a resilient and trustworthy manner.

Furthermore, these intelligent vehicle systems must be capable of estimating a vehicle's capabilities as it degrades, especially for new vehicles systems entering the airspace. Monitoring the system health state has an impact on system operating cost, performance, efficiency, and improved system safety. Predictive maintenance reduces maintenance cost and vehicle down-time through reduced unnecessary maintenance and improved vehicle availability and throughput. Development of approaches and techniques for integrating diagnostic and prognostic information into maintenance and fault management strategies for sustainable aviation vehicles (i.e., predictive and condition-based maintenance). These are critical features that would allow new sustainable aviation vehicles to have more rapid introduction into the airspace. This call seeks proposals in both for Electric/Hybrid Sustainable Designs as well as Sustainable Aviation Fuel Systems

In health management technologies for *electric/hybrid aircraft designs*, the technologies should be able to operate as needed in a high electric noise flight environment and provide actionable information for higher level diagnostics and prognostics. New electric/hybrid vehicles and their propulsion systems can be more economic, smarter, and safer by enabling increased health management capabilities. Areas of interest include:

- Health management technologies for the sensing, diagnosis, and prognosis of degradation and faults in flight quality electrical hardware and systems. The technology could be focused on electrical systems such as:
    - Electric machines (motors/generators) including the health of bearings, lubrication and cooling, windings, rotor, insulation, etc.
    - Converters (inverters/rectifiers) including the health of electronic components, cooling system, etc.
    - High voltage wire and cables, including short or open circuits and insulation breakdown.
    - Overall power quality including degradation/faults leading to voltage ripple, power instabilities, etc.
    - Thermal management system health.

- System-level approaches that leverage measurement data collected across sustainable aviation systems including electromechanically coupled subsystems to infer overall system health. This includes distributed or coupled architectures comprised of electrical systems, motor driven propulsors, energy storage devices, gearboxes, mechanical drives, and fuel burning engines.

In health management technologies *for alternate fuel aircraft and new sustainable aircraft designs*, the technologies should be able to provide actionable information for higher level diagnostics. Alternate fuel vehicles and their propulsion systems can be more economic, smarter, and safer by enabling increased health management capabilities. However, changing the fuel, e.g., the adoption of cryogenic hydrogen, can have massive impact on vehicle operations and health. Areas of interest include:

- Health management technologies for the sensing, diagnosis, and prognosis of degradation and faults in sustainable aviation fuel systems such as hydrogen vehicles that include cryogenic systems. The use of such fuels introduces their own health management challenges beyond that of conventional fuel systems.
- System-level approaches that leverage measurement data collected across sustainable aviation systems including alternate fuel vehicle subsystem and component information correlating multiple aspects of overall system health including structural degradation, fuel tank integrity, and fuel safety.

This subtopic is not seeking proposals in:

- Battery health management technologies
- Electrical fault management systems and protective devices (such as circuit breakers).

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

Primary Technology Taxonomy:

- Level 1: TX10 Autonomous Systems
- Level 2: TX10.1 Situational and Self-Awareness Technologies
- Level 3: TX10.2.5 Fault Diagnosis and Prognosis

Desired Deliverables of Phase I:

Phase I deliverables should include, but are not limited to:

- A final report clearly stating the technology challenge addressed, the state of the technology before the work was begun, the state of technology after the work was completed, the innovations that were made during the work period, the remaining barriers in the technology challenge, a plan to overcome the remaining barriers, and a plan to infuse the technology developments into applications.
- A technology demonstration that clearly shows the benefits of the technology developed.
- A written plan to continue the technology development and/or to infuse the technology. This may be part of the final report.

Resulting products can include hardware, software, demonstrations, reports, products, components, and integrated systems.

Desired Deliverables of Phase II:

Phase II deliverables should include, but are not limited to:

- A final report clearly stating the technology challenge addressed, the state of the technology before the work was begun, the state of technology after the work was completed, the innovations that were made during the work period, and a plan to infuse the technology developments into applications.
- A technology demonstration in an appropriate environment which clearly shows the benefits and viability of the technology developed.
- There should be evidence of efforts taken to infuse the technology into applications or a clear written plan for near term infusion of the technology. This may be part of the final report.
- Resulting products can include hardware, software, demonstrations, components, and integrated systems.

Desired Deliverable Types of Phase II:

- Prototype
- Hardware
- Test Results
- Software

State of the Art:

The technical state-of-the-art in terms of vehicle health management is that for standard combustion engines there has been significant work over a period of time with increasing adoption by industry. (Please, see e.g., documents associated with the SAE HM-1 Integrated Vehicle Health Management Committee or E-32 Aerospace Propulsion Systems Health Management committees. https://standardsworks.sae.org/standards-committees)

However, the technologies associated with health management of traditional aircraft are not appropriate for the evolving vehicle designs for sustainable aviation. For example, measuring the health state of a combustion engine at high temperatures is significantly different than measuring the health state of electrical subsystems operating in ambient environments. Overall, the parameters that need to be measured and the environments in which they are measured are vastly different in parts and subsystems of the vehicle that enable sustainability. The technologies needed do not exist or are in need of further development and also depend on the type of sustainable vehicle. It is this SBIR subtopic that addresses those Critical Gaps as describe below for both electric and hybrid electric, as well as alternate fuel vehicles.

Critical Gaps:

The technical need is for system health management in the evolving field of sustainable aviation. For electrified aircraft propulsion (EAP) and vehicles, many conventional subsystems remain in EAP architectures – e.g., gas turbines, rotating drives, gearboxes, propellers/fans, etc. but new challenges in sensing, diagnosis, and prognosis must be addressed:

- Architectures are more coupled and integrated in nature.
- Boundary between propulsion system and vehicle not as clearly defined.
- Might require means of partitioning the health management problem by subsystem.
- Data compression and feature extraction techniques for high-frequency electrical system measurements will be necessary.
- Electrical systems may not exhibit graceful degradation / failure making timely diagnostics and prognostics more challenging.

Technologies that address these gaps enable sustainable aircraft, which in-turn enables new aircraft configurations and capabilities for the point-to-point on-demand mobility market and a new type of innovation for transport aircraft to reduce fuel consumption and emissions.

For alternate fuel vehicles such as those using hydrogen, especially cryogenic hydrogen, safety considerations presently constrain the acceptable airframe/tank/passenger layout. There is a need for better leak and fire detection methods for hydrogen applicable wherever hydrogen could accumulate. Further, there is potential for structural degradation of multiple system components using cryogenic hydrogen: seals, insulation, material embrittlement, and thermal expansion characteristics. Sensing, diagnosis, and prognosis of faults and degradation of these systems is required.

- Structural sensing, diagnosis, and prognosis for sustainable vehicles whose design may notably differ compared to conventional vehicle systems requiring new approaches and techniques to identify faults and degradation. This includes both electric and alternative fuel vehicles.
- Advanced sensing technologies such as embedded additive manufactured sensors into sustainable vehicle components that offer light weight minimally intrusive sensing solutions.
- System-level approaches that leverage measurement data collected across sustainable aviation systems.
- The use of data analytics and artificial intelligence to provide a more complete system level view of sustainable vehicle health.
- Health management and intelligent maintenance technologies and approaches for sustainable aviation vehicles.

Shortfalls And Decadal Surveys:

The section appears to be relevant to Subtopics related to Space Sciences or Exploration. The last Aeronautics Decadal Survey seems to be in 2006. Nonetheless, the website https://www.nasa.gov/spacetechpriorities/ does have several shortfalls that in principle are relevant to this subtopic:

553: Foundational Technologies for Future Avionics Devices and Systems/Avionics

701: Green Propellant Propulsion Systems/ Propulsion: Non Nuclear

611: Sub-kW and kW Class Electric Propulsion Systems: Propulsion: Non Nuclear

612: In-Space Diagnostics for Electric Propulsion/ Propulsion: Non Nuclear

755: Cross-Discipline Cryogenic Fluid Management Technologies/ Cryogenic Fluid Management

1626: Advanced Sensor Components: Imaging/ Sensors and Instruments

In summary, the technologies developed for Sustainable Aviation may be adaptable for other applications relevant to Exploration.

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

References:

1. D. Simon, "Health Management Considerations for Electrified Aircraft Propulsion Systems", SAE E32 Aerospace Propulsion Health Management Committee Meeting March 29-31, 2022. https://ntrs.nasa.gov/api/citations/20220004260/downloads/EAP_HealthMangementConsideration_DSimon_v2.pdf
2. EAP is called out as a key part of Thrust 3 in the ARMD Strategic Implementation Plan: https://www.nasa.gov/directorates/armd/armd-strategic-implementation-plan/

3. Overview of NASA's EAP Research for Large Subsonic Aircraft: https://ntrs.nasa.gov/search.jsp?R=20170006235
4. NASA X-57 Project: https://www.nasa.gov/aeroresearch/X-57/technical/index.html
5. R. H. Jansen et al. "High Efficiency Megawatt Motor Preliminary Design," https://ntrs.nasa.gov/citations/20190029589
6. L. Tang, A. Saxena, and K. Younsi, "Prognostics And Health Management For Electrified Aircraft Propulsion: State Of The Art And Challenges", Proceedings of ASME Turbo Expo 2024 Turbomachinery Technical Conference and Exposition, June 2024, London, GT2024-12229, https://doi.org/10.1115/GT2024-122290
7. C. Teubert, A. A. Pohya, and G. Gorospe, "An Analysis of Barriers Preventing the Widespread Adoption of Predictive and Prescriptive Maintenance in Aviation", April, 2023, NASA/TM– 20230000841, https://ntrs.nasa.gov/citations/20230000841
8. C. Snyder, "NASA Meeting on Cryogenic Fuel Systems for Aircraft, Overview of Previous Workshops and Studies", September 2022, https://ntrs.nasa.gov/api/citations/20220014107/downloads/NASA-CryoFuels_Workshops-studies_2022-09_CSnyder_final-STI.pdf
9. NASA Funded Center for High Efficiency Electrical Technologies for Aircraft (CHEETA), https://cheeta.illinois.edu/research
10. J. Moder, M. L. Meyer, and W. L. Johnson, "NASA Liquid Hydrogen Aircraft Opportunities and Technologies", presented at the Cryogenic Engineering Conference and International Cryogenic Materials Conference, Honolulu, HI, July 2023, https://ntrs.nasa.gov/api/citations/20230009800/downloads/CEC%20NASA%20aircraft%20overview_v2-c.pdf
11. J. Cavolowsky and I. Jakupca, "NASA Hydrogen and Fuel Cell Perspectives", 2022 H2-Aero Symposium & Workshop, March 29, 2022, https://ntrs.nasa.gov/api/citations/20220005022/downloads/NASA%20Hydrogen%20and%20Fuel%20Cell%20Perspectives%20-%2020220329.pdf
12. V. Lvovich, D. Perkins, T. Lavelle, P. Hanlon, H. Hasseeb, et al., "Commerically-viable Hydrogen Aircraft for Reducton of Greenhouse Emissions", 26th ISABE Conference, Toulouse, FR, 2024, https://ntrs.nasa.gov/api/citations/20240008370/downloads/ISABE2024%20September%202024.pdf
13. W. L. Johnson, S. L. Vivod, V. F. Lvovich, G. W. Hunter, Z. Martinovic, et al., "The Need for the Development of Liquid Hydrogen Test Capability for Aviation and Beyond", Presented at the 2025 Cryogenic Engineering Conference, Reno NV, May 21, 2025, https://indico.cern.ch/event/1431974/contributions/6399016/attachments/3069801/5430656/CEC_pres_Hydrogen%20Testing%20Area_v2.pdf

AERO.2.S26B: Quiet Performance-Aircraft Propulsion Noise (SBIR)

Lead Center: GRC

Participating Center(s): LaRC

Subtopic Problem Statement/Description:

Safer, cleaner, and quieter aircraft have a competitive advantage in the global market. Improved aircraft propulsion systems are needed for aircraft of all sizes, shapes, speeds, and altitudes so that a commercial air transportation system is accessible to move people and cargo around the world. Reductions in aircraft noise could lead to wider community acceptance, lower airline operating costs where noise quotas or fees are employed, and increased potential for air traffic growth on a global scale. The goal of this subtopic is to support the development and commercialization of tools and technologies to predict, diagnose, and reduce noise from aircraft propulsion systems and components.

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

Primary Technology Taxonomy:

- Level 1: TX01 Propulsion Systems
- Level 2: TX01.3 Aero Propulsion

Desired Deliverables of Phase I:

Tools and technologies that enable prediction, diagnostics, and reduction of propulsion noise, at the component or system level, for subsonic and supersonic aircraft. Clear definition of path(s) for commercialization and infusion of these technologies.

Phase I deliverables can include:

• Demonstration of models/codes for predicting propulsor noise using available model test problems.

• Demonstration of advanced noise diagnostic tools/techniques using canonical or virtual test problems.

• Proof-of-concept demonstration of propulsion noise reduction concepts or technologies in laboratory environment.

Desired Deliverables of Phase II:

Phase II deliverables can include:

• Models/codes that accurately predict propulsor noise for realistic fans and open rotors.

• Matured advanced noise diagnostic tools/techniques applicable to realistic propulsors in relevant test environments (e.g., wind tunnels).

• Maturation of propulsion noise reduction concepts or technologies to realistic propulsion components, subsystems, or systems.

Desired Deliverable Types of Phase II:

- Analysis
- Prototype
- Hardware
- Software

State of the Art:

State-of-the-art technologies for propulsion noise reduction are generally passive and tend to be designed for a specific operating condition. Adaptive materials and mechanisms that can modify their acoustic performance based on the noise state of the engine are highly desirable. New prediction tools, diagnostic capabilities, and noise-reduction technologies would enable development of quieter propulsion systems.

Critical Gaps:

Efficient high-fidelity prediction tools that enable timely evaluations of various engine architectures and operating conditions are lacking. Availability of such tools is essential at the design stage or for system-level assessment.

Accurate and robust diagnostic tools for source identification and characterization do not exist for most of the important propulsion noise sources such as fans, combustors, and turbines.

Shortfalls And Decadal Surveys:

The needs for safer, cleaner, and quieter aircraft propulsion are described in the NASA Aeronautics Strategic Implementation Plan 2023.

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

References:

1. https://www.nasa.gov/directorates/armd/
2. https://www.nasa.gov/directorates/armd/armd-strategic-implementation-plan/

AERO.3.S26B: Advanced Thermal Management for High-Efficiency Engine Cycles (SBIR)

Lead Center: GRC

Subtopic Problem Statement/Description:

The commercial aviation industry is undergoing a transformative shift toward more efficient and sustainable propulsion systems. Emerging engine architectures such as hybrid-electric, all-electric, and advanced non-electric cycles with recuperation and intercooling promise significant improvements in fuel efficiency, emissions reduction, and operational costs. However, these next-generation propulsion systems generate higher thermal loads and rely more heavily on thermal technologies than conventional gas turbine engines.

Hybrid-electric and all-electric propulsion systems introduce new thermal management challenges. High-power-density electric motors and battery systems generate concentrated heat that must be efficiently dissipated to maintain safe operating temperatures and prevent performance degradation or premature failure. NASA-funded research on electrified propulsion has identified that current electric motors achieve approximately 2 kW/kg, with 2035 projections reaching 9-16 kW/kg, while power electronics are projected to reach 9-19 kW/kg [1]. All these electrical components generate waste heat requiring effective thermal management. Lithium-ion and next-generation battery chemistries are particularly sensitive to temperature, with performance, cycle life, and safety all critically dependent on maintaining optimal thermal conditions.

Advanced gas turbine cycles, such as intercooled and recuperated cycles, offer the potential for substantial fuel efficiency gains by recovering waste heat from the turbine exhaust. Historical NASA studies found that recuperated cycles with heat exchangers operating at 80-85% effectiveness could theoretically reduce fuel consumption by 15% [2]. However, realizing these efficiency improvements in aviation applications requires compact, lightweight heat exchangers capable of operating at high effectiveness while withstanding the demanding temperature, pressure, and vibration environment. Past implementations faced severe weight penalties – adding 60% to engine weight and 70% to engine volume – which eliminated the theoretical benefits [2]. Recent studies using compact heat exchangers have reduced the weight and volume penalty, but further improvements are needed for these cycles to become feasible.

Current thermal management solutions developed for ground-based applications are often inadequate for aviation due to weight, volume, reliability, or performance constraints. NASA research has also shown that engine bypass streams are highly sensitive to pressure losses from thermal management hardware, making low-pressure-drop designs critical [3]. NASA seeks innovative thermal management devices, systems, and strategies that can enable high-efficiency engine cycles for commercial aviation applications while meeting stringent aviation constraints.

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

Primary Technology Taxonomy:

- Level 1: TX14 Thermal Management Systems
- Level 2: TX14.X Other Thermal Management Systems

Desired Deliverables of Phase I:

Phase I Deliverables and Objectives

Phase I efforts should focus on feasibility demonstration and preliminary design. Expected deliverables include:

- Conceptual design of the proposed thermal management system with detailed technical specifications
- Analytical or computational modeling demonstrating feasibility and projected performance
- Preliminary experimental validation of key technical concepts or components (lab-scale demonstration)
- Assessment of scalability to aviation propulsion requirements
- Identification of key technical risks and mitigation strategies
- Technical report documenting Phase I results
- **Target TRL progression: TRL 2-3 to TRL 3-4**

Desired Deliverables of Phase II:

Phase II Deliverables and Objectives

Phase II efforts should advance toward technology demonstration in relevant environments. Expected deliverables include:

- Detailed design and fabrication of a prototype thermal management system
- Experimental testing under simulated or actual aviation-relevant conditions (temperature ranges, pressures, thermal loads, vibration profiles)
- Performance characterization including heat transfer rates, pressure drops, weight, and efficiency metrics
- Reliability and durability testing appropriate for aviation applications
- Pathway for integration into target propulsion systems
- Final technical report and recommendations for Phase III transition
- **Target TRL progression: TRL 4 to TRL 5-6**

Desired Deliverable Types of Phase II:

- Analysis
- Test Results
- Hardware
- Prototype

State of the Art:

There are no hybrid-electric commercial engine cycles nor cycles involving intercooling or recuperation flying today. The associated thermal systems are still too heavy and consume too much power from the gas turbine to enable these advanced architectures. Improvements in heat exchanger designs have mostly remained in scaled-down laboratory settings and haven't been sized or implemented in gas turbine engines or relevant environments. Likewise, thermal management technologies pertaining to power electronics and motors have yet to transition from laboratory to flight demonstration, despite many promising technologies in this area. An alternative approach to intercooling, via water injection, has been identified as a potentially advantageous strategy for numerous reasons but requires further development to understand all the impacts this would have on the cycle (and the components themselves).

Critical Gaps:

Next generation engines will require thermal management of the turbine inlet temperature to enable higher overall pressure ratio (OPR) without exotic materials in the last stages of the high pressure compressor (HPC). Technology development to enable more efficiencies such as compact, durable, low loss heat exchangers, water injection technologies or other technologies that enable higher P3. megawatt-class (MW-class) thermal bus technologies may be needed to 'move' heat around the engine cycle and cool other heat loads like electric machines. The engine thermal management system may also need to interact with heat loads on the airframe that process cryo fuels prior to onboarding to the engine.

Technology needed to advance the State-of-the-Art (SOA) include:

- Innovative cooling systems for high-power-density electric motors (>12 kW/kg) used in aviation propulsion
- Advanced thermal management solutions for aircraft battery systems, including active and passive cooling strategies
- Compact, lightweight heat exchangers for recuperated thermodynamic cycles with high effectiveness (>0.85) and low pressure drop
- Novel heat transfer enhancement techniques applicable to aviation propulsion thermal management (e.g., advanced fin geometries, microchannels, phase-change systems)
- Integrated thermal management architectures that couple multiple heat sources and sinks within propulsion systems
- Thermal energy storage systems that can buffer transient thermal loads during flight operations
- Lightweight materials and coatings that enhance heat transfer or thermal resilience in propulsion applications
- Technologies applicable to Technology Readiness Level (TRL) 3-6 within Phase I/II timeframe

Shortfalls And Decadal Surveys:

Although there is an invitation to solicit feedback for the prioritization of technology shortfalls critical to civil space by February 20, 2026, the most recent publicly available document is the Civil Space Shortfall Ranking from July 2024. Based on that document, the following are addressed by this subtopic, and are relevant to civil aeronautics applications as well:

Thermal Management Systems capability category:

- (1623) Advanced thermal modeling capabilities

- (1624) Advanced thermal management technologies for diverse applications

This subtopic is for aeronautics and is not linked to current Decadal Surveys.

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

References:

1. Hall, D. K., Greitzer, E. M., et al., "Feasibility of Electrified Propulsion for Ultra-Efficient Commercial Aircraft," NASA/CR-2019-220382, December 2019. https://ntrs.nasa.gov/citations/20190033478
2. Eisenberg, J. D., "A Preliminary Study of the Use of Intercooling and Reheat in Conjunction with Regeneration for Aircraft Turbine Engines," NASA TM X-73617, Lewis Research Center, March 1977. https://ntrs.nasa.gov/citations/19770014143
3. Snyder, C. A., "Effects of Energy Capture and Recovery on an N+3 Technology Level Reference Propulsion System," NASA/TM-20210021504, September 2021. https://ntrs.nasa.gov/citations/20210021504
4. NASA High-Efficiency Megawatt Motor (HEMM), https://www.nasa.gov/eap-technology/electric-machines/hemm/
5. NASA Aeronautics Ultra-Efficient Aviation Overview, https://www.nasa.gov/aeronautics/ultra-efficient-aviation/

AERO.4.S26B: Flight Test Measurement Technologies (SBIR) (previously A2.01)

Lead Center: AFRC

Participating Center(s): ARC, GRC, LaRC

Subtopic Problem Statement/Description:

NASA continues to use flight research as a critical element in the maturation of technology. This includes developing test techniques that improve the control of in-flight test conditions, expand measurement and analysis methodologies, and improve test data acquisition and management with sensors and systems that have fast response, low volume, minimal intrusion, and high accuracy and reliability. By using state-of-the-art flight test techniques along with novel measurement and data acquisition technologies, NASA and the aerospace industry will be able to conduct flight research more effectively and meet the challenges presented by NASA's and industry's cutting-edge research and development programs.

The role of UAV (Uncrewed Aerial Vehicles) in human endeavors is expanding rapidly. Besides imaging, small UAVs can play a vital role in scientific explorations in challenging environments. Evolving small UAV architectures to meet NASA needs and unique applications has the potential to spur the domestic small UAV market to new heights. NASA invites small businesses to provide out-of-the box solutions to further advance the small UAV platform architecture by incorporating novel solutions in operational elegance, power management, and effective data processing and dissemination. This solicitation involves small businesses in proposing technological advancements for small UAV architectures, focusing on reducing size, weight, power consumption, and cost, as well as improving form, fit, and functionality to aid NASA applications.

NASA's Flight Demonstrations and Capabilities (FDC) Project supports a variety of flight regimes and vehicle types, ranging from low-speed, subsonic applications and electric propulsion through transonic and high-speed flight regimes. Therefore, this subtopic covers a wide range of flight conditions and vehicles.

NASA also requires improved measurement and analysis techniques for acquisition of real-time, in-flight data used to determine aerodynamic, structural, flight control, and propulsion system performance characteristics. These data will be used to provide information necessary to safely expand the flight and test envelopes of aerospace vehicles and components. This requirement includes the development of sensors for both in situ and remote sensing to enhance the monitoring of test aircraft safety and atmospheric conditions during flight testing.

Flight test and measurement technology proposals may significantly enhance the capabilities of major government and industry flight test facilities. Proposals may address innovative methods and technologies to reduce costs and extend the health, maintainability, communication, and test techniques of flight research support facilities to directly enhance flight test and measurement.

For this year's solicitation, areas of interest emphasizing flight test measurement technologies will be focusing on digital data processing, telemetry, and optical sensing. An extra emphasis is placed on current state-of-the-art in UAV technologies to further develop and/or adapt and test new sensor suites to supporting NASA ARMD mission and beyond.

- Advance UAV-based navigation in urban and extreme environmental settings, aid in future vertiport management, assess environmental safety including hazardous weather conditions due to wind, snow, wildfire.
- Novel sensor architectures with limited range but increased precision or resolution in performance for UAV applications involving altimeters, ranging, terrain slope, rock/debris locations, thermal locations, landing beacon navigation, landers for extreme environments
- Development of UAVs with low size, weight, power consumption and cost (SWaP-C) with autopilot with multiple integrated components.
- High-efficiency digital telemetry techniques and/or systems to enable high–data rate and high-volume telemetry for flight test, including air-to-air and air-to-ground communication.
- Improved processing technologies that can perform low-latency near real-time telemetry processing that can utilize open-source operating system.
- Real-time integration of multiple data sources from onboard, off-board, satellite, and ground-based measurement equipment, including recording of data bus/avionics architectures.
- Test techniques, including optical-based measurement methods that capture data in various spectra, for conducting quantitative in-flight boundary layer flow visualization, Schlieren photography, near- and far-field sonic boom determination, and atmospheric modeling, as well as measurements of global surface pressure/shear and shock wave propagation.
- Improved ruggedized, single-longitudinal mode, wide bandwidth wavelength-sweeping laser system design for in-situ flight structural health monitoring to be operated in aircraft, specifically for optical frequency domain reflectometry (OFDR) technology utilized in NASA's Fiber Optic Sensing System (FOSS).

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

Primary Technology Taxonomy:

- Level 1: TX15 Flight Vehicle Systems

Desired Deliverables of Phase I:

For a Phase I effort, the small business is expected to generate a midterm report showing progress of the work. A summary report is expected at the end of Phase I that describes the research effort's successes, failures, and the proposed path ahead.

Desired Deliverables of Phase II:

For a Phase II effort, the small business should show a maturation of the technology that allows for a presentation of a thorough demonstration. Most ideally, a delivery of a prototype that includes beta-style or better hardware and/or software that is suitable to work in ground testing and can be proven, via relevant environment testing, to work in a flight environment. This relevant environment testing would satisfy NASA's technical readiness level expectations at the end of Phase II.

Desired Deliverable Types of Phase II:

- Analysis
- Test Results
- Hardware
- Prototype

State of the Art:

Current atmospheric flight systems cover a large range of uses, from point-to-point drones to high-performance small aircraft to large transport to general aviation. In all areas, advancements can be possible if insights can be gained, studied, and used to create new technologies. New insights will require an evolution of current testing and measurement techniques as well as novel forms and implementations.

For low Size Weight, Power and Cost (SWaP-C) Unmanned Air Vehicle (UAV) development, current state of the art can be developing communication payload equipment for high altitude endurance aircraft that supports high bandwidth direct-to-device communication (5G) for disaster response, as well as sensor suite for integrated sensors that provide airborne position, navigation, and timing solutions to increase precision and accuracy of aircraft location for a GPS-denied geographic region.

For single longitudinal mode continuously tunable laser system, current state of the art can either utilize an external cavity setup that involves a mechanically swept-tuned laser that is susceptible to vibration, or an electronically tunable laser that will mode-hop at low bandwidth range (for a couple of nanometers of tuning range). Desirable laser is an electrically tuned laser can sustain 10 nanometers of tuning range while maintaining single mode throughout the sweeping range.

Critical Gaps:

Known gaps include advanced telemetry techniques; intelligent internal state monitoring for air and space vehicles; techniques for studying sonic booms, including novel photography techniques; advanced techniques for capturing all dimensions of system operation and vehicle health (spatial/spectral/temporal); and extreme environment, high-speed, large-area distributive sensing techniques. Along with these comes the need for secure telemetry of data to ensure informed operation of the flight system.

Shortfalls And Decadal Surveys:

Based on Civil Space Shortfall Ranking (2024)
https://www.nasa.gov/wp-content/uploads/2024/11/alowry-shortfall-rankings-tagged.pdf?emrc=67349ea90c923
Integrated Rank - 3 - Shortfall ID: 1554 - High Performance Onboard Computing to Enable Increasingly Complex Operations - Category - Avionics
Integrated Rank - 18 - Shortfall ID: 1548 - Sensing for Autonomous Robotic Operations in Challenging Environmental Conditions - Category - Autonomous Systems and Robotics
Integrated Rank - 49 - Shortfall ID: 1553 - Foundational Technologies for Future Avionics Devices and Systems - Category - Avionics

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

References:

1. NASA Advanced Air Mobility missions https://www.nasa.gov/centers-and-facilities/armstrong/building-the-infrastructure-for-advanced-air-mobility/
2. NASA Advanced Capabilities for Emergency Response Operations (ACERO) https://www.nasa.gov/centers-and-facilities/ames/acero-and-wildland-fires/
3. NASA's Quesst mission to reduce the loudness of a sonic boom and gather data on human responses to supersonic flight overhead: https://www.nasa.gov/X59
4. Fiber Optic Sensing System - Smart Sensing and Sensor Development https://www.nasa.gov/centers-and-facilities/armstrong/smart-sensing-and-sensor-development/
5. Schlieren Images Reveal Supersonic Shock Waves: https://www.nasa.gov/centers/armstrong/features/supersonic-shockwave-interaction.html
6. NASA's Commercial Supersonic Technology (CST) Project: https://www.nasa.gov/aeroresearch/programs/aavp/cst
7. NASA's Revolutionary Vertical Lift Technology (RVLT) Project: https://www.nasa.gov/aeroresearch/programs/aavp/rvlt
8. NASA's Aerosciences Evaluation and Test Capabilities (AETC) Portfolio Office: https://www.nasa.gov/aetc
9. NASA's Transformative Aeronautics Concepts Program https://www.nasa.gov/directorates/armd/tacp/

AERO.5.S26B: Improved Material Discovery through Leveraging Novel Modeling and Experimental Approaches (SBIR)

Lead Center: GRC

Participating Center(s): ARC, LaRC

Subtopic Problem Statement/Description:

NASA aeronautics has wide-ranging material needs across multiple flight regimes (subsonic, supersonic, hypersonic) and multiple vehicles classes from more traditional commercial transport to emerging areas such as urban air mobility (UAM), electric vertical take-off and landing (eVTOL) and others. To support these diverse applications, new materials are needed to support advances in propulsion, structures, and electrification, among others, to enable the high-performance vehicles of the future. Advances in the associated manufacturing processes will also be critical for high-rate production, additive manufacturing of complex parts, etc. Rapid qualification and certification of new materials and processes will be crucial to facilitate the adoption and deployment of new technologies. Acceleration of material development will require advances in characterization/testing as well as multiscale modeling that leverage physics-based as well as data-driven (AI/ML) approaches across multiple length and time scales, high-throughput computing, digital workflow/assistants, etc.

NASA recently published a report, "Vision 2040: A Roadmap for Integrated, Multiscale Modeling and Simulation of Materials and Systems" [Ref. 1], which detailed a paradigm shift towards accelerated, fit-for-purpose material design. Proposals emphasizing modeling (both physics-based and data driven), materials informatics and advanced/novel experimentation which address gaps in that 2040 Vision are encouraged. The range of topics could include data management [Ref 2], data analytics, machine learning [Ref 3], linkage and integration across spatiotemporal scales [Refs 4, 5], and high through-put experiments and characterization of materials over their lifecycle as well as model parameter estimation methodologies [Ref 6].

Material systems and related technologies of high interest include but are not limited to:

- High temperature alloys
    - GRX-810 and other Ni-based oxide dispersion strengthened (ODS) alloys
    - Oxygen sensitive alloys (e.g. Nb-based)
- Shape memory alloys
    - Innovative Processing and Forming Techniques for High-Temperature Shape Memory Alloys
        - investigate ingot conversion processes and forming techniques through microstructure feature design and optimization, with the goal of overcoming challenges associated with processing these materials. Studies on grain structure and microstructure as a function of cold or hot working, heat treatments, reduction ratios, and related parameters are required, using both experimental and computational approaches. Additionally, proposals should include investigations into ingot surface treatments designed to prevent potential cracking and material loss during processing.
    - Utilizing Additive Manufacturing to Stabilize Shape Memory Alloy Responses
- Additive manufacturing
    - Nondestructive evaluation and characterization, including in-situ monitoring
- Structural composites
    - Nondestructive evaluation and characterization
    - Nonlinear models and model applications at, and across, all relevant length scales
- Environmental barrier coatings (EBC/CMC)
    - Multiphysics models capturing realistic microstructural features
    - Increased model accessibility through deployment of machine learning and artificial intelligence
    - Transport modeling of oxidizing species
- Materials informatics
    - AI agents for high-throughput materials simulation/discovery
    - Automated materials database curation
    - Data analysis/visualization tools for multiscale materials simulation
- Computational Modeling
    - Novel multiscale and Multiphysics modeling approaches
    - Machine learning approaches for creating surrogates of high-fidelity simulations

AI techniques to automate existing modeling workflows

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

Primary Technology Taxonomy:

- Level 1: TX12 Materials, Structures, Mechanical Systems, and Manufacturing
- Level 2: TX12.1 Materials

Desired Deliverables of Phase I:

The Phase I outcome should establish the scientific, technical, and commercial feasibility of the proposed innovation in fulfillment of NASA needs. Phase I should demonstrate advancement of a specific technology, supported by analytical and experimental studies that are documented in a final report. Phase I deliverables may also include preliminary software-based modeling tools and high-throughput computational and/or experimental workflows.

Desired Deliverables of Phase II:

Phase IIs could yield: (1) models supported with experimental data, (2) software related to a model that was developed, (3) a material system or subcomponent that has been demonstrated to have better properties/performance (ability to operate at a higher temperature, enhanced durability, carry more current, etc.), and (4) modeling tools for incorporation in software, etc. that can be infused into a NASA project or lead to commercialization of the technology. Phase II efforts are strengthened when they include a partnership with a potential end-user of the technology to increase the potential for post-Phase II continued funding.

Desired Deliverable Types of Phase II:

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

State of the Art:

Current aeronautics materials research is advancing rapidly to meet the demands of next-generation aircraft and propulsion systems. Ceramic Matrix Composites (CMCs), such as - silicon carbide fiber/silicon carbide matrix composite systems (SiC/SiC) systems with environmental barrier coatings, emerging as game-changers for high-temperature engine components, offering lightweight, damage-tolerant solutions that outperform traditional superalloys in thermal resistance and durability. Parallel efforts in additively manufactured alloys, including oxide dispersion-strengthened nickel-based systems, are enabling complex geometries and improved radiation resistance for extreme environments. In the realm of battery technology and electrification materials, solid-state chemistries, high-power-density ceramic electrodes, and high-voltage cables are being developed to achieve the energy density and safety required for electrified aviation, including eVTOL platforms. For airframe materials, research emphasizes polymeric composites and adhesive-free bonding techniques, alongside qualification of additively manufactured metallic structures, to reduce cost while enhancing structural integrity and manufacturability. Shape memory alloys are being developed as energy- and space-saving actuators, among other applications. Collectively, these innovations aim to deliver lighter, stronger, and more thermally resilient materials, supporting sustainable flight and advanced propulsion concepts for future aerospace vehicles.

Modern aeronautics materials research is increasingly leveraging computational modeling and digital workflows to accelerate innovation alongside advanced material systems. To shorten development cycles, Integrated Computational Materials Engineering (ICME) and multiscale modeling approaches—combining physics-based simulations with AI/ML-driven property prediction—are being deployed to link processing, structure, and performance across scales. These tools, coupled with high-throughput computing and digital twins, enable rapid qualification and certification of new materials and processes, reducing reliance on costly experimental iterations. NASA and industry initiatives increasingly focus on creating computational ecosystems for additive manufacturing, fatigue life prediction, and environmental degradation modeling, ensuring accelerated discovery and deployment of next-generation materials for sustainable, high-performance aerospace systems.

Critical Gaps:

NASA aeronautics has wide-ranging material needs across multiple flight regimes (subsonic, supersonic, hypersonic) and multiple vehicles classes from more traditional commercial transport to emerging areas such as urban air mobility (UAM), electric vertical take-off and landing (eVTOL) and others. To support these diverse applications, new materials are needed to support advances in propulsion, structures, and electrification, among others, to enable the high-performance vehicles of the future. Advances in the associated manufacturing processes will also be critical for high-rate production, additive manufacturing of complex parts, etc. Rapid qualification and certification of new materials and processes will be crucial to facilitate the adoption and deployment of new technologies. Acceleration of material development will require advances in characterization/testing as well as multiscale modeling that leverage physics based as well as data driven (AI/ML) approaches across multiple length and time scales, high-throughput computing, digital workflow/assistants, etc.

The increased use of various types of modeling and advanced experimental characterization and testing to improve R&D effectiveness and enable more rapid and revolutionary materials design has been identified as critical. NASA recently sponsored a study to define a potential 25-year goal for integrated, multiscale modeling of materials and systems to accelerate the pace and reduce the expense of innovation in future aeronautical systems. Through a series of surveys, workshops, and validation exercises, this study identified critical cultural changes and gaps facing the multiscale modeling community. The results of this study were published in a NASA report, "Vision 2040: A Roadmap for Integrated, Multiscale Modeling and Simulation of Materials and Systems" [Ref. 1]. Some of the critical gaps identified in this report are: (1) under-development of physics-based models that link length and time scales, (2) inability to conduct real-time characterization at appropriate length and time scales, (3) lack of optimization methods that bridge scales, (4) lack of models that compute input sensitivities and propagate uncertainties, and (5) lack of verification and validation methods and data.

Shortfalls And Decadal Surveys:

This subtopic addresses the community-developed NASA report, "Vision 2040: A Roadmap for Integrated, Multiscale Modeling and Simulation of Materials and Systems" [Ref. 1].

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

References:

1. Vision 2040: A Roadmap for Integrated, Multiscale Modeling and Simulation of Materials and Systems, NASA/CR-2018-219771, https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20180002010.pdf
2. Hearley, B. L. and Arnold S.M.: "NASA GRC ICME Schema for Materials Data Management: An Executive Summary", NASA TM-20230018337
3. Stuckner, J., Harder, B., & Smith, T. M.; "Microstructure segmentation with deep learning encoders pre-trained on a large microscopy dataset", *npj Computational Materials*, *8*(1), 2022.
4. Hearley, B. L. and Arnold, S.M.; "Automation of the ICME Workflow Incorporating Material Digital Twins at Different Length Scales Within a Robust Information Management System", TMS 2025, 154th Annual Meeting & Exhibition, Las Vegas, NV, March 2025.

5. Pineda, E., Bednarcyk, B.A., Ricks, T., Arnold, S., and Henson, G. "Efficient multiscale recursive micromechanics of composites for engineering applications" International Journal for Multiscale Computational Engineering, 19(4), 2021.
6. Saleeb, A.F., Gendy, A.S., and Wilt, T.E.; "Parameter Estimation Algorithms for Characterizing a Class of Isotropic and Anisotropic Viscoplastic Material Models", Mechanics of Time-Dependent Materials, Vol. 6, pp 323-362, 2002.
7. Arnold, Cribb, French, Ganguli, Goodman, Hatakeyama, Lorang, Matlik, Fischer, Schindel, Taylor and Wang; "Digital Thread: Definition, Value and Reference Model", An AIAA, AIA, and NAFEMS Position Paper, June 2023

AERO.6.S26B: Wind Tunnel Test Measurement Technologies (SBIR)

Lead Center: GRC

Participating Center(s): ARC, LaRC

Subtopic Problem Statement/Description:

NASA relies on a diverse portfolio of wind tunnel facilities to support aeronautics research, vehicle development, and validation of advanced computational and experimental methods. These facilities are critical for acquiring high-quality aerodynamic and aeroelastic data to inform design decisions, reduce technical risk, and improve predictive capabilities across subsonic, transonic, supersonic, and hypersonic regimes.

Current wind tunnel test measurement technologies, used for both on-body and off-body aerodynamic data acquisition, face limitations related to spatial and temporal resolution, intrusiveness, scalability, test productivity, and the ability to capture complex physical phenomena such as unsteady flow features, model deformation, and fluid–structure interactions. In addition, some existing measurement approaches require extensive setup, calibration, or manual intervention, which can increase test time, cost, and operational complexity.

As NASA advances new vehicle concepts and adopts more integrated experimental–computational engineering workflows, there is a growing need for innovative wind tunnel test measurement technologies that can enhance data quality, expand measurement capabilities, and improve test efficiency. This includes technologies applicable to aerodynamic force and moment measurements, surface and off-body flow characterization, and/or model deformation and aeroelastic response measurements. Solutions may be applicable to existing wind tunnel models, facilities, or test campaigns and should be adaptable for use in at least one NASA wind tunnel.

NASA seeks early-stage technologies that can enable more efficient test operations, reduce measurement uncertainty, minimize test intrusiveness, or provide new classes of data that support advanced engineering methods such as computational model validation, uncertainty quantification, and digital engineering. Considerations may include robustness across a range of flow conditions, compatibility with harsh test environments, ease of integration into current test processes, and potential for scalability to future facilities or missions.

Phase I efforts should focus on establishing technical feasibility, demonstrating core measurement concepts, and identifying pathways for application within NASA wind tunnel testing environments.

Expected TRL or TRL Range at completion of the Project: 1 – 6

Primary Technology Taxonomy:

- Level 1: TX13 Ground, Test, and Surface Systems

- Level 2: TX13.2 Test and Qualification Environments
- Level 3: TX13.2.5 Flight and Ground Testing Methodologies

Desired Deliverables of Phase I:

1. Measurement Concept Definition

- Detailed description of the measurement approach and operating principles
- Identification of targeted measurement type(s) (e.g., forces/moments, surface flow, off-body flow, deformation, unsteady phenomena)
- Assessment of applicability to at least one NASA wind tunnel facility

2. Analytical and Modeling Results

- Physics-based models or simulations supporting feasibility
- Predicted measurement resolution, uncertainty, bandwidth, and limitations
- Comparison against current state-of-the-art techniques

3. Wind Tunnel Integration Assessment

- Conceptual integration into existing wind tunnel models or test setups
- Identification of environmental challenges (flow conditions, vibration, thermal, optical access, etc.)
- Preliminary calibration and operational concepts

4. Phase II Development Plan

- Defined pathway to relevant-environment testing
- Identification of target NASA wind tunnel(s)
- Risk assessment and mitigation strategy
- Preliminary schedule and milestones

Phase I Non-Technical Deliverables

- Final Phase I Technical Report
- Data package and experimental results
- Go/No-Go criteria for Phase II

Desired Deliverables of Phase II:

1. Prototype Measurement System

- Engineering prototype or breadboard system
- Integrated hardware, software, and data processing pipeline
- Designed for wind tunnel-relevant environments

2. Relevant Environment Testing

- Demonstration in a wind tunnel or high-fidelity flow environment

- Testing across representative flow conditions
- Evaluation of performance under realistic operational constraints

3. Performance Validation

- Quantified spatial and temporal resolution
- Measurement uncertainty characterization
- Comparison with baseline or reference measurement techniques
- Assessment of unsteady and/or coupled phenomena (if applicable)

4. Operational Integration Demonstration

- Demonstration of setup, calibration, and data acquisition workflows
- Evaluation of test productivity improvements
- Assessment of intrusiveness and impact on tunnel operations

5. Robustness and Scalability Assessment

- Evaluation of environmental robustness (vibration, thermal, optical, pressure, etc.)
- Scalability to different tunnel sizes or flow regimes
- Adaptability to future NASA facilities or test campaigns

6. Transition and Infusion Plan

- Identification of specific NASA stakeholders and facilities
- Plan for Phase III infusion into NASA wind tunnel operations
- Commercialization or broader adoption strategy (government and/or commercial)

Phase II Non-Technical Deliverables

- Final Phase II Technical Report
- Prototype hardware and software
- Test data and validation results
- Transition-ready documentation

Desired Deliverable Types of Phase II:

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

State of the Art:

NASA and the broader aeronautics community currently employ a range of established wind tunnel measurement technologies for aerodynamic force and moment measurement, surface flow characterization, off-body flow diagnostics, and model deformation assessment. These include traditional force balances, pressure taps and pressure-sensitive paint (PSP), particle image velocimetry (PIV), laser Doppler velocimetry (LDV), schlieren and shadowgraph imaging, strain gauges, and optical model deformation measurement systems.

While these techniques have proven highly valuable, they each exhibit limitations that can restrict their effectiveness for emerging test needs. Many existing approaches are intrusive, requiring model modifications or instrumentation that can alter the flow field or structural response. Others are limited in spatial or temporal resolution, making it difficult to capture highly unsteady or localized flow phenomena. Additionally, some techniques involve delayed data availability, rely on offline post-processing, or require extensive manual intervention, which can reduce test productivity and increase operational complexity and cost.

In addition, several state-of-the-art optical and laser-based diagnostics face challenges related to scalability, optical access, environmental robustness, and applicability across multiple flow regimes or tunnel types. For aeroelastic and deformation measurements, existing methods may struggle to provide simultaneous, high-bandwidth measurements over complex geometries or across large measurement volumes.

As a result, there is an identified gap between current state of the art measurement capabilities and NASA's evolving requirements for higher-fidelity, more integrated, and more efficient wind tunnel data acquisition systems. Early-stage innovations that address these gaps—by improving resolution, reducing intrusiveness, simplifying operations, reducing reliance on offline or manual post-processing, or enabling new measurement modalities—represent a critical opportunity to advance NASA's experimental aeronautics capabilities.

Critical Gaps:

Current wind tunnel measurement technologies are constrained by limitations in resolution, intrusiveness, scalability, operational efficiency, and multi-physics data capture, creating a gap between available experimental data and NASA's evolving needs for high-fidelity, efficient, and computationally integrated testing.

Shortfalls And Decadal Surveys:

Across all speed regimes, wind tunnel test diagnostics face significant challenges in achieving accurate, high-resolution, and non-intrusive measurements under demanding conditions. Subsonic testing struggles with turbulence and relies on techniques like pressure sensitive paint and particle image velocimetry that require controlled environments. Transonic regimes add complexity with shock detection and unsteady flow, demanding high-speed optical and pressure sensors. Supersonic testing suffers from intrusive probes and limited optical resolution, while hypersonic diagnostics are constrained by extreme temperatures, chemical effects, and millisecond test durations, making conventional sensors unreliable and requiring advanced laser-based methods. These issues are compounded by calibration difficulties, high costs, and integration needs with computational fluid dynamics, highlighting the need for robust, fast-response, and non-intrusive diagnostic technologies.

This subtopic is for aeronautics and is not linked to Decadal Surveys.

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

References:

AETC - Aerosciences Evaluation and Test Capabilities

AERO.7.S26B: Airspace Operations and Safety (SBIR)

Lead Center: ARC

Participating Center(s): GRC, LaRC, AFRC

Subtopic Problem Statement/Description:

The Airspace Operations and Safety Program (AOSP) focuses on enabling safe, sustainable, and efficient aviation operations to benefit the flying public and keep U.S. global competitiveness. Its vision is to transform aviation into a digital, federated, and service-oriented architecture that supports all airspace users. AOSP drives the integration of emerging technologies and ensures access for new entrants, particularly those that include increasingly autonomous systems. Safety, efficiency, and resilience are attributes of the systems that are enabled by the AOSP agenda. AOSP's approach emphasizes several key areas: efficient operations, seamless integration of varied and emerging aviation systems, and advanced prognostic safety management for real-time decision-making. It also focuses on system-level autonomy and its verification and validation for vehicle command, control, and contingency management. By addressing future challenges in traffic variety, density, and operational complexity, AOSP aims to improve the National Airspace System (NAS) through scalable capabilities developed in collaboration with stakeholders. These efforts seek to reduce airline delays, lower operating costs, and enhance passenger experience.

Proposals should address one of the following needs related to airspace operations and safety:

Future Aviation Safety Framework

The aviation industry is moving toward increasingly automated and autonomous systems, requiring new safety management and assurance capabilities to maintain or improve safety. Research is needed to:

- Assess future automation modes and their effects on pilot behavior, and advance human-machine interface design for pilots, remote pilots, and air traffic controllers.
- Develop evaluation criteria and assurance frameworks for AI/ML and non-deterministic systems.
- Model fatigue, workload, and workflows for all aviation actors.
- Advance anomaly detection and predictive safety tools.
- Address safety challenges in transitioning from single-aircraft piloting to multi-aircraft operations with high automation.

Airspace Management Automation

Airline and Air Traffic Management operations need scalable, interoperable automation to replace fragmented, voice-based, controller-dependent workflows. Research is required to define and validate the requirements that enable a paradigm shift from tactical control to strategic traffic-flow and trajectory management, improving efficiency, productivity, and resilience.

- Design digital information exchange protocols that reduce reliance on voice communication and enable seamless coordination between airlines, ATC, and decision-support systems.
- Transition concepts from analysis to practical implementation, ensuring prototypes integrate effectively with NASA's future airspace system vision and enable scalable, situational awareness for real-time coordination.

Safe Routine Operations of Increasingly Automated Aircraft

Commercial aviation and new entrants are adopting digital, automated, and resilient operations. Key challenges include increasing operational complexity and ensuring safety as automation assumes greater control. Research areas include:

- Digital clearances and reroutes for improved accuracy and efficiency.
- Pilot-supervised surface automation with predictable behaviors and optimized interfaces.
- Human-systems integration for workload management and trust.
- Assurance and V&V for degraded communications and GPS-denied environments.
- Navigation and obstacle detection resilient to environmental challenges.
- Autonomous behavior design with graceful degradation mechanisms.

Nontraditional Aviation Operations for Wildfire Response

Wildfires are growing in severity, creating urgent needs for improved aerial firefighting and coordination. Current challenges include manual airspace management, limited visibility operations, intermittent monitoring, and unreliable communications. Research priorities include:

- Enable persistent wildfire monitoring and data dissemination.
- Optimize resource allocation and multi-mission planning.
- Extend UTM for wildfire-specific needs in disconnected environments.
- Improve communication throughput and reliability for UAS and emergency responders.
- Provide GPS-independent navigation for automated operations.
- Deliver predictive tools and common operating pictures for situational awareness.

Nontraditional Aviation Operations for Advanced Air Mobility (AAM)

AAM operations require scalable, service-based architectures and human-autonomy teaming to integrate new technologies safely. Research priorities include:

- Designing architectures for scalable AAM operations.
- Developing tools for effective human-autonomy collaboration.
- Dynamic route planning and scheduling under changing conditions.
- Integration of AAM with legacy low-altitude operations.
- Fleet and network management concepts.
- Cyber-resiliency is integrated into service architecture.

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

Primary Technology Taxonomy:

- Level 1: TX16 Air Traffic Management and Range Tracking Systems

Desired Deliverables of Phase I:

Summary of Phase I Deliverables

Across all subtopic research domains, proposals should include **Research**, **Analysis**, **Prototype**, and **Software** deliverables that align with NASA's current and future airspace concepts and support the vision for safe, automated, and integrated aviation operations.

Phase I Deliverables (Common Requirements)

- **Concept Definition:**
  Provide a clearly defined description of the proposed concept or concepts, including a **Concept of Operations (ConOps)** and supporting requirements documentation.
- **Performance Assessment:**
  Include analytical and/or experimental studies assessing the performance and feasibility of the proposed technology or solution.
- **Tradeoff Analysis:**
  For research domains involving automation and airspace management, provide comparative analyses against state-of-the-art solutions to justify the proposed approach.
- **Transition Path:**
  Outline how the technology could evolve beyond Phase I, including a roadmap for maturation toward operational use in future airspace systems.
- **Proof-of-Concept Demonstration:**
  Demonstrate feasibility through simulation or other appropriate methods to verify core functionality and performance.
- **Final Report:**
  Document scientific, technical, and commercial feasibility, supported by research findings, analysis, and demonstration results.

Additional Expectations for Nontraditional Operations (Wildfire Response & AAM)

- Establish potential for transition beyond Phase II SBIR funding to Phase III, enabling adoption by NASA programs, other government agencies, or commercial entities.
- Demonstrate advancement of a critical technology or technique that addresses NASA objectives and broader aviation community needs.
- Ensure deliverables support scalability, interoperability, and resilience for complex, dynamic operational environments.

Desired Deliverables of Phase II:

Summary of Phase II Deliverables

For all research domains, Phase II focuses on advancing innovations from conceptual design toward **functional prototypes**, validated in relevant environments, and preparing for commercialization or infusion into NASA projects.

Future Aviation Safety Framework

- Develop **hardware or software functional prototypes** integrated with existing and future NASA concepts.
- Demonstrate prototypes in **realistic operational environments** to validate performance and safety.
- Achieve **Technology Readiness Level (TRL) 5 or higher**, indicating validation in relevant conditions.
- Ensure progression from analysis to practical implementation for future airspace integration.

Airspace Management Automation

- Develop **functional prototypes** of proposed automation technologies.
- Achieve **TRL 4 or higher**, demonstrating component or breadboard validation in a laboratory environment.
- Transition from conceptual analysis to practical implementation supporting scalable airspace management.

Safe Routine Operations of Increasingly Automated Aircraft

- Develop **functional prototypes** for automation and human-systems integration concepts.
- Achieve **TRL 4 or higher**, validating core functionality in controlled environments.
- Prepare for integration into operational systems aligned with NASA's vision for safe, automated flight.

Nontraditional Aviation Operations for Wildfire Response

- Deliver one or more of the following:
    1. **Models supported by experimental data**.
    2. **Software related to developed models**.
    3. **Material systems or prototype tools**.
    4. **Modeling tools for incorporation into software**.
- Ensure solutions can be **infused into NASA projects** or lead to **commercialization**.
- Strengthen efforts through **partnerships with potential end-users**.
- Phase II should demonstrate clear **commercialization strategy** and readiness for continued funding or adoption.

Nontraditional Aviation Operations for Advanced Air Mobility (AAM)

- Deliverables similar to wildfire response:
    1. **Models with experimental validation**.
    2. **Software tied to developed models**.
    3. **Prototype tools or material systems**.
    4. **Modeling tools for integration into software**.
- Focus on **infusion into NASA projects** or **commercialization pathways**.
- Include **end-user partnerships** and a clear **transition strategy beyond Phase II**.

Key Objectives Across All Research Domains

- Advance TRL (4–5+) through prototype development and validation.

- Demonstrate feasibility in relevant or operational environments.
- Prepare for **commercialization or NASA infusion**.

Desired Deliverable Types of Phase II:

- Analysis
- Software
- Prototype

State of the Art:

Future Aviation Safety Framework

The aviation system is becoming increasingly complex due to growing air transportation demand and tightly coupled air and ground functions. Current safety assurance methods struggle to scale with this complexity. NASA's Airspace Operations and Safety Program (AOSP) is addressing these challenges by developing advanced safety management and assurance capabilities to support future operations.

Airspace Management Automation

Airline and Air Traffic Management coordination remains fragmented, relying on disparate systems and voice-based communication. Current processes for strategic and tactical flow management depend heavily on controller-initiated actions, creating high cognitive workload and frequency congestion. AOSP is working to define functional requirements and validated information flows to enable strategic coordination and reduce operational inefficiencies.

Safe Routine Operations of Increasingly Automated Aircraft

The industry is advancing toward digital and automated operations, supported by improvements in perception, autonomy, and communication technologies. Emerging prototypes include digital clearance exchanges, automated taxi functions, and trajectory negotiation, complemented by enhanced human-machine interfaces. For new entrants, remote piloting and detect-and-avoid capabilities are being integrated into early frameworks, while assurance methods and safety cases are evolving to address automation's growing role.

Nontraditional Aviation Operations for Wildfire Response

Current aerial firefighting coordination is largely manual, requiring collaboration across multiple entities and assets. This approach limits efficiency and scalability, especially as wildfire severity and operational complexity increase.

Nontraditional Aviation Operations for Advanced Air Mobility (AAM)

NASA is actively researching advanced air transportation concepts and technologies to enable scalable AAM operations within the National Airspace System (NAS). These efforts aim to bridge gaps between current practices and future high-density, automated airspace environments.

Critical Gaps:

Future Aviation Safety Framework

Current safety assurance methods cannot scale to increasingly complex, integrated aviation systems. Critical gaps include:

1. **Safe System Design Assurance** for advanced, distributed architectures.
2. **Continuous Monitoring and Data Fusion** to detect emergent anomalies across diverse sources.
3. **Predictive Risk Modeling** for hazardous event probabilities and safety impacts.
4. **Proactive Contingency Planning** to mitigate identified hazards. Additionally, safety research must expand to address unique risks introduced by **Advanced Air Mobility (AAM)** and **UAS operations**.

Airspace Management Automation

Coordination between airlines and Air Traffic Management lacks automation and remains fragmented. Gaps include:

- **Digital Information Exchange** to reduce reliance on voice communication and minimize controller workload.
- **Decision Support Tools** for automated strategic, tactical, and flow management with limited controller intervention.

Safe Routine Operations of Increasingly Automated Aircraft

Despite progress in automation, gaps persist in:

- **Functional and Performance Requirements** for pilot-supervised and remote operations.
- **Standardized Protocols** for digital taxi clearances, automated reroutes, and resilient ATC interaction under degraded conditions.
- **Assurance and V&V Frameworks** to address safety-critical decision-making shifts from humans to automation, especially under GPS-denied or adverse weather scenarios. Closing these gaps is essential for **workload acceptability, safety, and operational resilience**.

Nontraditional Aviation Operations for Wildfire Response

Current aerial firefighting coordination is manual and inefficient. Gaps include:

- Manual airspace management and visual/radio-based awareness.
- Limited integration of unmanned systems.
- No night operations and visibility-dependent missions.
- Surveillance updates only every 4 hours.
- Intermittent communications delaying response.
- Rapidly changing conditions requiring timely data.
- Overloaded decision-makers and fragmented tools across multiple applications.
- Lack of role-specific information delivery for emergency responders.

Nontraditional Aviation Operations for Advanced Air Mobility (AAM)

Significant gaps remain in developing scalable AAM airspace operations:

- **Integration of technologies across domains and operators**.
- **Human-autonomy teaming** for effective collaboration.
- **Dynamic scheduling and traffic management** for high-density operations.
- **Operational concepts for scaling demand and complexity**. Proposals must focus on **airspace operations**, not vehicle-specific technologies.

Key Themes Across All Research Domains

- Need for **automation and digital integration** to reduce workload and improve coordination.
- Development of **predictive, proactive safety tools** for complex, distributed systems.
- Creation of **resilient protocols and assurance frameworks** for automation and degraded conditions.
- Solutions for **scalability, interoperability, and real-time decision support** in dynamic environments.
- Strong emphasis on **human-autonomy collaboration** and **commercialization pathways** for future adoption.

Shortfalls And Decadal Surveys:

The Airspace Operations and Safety Program (AOSP) directly addresses several critical shortfalls in civil aviation systems. These include the need for scalable frameworks to integrate increasingly automated and autonomous systems into the National Airspace System (NAS), and the lack of robust safety assurance methods for Artificial Intelligence/Machine Learning (AI/ML) and other non-deterministic technologies. AOSP also mitigates vulnerabilities in degraded operational environments, such as GPS-denied conditions and communication failures, by advancing resilient navigation and graceful degradation mechanisms. Furthermore, the program tackles gaps in human-autonomy teaming by improving workload modeling, trust, and interface design for pilots, remote operators, and air traffic controllers. Finally, AOSP responds to the shortfall in airspace management for new entrants—such as Advanced Air Mobility (AAM) and wildfire response operations—through scalable architectures and extensions of Unmanned Aircraft System Traffic Management (UTM) tailored for emergency scenarios.

AOSP's research agenda aligns closely with priorities identified in the National Academies' Decadal Survey for Aeronautics (2016–2025). Its focus on transforming aviation into a digital, federated architecture supports the goal of enabling safe and efficient growth in global operations. The program's emphasis on prognostic safety management and anomaly detection reflects the Survey's call for real-time system-wide safety assurance, while its work on autonomy verification and validation addresses the need for assured autonomy in future aviation systems. Additionally, AOSP's wildfire response initiatives contribute to Earth Science Decadal Survey objectives for improved disaster response and resilience. By advancing scalable, service-oriented architectures and human-autonomy collaboration for AAM, AOSP builds the foundation for modernized airspace operations that meet both current and emerging challenges.

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

References:

1. NASA Aeronautics Research Mission Directorate (ARMD) Strategic Implementation Plan: https://www.nasa.gov/directorates/armd/armd-strategic-implementation-plan/
2. AOSP: https://www.nasa.gov/aeroresearch/programs/aosp

AERO.8.S26B: Fuel to Electric Conversion (SBIR)

Lead Center: GRC

Subtopic Problem Statement/Description:

The purpose of this subtopic is to stimulate near term U.S. entrepreneurship in aircraft systems which convert fuel to on board aircraft electric power for small drones and piloted aircraft. There is a need for additional electrical power on aircraft with minimal impact on the overall weight of the aircraft. The key gap being addressed is for integrated systems which use common aviation fuels and output regulated electrical power with high efficiency and light weight in an aircraft grade system. This is particularly important for small drones and aircraft which are enabled by electric propulsion because it allows fuel to be used instead of batteries which are much heavier. The aircraft level benefits are longer range, longer flight duration and sufficient onboard electric power for electrically actuated control surfaces, electric deicing, advanced sensor systems, and other high power electric subsystems. Demonstration should be conducted at a scale which has a near term path to product introduction in the drone or small aircraft market.

The outcome sought at the end of phase II is a fully integrated fuel to electric conversion system prototype with lab test results measuring the total system weight and end to end conversion efficiency. Additionally, a report should be completed documenting the target market, one or more specific customer requirements set and the remaining steps to advance from the prototype to the product.

Strong proposals will have several characteristics.

- One or more identified launch customers with letters of commitment
- Proposals should support market introduction to the existing Unmanned Aerial Vehicle (UAV) or the emerging electric and hybrid electric aircraft markets.
- An indication of what aircraft certification requirements are applicable to the system should be included. Certification requirements including maximum aircraft weight for those markets can be found in Code of Federal Regulations (CFR) Part 107 [1] and Part 23 [2] and the Department of Defense definition of drone categories [3]
- A clear awareness of additional applicable product, environment or test standards should be shown. This can be simply a list of the standards. Examples are: RTCA DO-160G [4] and MIL-STD-704 [5]
- A path to Federal Aviation Administration experimental certification by 2030 or earlier must be shown. It is understood that this part of the effort would be beyond Phase II.
- In phase II the requirements should be mapped to an expected launch customer's need.
- An initial operational concept which describes the expected operation of the system during the flight segments: takeoff, climb, cruise, decent, landing.
- Facilities to support development and testing in Phase I and Phase II.

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

Primary Technology Taxonomy:

- Level 1: TX15 Flight Vehicle Systems
- Level 2: TX15.X Other Flight Vehicle Systems

Desired Deliverables of Phase I:

The deliverables sought at the end of phase I are:

- A combination of analysis, design, and/or prototyping work that gives confidence that the requirements for Phase II can be completed.
- An identified target market segment for the product
- One or more identified launch customers with letters of commitment.
- Top level requirements that map to one or more potential launch customers' needs and relevant Federal Aviation Administration, Department of Defense, or industry requirements.
- A draft test plan for phase II to measure the weight and end to end efficiency the prototype system.
- Evidence that specific facilities have been secured to support development and testing in Phase II.
- A list of applicable Federal Aviation Administration or Department of Defense requirements for the product
- A list of other applicable standards for the pr describes the expected operation of the system during the flight segments: takeoff, climb, cruise, decent, landing.

Desired Deliverables of Phase II:

The deliverables sought at the end of phase II are:

- A fully integrated fuel to electric conversion system prototype with lab test results measuring the total system weight and end to end conversion efficiency.
- A report should be completed documenting the target market, one or more specific customer requirements sets, and the remaining steps to advance from the prototype to the product.
- Letters of commitment for funding or co-funding follow on work

Desired Deliverable Types of Phase II:

- Analysis
- Test Results
- Hardware
- Software
- Prototype

State of the Art:

- Modern aircraft and unmanned aerial systems employ diverse onboard power generation approaches tailored to their operational requirements. Federal Aviation Administration Part 25 transport category aircraft primarily utilize integrated auxiliary power units (APUs) and engine-driven generators. Contemporary wide-body aircraft typically feature 90-250 kVA generators per engine, with APUs providing 90-150 kVA for ground operations and emergency backup. The trend toward more-electric aircraft architectures has driven adoption of variable-frequency starter-generators and increased electrical loads exceeding 1 MW for systems like electro-hydraulic actuators and environmental control systems.
- Federal Aviation Administration Part 23 aircraft, encompassing small airplanes with 19 or fewer seats and maximum certificated takeoff weight of 19,000 pounds or less, predominantly employ engine-driven alternators (28V DC systems at 60-100A for piston aircraft) or generators (115V AC, 400 Hz at 5-20 kVA for turboprops). Many general aviation aircraft rely solely on battery power with alternator charging, though some turboprop designs incorporate small APUs or auxiliary generators for enhanced electrical redundancy.

- Federal Aviation Administration Part 107 small, unmanned aircraft systems (sUAS), limited to less than 55 pounds, almost universally depend on battery-electric propulsion without onboard generation capability. Lithium-polymer and lithium-ion batteries dominate, providing 10-45 minute endurance for commercial multirotor platforms. Emerging fuel cell and hybrid-electric concepts are extending flight times beyond 2 hours for specialized applications.
- Department of Defense Group 1 drones (0-20 pounds, <1,200 feet AGL) [3] similarly utilize battery-only architectures, while Group 2 systems (21-55 pounds) [3] predominantly employ batteries, though some tactical platforms integrate small internal combustion engine-generators or heavy fuel engines with integrated alternators producing 50-500W for extended missions requiring 2-8+ hour endurance.
- Current research emphasizes high-power-density generators, distributed electric propulsion, hybrid-electric architectures combining batteries with turbogenerators or fuel cells, and advanced thermal management for increasingly electrified platforms across all categories.

Critical Gaps:

The key gap being addressed is for integrated systems which use common aviation fuels and output regulated electrical power with high efficiency and light weight in an aircraft grade system. The specific gaps vary based on whether the fuel to electric conversion implemented is using

- Combustion-based cycles combined with a generator
- electrochemical conversion
- a system which combines combustion cycles and electrochemical conversion
- a novel approach.

Almost all systems will also require power conditioning equipment in order to create a stable electrical power bus with a regulated voltage level.

There is a gap at the integration level for systems in the aircraft categories called out in this subtopic. Few if any integrated, aircraft grade systems are available on the market in the size class called out in this solicitation. Among the few that may be available, they are not specifically optimized for maximum efficiency performance to extend range and loiter times of drones and aircraft.

Shortfalls And Decadal Surveys:

This subtopic is for aeronautics and is not linked to the Civil Space Shortfalls or Decadal Surveys.

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

References:

1. Federal Aviation Administration Small Unmanned Aircraft Definition: 14 CFR § 107.3, https://www.ecfr.gov/current/title-14/chapter-I/subchapter-F/part-107/subpart-A/section-107.3
2. Definition of Federal Aviation Administration Part 23 aircraft weight and capability: 14 CFR § 23.2005, https://www.ecfr.gov/current/title-14/chapter-I/subchapter-C/part-23/subpart-A/section-23.2005
3. Definition of Department of Defense drone size categories: Congressional Research Service, "U.S. Military Unmanned Aerial Systems," IF12797, https://www.congress.gov/crs-product/IF12797
4. RTCA DO-160G, "Environmental Conditions and Test Procedures for Airborne Equipment" 14. https://www.rtca.org/do-160/
5. MIL-STD-704F, "Aircraft Electric Power Characteristics", https://ieee.li/pdf/standards-handbooks/MIL-STD-704F.pdf

6. Advanced Research Projects Energy (ARPA-E) Range Extenders for Electric Aviation with Low Carbon and High Efficiency (REEACH) Program: https://arpa-e.energy.gov/programs-and-initiatives/view-all-programs/reeach
7. Advanced Research Projects Energy (ARPA-E) Seeding Critical Advances for Leading Energy technologies with Untapped Potential (SCALEUP) Program: https://arpa-e.energy.gov/programs-and-initiatives/SCALEUP-program
8. AFWERX Shift to hybrid electric: https://airforcetechconnect.org/news/afwerx-says-agility-prime-evtols-lack-range-shifts-hybrid

GO – Space Transportation (GO)

GO.2.S26B: Development of cost-effective 3D printing of SOA Hall thruster magnetic circuits (SBIR)

Lead Center: GRC

Participating Center(s): JPL, MSFC

Subtopic Problem Statement/Description:

Electric propulsion (EP) for space applications has demonstrated tremendous benefit to a variety of NASA, military, and commercial missions. Critical NASA electric propulsion needs have been identified in the scope areas detailed below. Proposals outside the described scope shall not be considered. Proposers are expected to show an understanding of the current state of the art (SOA) and quantitatively (not just qualitatively) describe anticipated improvements over relevant SOA materials, processes, and technologies that substantiate NASA investment.

To shape the magnetic fields necessary to achieve nominal operation, Hall-effect thrusters utilize a magnetic circuit that also forms the thruster structure. The magnetic circuit components direct magnetic flux (typically produced by electromagnetic coils) and may experience operational temperatures in excess of 500 °C due to heating from the plasma discharge (proximity to plasma-wetted surfaces) and coil self-heating. Both low-carbon magnetic iron and cobalt-iron (Co-Fe) soft ferromagnetic alloys have been traditionally used for this application; low-carbon magnetic iron is typically cheaper with larger billet size availability, whereas Co-Fe soft ferromagnetic alloys are attractive due to high magnetic saturation and Curie temperature properties.

The current SOA is to manufacture magnetic circuit components from billet/plate/rod stock material. NASA is seeking proposals to develop additively manufactured (AM) Hall thruster magnetic circuits that can achieve similar magnetic circuit topologies and structural integrity as magnetic circuits manufactured using traditional processes for operational thruster environments.

This solicitation seeks the development and demonstration of the capability to additively manufacture (i.e, 3D print) a 5kW class Hall thruster magnetic circuit that has the magnetic, structural, and thermal performance as SOA traditional (wrought) manufactured magnetic circuit.

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

Primary Technology Taxonomy:

- Level 1: TX01 Propulsion Systems
- Level 2: TX01.2 Electric Space Propulsion

- Level 3: TX01.2.2 Electrostatic Propulsion

Desired Deliverables of Phase I:

1. Hold a virtual kickoff meeting with the NASA Technical Monitor and potential stakeholders within the first month of the period of performance.
2. Demonstrate feasibility to additively manufacture a partial magnetic circuit (backpole, inner core, and outer core) of a 5 kW class Hall thruster.
3. Produce material samples that can be utilized for independent verification of AM material properties.
4. Provide cost and duration for AM component production and final machining of a 5 kW class Hall thruster entire magnetic circuit.

Deliver a final report containing test data characterizing key material properties (magnetic and structural) as well as an assessment of AM size scalability for future magnetic circuit production.

Desired Deliverables of Phase II:

1. Hold a virtual kickoff meeting with the NASA Technical Monitor and potential stakeholders within the first month of the period of performance.
2. Hold quarterly virtual meetings with the NASA Technical Monitor and potential stakeholders to update on progress of Phase II effort.
3. Deliver an AM 5 kW class Hall thruster magnetic circuit that can be integrated (by NASA) with remaining thruster components for hot-fire tests of the thruster.
4. Provide cost and duration for AM component production and final machining of a 5 kW class Hall thruster magnetic circuit.
5. Deliver quarterly progress and final reports.

Desired Deliverable Types of Phase II:

- Test Results
- Hardware
- Prototype

State of the Art:

State-of-the-Art magnetic circuit materials used for Hall-effect thrusters are typically in two families: low-carbon magnetic iron or cobalt-iron (Co-Fe) soft ferromagnetic alloys (e.g., Hiperco®). While Co-Fe alloys are frequently preferred because of their magnetic properties, their available billet sizes and traditional manufacturing process do not readily accommodate low-cost mass production of such magnetic circuit assemblies.

Critical Gaps:

In practice, the SOA (traditional) manufacturing techniques of Hall thruster magnetic circuit components result in significant material waste and require hundreds of traditional machining hours. The present SOA Hall thruster high performance magnetic circuit manufacturing approach could be significantly improved with AM to reduce cost and duration of manufacturing a Hall thruster magnetic circuit.

Shortfalls And Decadal Surveys:

2026 Civil Space Shortfalls, Released January 12, 2026

Transport and maneuver uncrewed spacecraft for missions in cis-lunar and deep space:

1. Develop novel power and propulsion technologies for rapid and efficient in-space transportation across the solar system.
2. Provide magnetically shielded, human-rated electric propulsion.
3. Transfer electric propulsion propellant between assets in space.

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

References:

1. ASTM Standard A801-14, "Standard Specification for Wrought Iron-Cobalt High Magnetic Saturation Alloys (UNS R30005 and K92650)."
2. ASTM Standard A848-17, "Standard Specification for Low-Carbon Magnetic Iron."
3. S. Firdosy, et al., "Processing-Microstructure-Property Relationships in a Laser-Deposited Fe-Co-V Alloy," Advanced Engineering Materials Journal, 2022, 24, 2100931.
4. D.F. Susan, et al., "Equal Channel Angular Extrusion for Bulk Processing of Fe-Co-2V Soft Magnetic Alloys, Part I: Processing and Mechanical Properties," Journal of Materials Research, 33.15 (2018): 2168-2175.
5. A.B. Kustas, et al., "Equal Channel Angular Extrusion for Bulk Processing of Fe-Co-2V Soft Magnetic Alloys, Part II: Texture Analysis and Magnetic Properties," Journal of Materials Research, 33.15 (2018): 2176-2188.
6. Z. Turgut, et al., "High Strength Bulk Fe-Co Alloys Produced by Powder Metallurgy," Journal of Applied Physics, 103.7 (2008): 07E724.
7. M.S. Masteller, J.W. Bowman, and L. Li, "High Temperature Aging Behavior of High Strength 49% Co-1.9% V-0.3% Nb-Fe Soft Magnetic Alloy," IEEE Transactions on Magnetics, 32.5 1996): 4839-4841.
8. Decadal surveys for each of the SMD divisions, https://science.nasa.gov/about-us/science-strategy/decadal-surveys
9. 2020 NASA Technology Taxonomy, https://www.nasa.gov/offices/oct/taxonomy/index.html

GO.3.S26B: Advanced Momentum Management and Propellant less Control Technologies for Solar Sail Spacecraft (SBIR)

Lead Center: MSFC

Subtopic Problem Statement/Description:

Solar sail propulsion leverages solar radiation pressure (SRP) acting on large, lightweight reflective membranes to provide continuous, propellant-less thrust. This capability enables long-duration missions, non-Keplerian orbits, solar polar trajectories, and other mission architectures aligned with NASA's heliophysics, astrophysics, and deep-space exploration goals.

However, the same continuous SRP forces that enable propulsion also generate persistent disturbance torques. Small offsets between the sail's center of pressure and center of mass, combined with structural flexibility and environmental disturbances, result in steady angular momentum accumulation. Over time, this can lead to reaction wheel saturation, degraded pointing performance, and increased mission risk.

Conventional spacecraft use propellant-based thrusters to unload stored angular momentum. For solar sail systems, reliance on consumables diminishes mission lifetime, increases mass, and erodes the fundamental advantages of propellant-less propulsion. As sail architectures scale to larger areas with lighter, more flexible structures, the magnitude and complexity of momentum management challenges increase.

There is a critical need for flight-viable, propellant-less momentum management methods that can be implemented through hardware, structural features, or integrated sail mechanisms to support sustained solar sail operations.

NASA seeks innovative, propellant-less momentum management **methods** that enable reliable attitude control and angular momentum regulation for solar sail spacecraft. Of particular interest are methods that modify the shape of the sail. These methods could be static (e.g, a fixed "fin" on a single boom), or dynamic (e.g., the capability to actively deform the booms or membrane).

The following definitions are to be used for this solicitation. The angle between the normal axis of the solar sail and the sun is defined as the "Sun Incidence Angle" or SIA.

The following specific concepts are suggested:

1. A fixed fin on one boom (out of a presumed four sail booms) to be used specifically for momentum management about the normal axis of the sail. This method will only work at non-zero SIAs (Sun Incidence Angles)
2. A method of deforming or articulating the booms to change the shape of the sail.
3. For the quadrant sail design (four roughly triangular quadrants segmented by booms), the capability to gimbal the individual panels.

The proposals will be evaluated based on which best can trim the SRP torque to manage momentum. For reference, the follow maximum torques should be addressed:

Torque Results (No Center of Mass offset)

- Max Moment in X Direction: 0.0018533 Nm
- Max Moment in Y Direction: 0.0018571 Nm
- Max Moment in Z Direction: 6.7941e-05 Nm
- Max Moment in Sail Plan: 0.0026236 Nm

The mass of any additional system added to manage the momentum will ideally be limited to less than 5 kg. Masses up to 10 kg may be considered with sufficient justification.

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

Primary Technology Taxonomy:

- Level 1: TX01 Propulsion Systems
- Level 2: TX01.4 Advanced Propulsion
- Level 3: TX01.4.1 Solar Sails

Desired Deliverables of Phase I:

1. Phase I Final Report
2. Concept Definition and Design Package

3. Analytical Modeling and Simulation Results
4. Feasibility Demonstration
5. Risk and Scalability Assessment
6. Phase II Development Plan

All deliverables should include comprehensive documentation of the design approach, testing methodology, and performance results. Phase I proposals should delineate the scope and benefit of proposed products that could be realized in Phase II and what further development would be necessary beyond Phase II.

Desired Deliverables of Phase II:

1. Detailed Design Package
2. Engineering Development Unit (EDU) or Prototype System
3. Updated Modeling
4. Infusion and Transition Plan
5. Final Report

All deliverables should include detailed analysis showing how the technology meets the Technology Readiness Level (TRL). Phase II deliverables should also include/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
- Digital Models

State of the Art:

Solar sail propulsion has progressed from theoretical concept to demonstrated flight capability. Missions such as ACS-3, along with non-NASA demonstrations such as LightSail 2, have validated solar radiation pressure (SRP) as a viable means of propellant-less propulsion.

The current state of the art in solar sail attitude control relies primarily on combinations of technologies.

Closing this gap is critical to enabling the next generation of solar sail missions. Without advancements in propellant-less momentum management methods, future missions risk reduced pointing stability, shortened operational lifetimes, and limited scalability.

Critical Gaps:

ACMC2 (Active sail shaping) - Articulating vanes; quadrant twisting/pinwhelling

ACMC4 (Alternative control and momentum management) - Including diffractive sails, distal micro-ep, guy-wires, and other solutions

Shortfalls And Decadal Surveys:

700: Solar Sails for Propellant-less Propulsion

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

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ENABLE – Foundational Capabilities (ENABLE)

ENABLE.1.S26B: Laser Welding System and Integrated Real-Time Nondestructive Inspection (SBIR)

Lead Center: LaRC

Participating Center(s): MSFC, GSFC

Subtopic Problem Statement/Description:

Develop an innovative, laser welding system with integrated real-time nondestructive inspection capability for performing high-quality welds on the lunar surface. The system shall enable autonomous or semi-autonomous joining of metallic structures for lunar habitat construction, infrastructure assembly, equipment fabrication, and repair operations in support of NASA's Artemis program.

Background:

NASA's Artemis program is establishing sustained human presence on the Moon, requiring robust capabilities for habitat construction, infrastructure development, and equipment repair directly on the lunar surface. The ability to weld and join metallic structures in the lunar environment is critical for assembling habitats, constructing power systems, fabricating equipment, repairing rovers and tools, and building infrastructure.

Laser welding offers distinct advantages for lunar applications including precision, no consumable materials requirement, compatibility with automation, high-quality repeatable joints, and tolerance for dusty environments. Real-time nondestructive inspection is essential to verify weld quality without requiring extensive astronaut inspection time or impractical destructive testing on the lunar surface.

Lunar Environment Challenges:

The lunar surface presents extreme operational challenges. The environment includes high vacuum conditions, temperature cycling between +127°C in sunlight and -173°C in shadow, intense solar and cosmic radiation, and electrostatic charging. The lunar day/night cycle spans approximately 14 Earth days each, requiring systems to survive and operate through extended darkness and extreme cold.

Lunar dust presents severe challenges due to its extremely abrasive and adhesive properties. The dust adheres to and contaminates optical surfaces, interferes with mechanical systems, and complicates thermal control. Combined with 1/6 Earth gravity affecting molten metal behavior and convection patterns, these factors create a uniquely challenging welding environment.

Operational constraints include limited power availability from solar or nuclear sources, strict mass and volume restrictions for transported equipment, need for long-term reliability with minimal maintenance, and limited real-time communication with Earth due to 2.6 second signal delays. Systems must operate autonomously or be compatible with astronaut operation while wearing bulky Extravehicular Activity (EVA) suits.

Technical Scope:

This SBIR subtopic seeks innovative solutions for a laser welding system with integrated nondestructive inspection specifically designed for lunar surface deployment. The system must address (1) thermal management without atmospheric cooling, (2) dust contamination of optical components, (3) operation across extreme temperature ranges, and (4) integration with lunar surface mobility systems or EVA operations.

The laser source should be in the 500W to 5kW power range with consideration for limited power budgets and efficiency optimization. Welding process control must adapt to lunar temperature extremes and provide real-time monitoring of melt pool characteristics in reduced gravity. The system should include seam tracking and accommodate joint preparation tolerances.

Nondestructive inspection technologies may include but not limited to: optical coherence tomography, laser ultrasonics that requires no couplant in vacuum, phased array ultrasonics with dry coupling, thermographic imaging, x-ray imaging, acoustic emission monitoring, visual inspection with machine vision, or artificial intelligence-based defect detection with onboard processing capability.

The system should integrate effectively with lunar surface operations through rover mounting, tripod deployment, or handheld EVA-compatible configurations. Dust mitigation strategies should include protective covers, purging systems if available, or electrostatic repulsion. Thermal management must rely on radiators, thermal storage, or operational timing strategies. Target system mass is under 50 kilograms for primary components, with volume compatible with lunar lander payload constraints.

Materials of interest include aluminum alloys used in spacecraft structures, stainless steels, titanium alloys, and dissimilar metal combinations. Joint configurations include butt, lap, corner, and T-joints with typical thickness range of 1 to 10 millimeters. Future consideration should be given to metals derived from in-situ and or recycled materials.

The system should provide semi-autonomous operation with astronaut supervision, support pre-programmed welding sequences, enable remote operation from lunar habitat or Earth with delay tolerance, provide automated quality assessment and capable of recording data.

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: TX12.4.5 Nondestructive Evaluation and Sensors

Desired Deliverables of Phase I:

Conduct detailed analysis of lunar surface operational scenarios including (1) habitat assembly, (2) equipment fabrication, and (3) repair operations. Define mission use cases and establish system-level requirements for lunar deployment. Analyze power, mass, and volume constraints from lunar lander capabilities.

Evaluate laser welding approaches suitable for lunar surface conditions and assess nondestructive inspection technologies that function reliably in vacuum and temperature extremes. Compare deployment concepts such as rover-mounted, portable, or fixed installation configurations. Select promising technology combinations and develop dust mitigation and thermal management strategies.

Demonstrate feasibility through proof-of-concept experiments simulating lunar conditions. Conduct welding demonstrations in vacuum chambers at temperature extremes. Test in reduced gravity simulation or analyze expected behavior in 1/6 gravity. Validate nondestructive inspection capability in lunar-relevant conditions and assess dust contamination effects on critical components. Characterize weld quality on spacecraft-grade materials.

Develop system-level design concept for lunar deployment with mass, power, and volume estimates for lunar lander compatibility. Design thermal management approach and identify space-qualified or space-qualifiable components. Assess technology readiness level advancement pathway to flight readiness.

Deliverables include (1) final technical report documenting feasibility study results, (2) preliminary system design with lunar-specific requirements addressed, (3) experimental data demonstrating key capabilities in lunar-simulated conditions, (4) dust mitigation and thermal management strategy, mass/power/volume estimates with margin analysis, and (5) Phase II development plan with lunar qualification pathway.

Desired Deliverables of Phase II:

Phase II shall develop, build, and test a lunar-qualified prototype laser welding system with integrated nondestructive inspection capability, advancing technology readiness level from 3-4 to 5-6.

Complete engineering design for lunar surface operations including selection of space-qualifiable components rated for the lunar environment. Design dust protection systems for optical and mechanical components, develop thermal management system using passive radiators or thermal storage, and design power management for solar or battery operation. Develop control algorithms with autonomous operation capability and design EVA-compatible or robotic interface.

Build engineering prototype system integrating laser source, optics, nondestructive inspection sensors, and thermal management. Fabricate deployment fixture or rover mounting interface, implement dust mitigation features, and develop control system with human-machine interface.

Conduct comprehensive lunar environment testing and validation. Operate the system in high-vacuum chambers at 10^-6 torr or better, demonstrating welding and inspection in vacuum while validating thermal management without convective cooling. Test operation across lunar temperature extremes from +127°C to -173°C, demonstrate survival through thermal cycles, and validate thermal management strategy.

Expose the system to lunar regolith simulant such as JSC-1A to test dust mitigation effectiveness and assess performance degradation and cleaning procedures. Analyze weld pool behavior in 1/6 gravity through modeling, simulation, or parabolic flight testing if feasible.

Conduct material testing by welding spacecraft aluminum alloys, stainless steels, titanium, and dissimilar metal combinations. Test on lunar regolith simulant-derived metals if available. Validate welds through destructive testing including tensile tests, bend tests, and metallographic analysis.

Validate nondestructive inspection by demonstrating defect detection accuracy and reliability. Compare inspection results to destructive test findings, establish detection thresholds for critical defects, and test across temperature range and after dust exposure.

Demonstrate operational scenarios simulating realistic lunar construction and repair tasks. Demonstrate autonomous operation sequences and test with EVA-suited operators or robotic manipulators. Validate simplified controls and status feedback while assessing reliability and failure modes.

Define integration with lunar lander payload systems and develop operational procedures for astronaut use. Create maintenance and troubleshooting procedures, assess compatibility with Artemis mission architecture, and identify path to flight qualification in Phase III.

Deliverables include (1) lunar-qualified engineering prototype system, (2) comprehensive test reports from lunar environment simulation testing, (3) weld quality database for relevant materials and conditions, (4) nondestructive inspection validation data with accuracy metrics, (5) thermal/dust/vacuum performance characterization, (6) system operations and maintenance manual, (7) integration plan for Artemis missions, (8) final technical report, and (9) commercialization plan.

Desired Deliverable Types of Phase II:

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

State of the Art:

Currently, there are several systems that have been designed for in-space laser welding. There are also several systems that have been developed for nondestructive evaluation in space.

NASA currently does not have a laser-based welding system that includes real-time nondestructive inspection capability for terrestrial or in-space applications.

Critical Gaps:

- In-Situ Resource Utilization (ISRU) technology gap assessments.
- Lunar surface systems technology needs.
- Artemis capability gap analyses.
- Manufacturing and repair technology assessments.
- **Environmental Testing Data:** Limited experimental data on welding behavior in actual lunar conditions (1/6 gravity, vacuum, thermal extremes combined).
- **Dust Mitigation:** Lack of proven long-duration dust protection for optical systems in lunar regolith environment.
- **Thermal Management:** No demonstrated thermal control solutions for high-power systems operating through lunar day/night cycles.
- **Nondestructive Inspection in Extreme Conditions:** Limited validation of NDI techniques across -173°C to +127°C temperature range in vacuum.
- **Autonomous Operation:** Gap between current teleoperation capabilities and required autonomous decision-making for welding quality.
- **Materials Data:** Limited understanding of weld behavior for lunar-derived metals or dissimilar materials in lunar conditions.
- **Long-Duration Reliability:** No demonstration of welding systems surviving multiple lunar day/night cycles (50+ cycles).

- **Integration:** Lack of demonstrated integration with lunar mobility systems or EVA operations.
- **Space Environment and Launch Ruggedization:** Radiation, vibration, and vacuum sensitivity of electronics, doped laser fibers, and precision optics.

Shortfalls And Decadal Surveys:

- Support construction and manufacturing operations on the lunar surface using both Earth-delivered and lunar-derived metals.
- Operate with minimal power consumption while managing extreme thermal environments and lunar dust contamination.
- Function autonomously or semi-autonomously as part of human-robot teams with inspection and quality verification capabilities.
- Enable repair and maintenance of surface assets to support extended duration operations.
- Operate reliably over high-latency communication networks with Earth-independent decision-making for weld quality assessment.
- Support EVA operations and integrate with surface mobility systems for infrastructure construction.
- Contribute to domestic supply chain resilience by enabling in-situ fabrication and repair rather than relying solely on Earth-supplied components.
- Construct structures on the lunar surface through advanced manufacturing techniques. Reference ESDMD #0505 for specific details.
- Implement space-based manufacturing techniques for in-situ repairs and replacement of hardware components. Reference ESDMD #0502 for specific details.
- 1486: In-Space and On-Surface NDE and Qualification of Components for Manufacturing, Assembly, and Construction.
- 1490: Additive Manufacturing for New and High-Performance Materials.
- 1537: Free-Flying Systems for Robotic Inspection, Data Collection, and Servicing of In-Space Assets.
- 1487: In-Space and On-Surface Welding Technologies for Manufacturing, Assembly, and Construction.

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

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ENABLE.2.S26B: High Performance Onboard Computing (SBIR)

Lead Center: JPL

Participating Center(s): JSC, GSFC

Subtopic Problem Statement/Description:

NASA is seeking avionics technologies to broadly enable increased onboard compute capability for future exploration and science missions. As future missions require increasingly complex distant operations, there will be an increased need for autonomy, as well as onboard data reduction where sensor bandwidth exceeds downlink bandwidth. This subtopic seeks to develop and mature technologies to provide increased onboard processing performance, AI/ML capabilities, input/output (I/O) bandwidth, and data storage.

Technologies of interest include, but are not limited to, Sensor Open Systems Architecture (SOSA) Space compatible Plug-In Cards (PICs) and Power Supply Cards (PSCs), coprocessors that augment general purpose processing or provide mission-specific capabilities, and software tools and libraries to improve performance of space computing applications while simplifying their development.

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

Primary Technology Taxonomy:

- Level 1: TX02 Flight Computing and Avionics

Desired Deliverables of Phase I:

Phase I Deliverables:

For software and hardware elements, a solid conceptual design that includes plan for full-scale prototyping with simulations, testing, and bench-marking results to justify prototyping approach. Also, include detailed specifications for intended Phase II deliverables.

Desired Deliverables of Phase II:

Phase II Deliverables:

For software and hardware elements, a prototype that demonstrates sufficient performance and capability and is ready for future development and commercialization.

Desired Deliverables of Phase II:

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

State of the Art:

In order to meet the foreseeable needs of future NASA missions, it is apparent that an evolution in general-purpose computing is required from the current state of the art used in space applications. A 100X increase in computational capability for the same power utilization of current space-based processors is envisioned for the next generation of computation capability. Potential use cases include crewed exploration missions in cislunar and Mars environments, robotic science missions destined to outer planets, and science observatories in Earth orbit. The qualities that NASA needs that might not naturally be provided by commercially available solutions are:

- Radiation tolerance
- Fault tolerance
- Mechanical robustness
- Energy management combined with scalable power efficiency
- Performance - Ability to process a large amount of sensor data in real time to make safe decisions for next-generation autonomous systems
- Scalability/Versatility - Existing accelerator devices are often designed for specific workloads, such as machine learning or image processing. Next-generation autonomous systems need to be used for a variety of different workloads, such as perception, planning, and control. These needs will be mission specific.

Critical Gaps:

Commercial coprocessor/accelerator devices and design IP are continuously being developed to support heterogeneous computing systems for use in self-driving cars, data centers, and modern smartphones. State-of-the-art heterogeneous computing systems use field programmable gate arrays (FPGAs), graphics processing units (GPUs), tensor processing units (TPUs), and neuromorphic processors, and Processing in Memory (PIM) as accelerators to offload specialized tasks like machine learning or image processing. Accelerator programming models include a variety of different programming models, such as OpenCL, Compute Unified Device Architecture (CUDA), and TensorFlow. These programming models make it easier to develop and deploy applications for accelerators in heterogeneous computing systems. General programming models for PIM systems are yet to be developed, and are specific to the implementation. Preferred processor interface is Compute Express Link (CXL) or, alternatively, Peripheral Component Interconnect Express (PCIe). Critical technology gaps include:

1. Performance - Existing space-grade coprocessor/accelerator devices are not yet powerful enough to meet the performance requirements of NASA's next-generation systems for future missions. Next-generation autonomous systems need to be able to process a large amount of sensor data in real time to make safe decisions.
2. Energy Efficiency - Existing accelerator devices are not yet efficient enough to meet NASA's power and thermal constraints. Next-generation systems need to be able to operate under solar-array-with-a-battery power constraints (no radioisotope thermoelectric generators (RTGs)).
3. Scalability/Versatility - Existing accelerator devices are often designed for specific workloads, such as machine learning or image processing. Next-generation autonomous systems need to be used for a variety of different workloads, such as perception, planning, and control. These needs will be mission specific.

4. Resilience - NASA systems need to self-heal due to harsh environmental conditions. Commercial accelerator devices can be leveraged, but a redundant system design with health monitoring is needed.

Addressing critical gaps for RISC-V architectures is essential to unlock the full potential of these architectures in the specified domains, enabling their widespread adoption in various applications, including those relevant to NASA's needs. Example gaps in RISC-V software tools are:

1. Lack of Optimization: A critical gap lies in the absence of optimized software and libraries for RISC-V architectures in these domains. Existing software is primarily tailored for x86 and ARM, resulting in suboptimal performance on RISC-V platforms.
2. Limited Ecosystem: RISC-V lacks a mature software ecosystem compared to x86 and ARM. This includes development tools, libraries, and a robust community of developers, which is crucial for rapid software development and adoption.
3. GPU Support: The absence of comprehensive GPU support for RISC-V hinders the acceleration of graphics and computation-intensive workloads, making RISC-V less attractive for applications that rely on GPU power.
4. Compatibility: Many existing applications and systems are not compatible with RISC-V, making it challenging for organizations to transition to RISC-V platforms without significant software redevelopment efforts.
5. Community Engagement: Building a vibrant open-source community around RISC-V software is essential but currently lacking. This gap affects collaborative development and support for RISC-V software projects.

Shortfalls And Decadal Surveys:

2026 Shortfalls and Need Statements:

Provide on-board advanced computing capabilities for space operations.

- Provide radiation-tolerant onboard computing operations to support autonomy, navigation, and other high-performance use cases in relevant environments. Reference ESDMD #0202 for specific details.
- Develop space-based computing technology needed for autonomous on-board operations.
- Distribute avionics systems and functions within spacecraft or surface systems.
- Provide advanced computing needed for multi-spacecraft responsive space operations.

Develop infrastructure and capabilities for assets to operate for extended duration in the lunar environment.

- Perform high-performance computing in extreme temperature, high radiation, and dusty environments. Reference ESDMD #0201 (lunar) for specific details.

Develop infrastructure and capabilities for assets to operate for extended duration in the Martian environment.

- Perform high-performance computing in extreme temperature, high radiation, and dusty environments. Reference ESDMD #0201 (Mars) for specific details.

NASA Moon to Mars Architecture Definition Document Architecture Driven Technology Gap Appendix.

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

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2. Sensor Open Systems Architecture (SOSA) https://www.opengroup.org/sosa
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EXPAND – In-Space Infrastructure and Discovery (EXPAND)

EXPAND.2.S26B: Orbital Debris Tracking (SBIR)

Lead Center: ARC

Participating Center(s): GSFC

Subtopic Problem Statement/Description:

The rise in spacecraft launches is causing congestion in low Earth orbit (LEO) and higher orbits.

The U.S. National Space Policy [1] has focused on orbital debris prevention since 1988, with its 2020 update stating that the United States shall (among others):

- Develop, maintain, and use Space Situational Awareness information (...)
- Limit the creation of new debris, (…)
- Pursue research and development of technologies and techniques to characterize and to mitigate risks from orbital debris , reduce hazards, (...);
- Evaluate and pursue,(...), active debris removal as a potential long-term approach to ensure the safety of flight in key orbital regimes;
- Continue to foster the development of best practices to prevent on-orbit collisions.

Space situational awareness refers to the knowledge and characterization of space objects and their operational environment to support safe, stable, and sustainable space activities. Space traffic coordination refers to planning, coordinating, and synchronizing on-orbit activities to enhance the safety, stability, and sustainability of operations in space. NASA views orbital debris management as the ability to mitigate the creation of new debris through design and operations, to implement operational procedures for spacecraft to avoid collisions with debris, to protect missions from damage due to strikes of orbital debris, to limit reentry casualty risks, to characterize the populations of debris that are not currently tracked, and to clean up debris through various remediation methods [2]. Space weather awareness regards obtaining knowledge of and predicting the varying natural environment in response to changing solar conditions.

The purpose of this sub-topic is to develop a (primarily) ground-based tracking solution that can maintain custody of a piece of small debris from the time it rises above the horizon to the time it descends below the horizon. This solution is primarily intended to support laser removal of orbital debris and to provide near-term improvements to existing space situational awareness (SSA) capabilities.

The U.S. economy depends on space for critical infrastructure, from communications and financial exchanges to national security, transportation, and climate monitoring. Orbital debris such as abandoned vehicle stages, non-functional satellites, and fragments of launched materials impedes our ability to use space by increasing the cost of space operations. More than 23,000 pieces of orbital debris are larger than a softball (about 10 centimeters) and tracked by the Department of Defense's global Space Surveillance Network (SSN) sensors. Because the debris is tracked, spacecraft operators can predict conjunctions with this debris and maneuver to avoid potential collisions. However, less than 1 percent of debris objects that could cause damage to a spacecraft are currently tracked and can damage satellites and crewed spacecraft without warning. In the space environment, there are approximately half a million pieces of debris larger than the size of a pea (1 centimeter) and approximately 100 million pieces of debris larger than the size of a grain of sand (1 millimeter). Spacecraft cannot feasibly be shielded from debris that are larger than a few millimeters. Thus, the only feasible approaches to protect spacecraft from this risk are to track them well enough to enable spacecraft to maneuver to avoid them or to remove them altogether [3,4]. Both approaches require the ability to maintain custody of small debris at least as they pass overhead, ideally for multiple revisits.

NASA seeks innovative, (primarily) ground-based technologies that could be used to provide the following level of custody:

Addresses debris as small as 1 centimeter, in orbits from 350 to 800 kilometers altitude or higher.

- Acquires custody of the debris as it rises above the horizon, possibly by being tipped with an externally provided orbital solution.
- Maintains custody of the debris at least until it is directly overhead, but ideally also until it descends below the horizon. In the best case, orbit determination is sufficient to allow for re-acquisition by sensors in other locations.

Relevant technologies for this topic include, but are not limited to:

- Light Detection and Ranging (LiDAR) systems that could maintain custody of such debris.
- Adaptive optics capabilities for observing and/or delivering pre-compensated beams to fast-moving objects in LEO.
- Phased-array radar systems that could detect, rapidly perform orbit determination, and maintain custody of such debris.
- Passive optical or infra-red IR systems if they can maintain custody of such debris in darkness.

Space-based and air-based sensor architectures are acceptable, if they can provide orbit determination for a significant fraction of objects in at least one orbital regime (Low Earth Orbit, Medium Earth Orbit, Geostationary Orbit, or lunar orbit).

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

Primary Technology Taxonomy:

- Level 1: TX05 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems
- Level 2: TX05.X Other Communications, Navigation, and Orbital Debris Tracking and Characterization Systems
- Level 3: TX05.6.1 Orbital Debris Tracking

Desired Deliverables of Phase I:

At the end of Phase I, the performer should provide (1) a preliminary analysis of the trades and requirements that would be placed on the technology, (2) an early design or prototype (of the system or a subsystem) that is analyzed to show that it meets a reasonable set of requirements, and (3) an implementation plan for maturation of the technology in Phase II, including technical risks and mitigations. If testing of the technology requires access to equipment or facilities beyond those owned by the performer, the Phase II plan should include a letter of support from a entity that can provide access to such facilities.

Desired Deliverables of Phase II:

At the end of Phase II, a prototype of the technology (at system or subsystem level) should be completed and is capable of being tested in a laboratory or relevant environment. Ideally, the performer will also be able to test the prototype with their own laboratory equipment. A final report, including relevant analytical and test data should be delivered to NASA. Likewise, the prototype should be made available to NASA for further testing. The final report should include a proposal for demonstration activity scalable to operational needs.

Desired Deliverable Types of Phase II:

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

State of the Art:

NASA has identified the following as the likely state of the art for the relevant capabilities.

LIDAR Systems:

- Researchers from Electro Optic Systems (EOS) working at the Space Environment Research Centre (SERC) in Australia demonstrated laser ranging to debris smaller than 10 centimeters debris during project Razor View in 2014.
- In 2024, the French national aerospace research center (ONERA) demonstrated a bidirectional laser link pre-compensated by adaptive optics between its FEELINGS ground station (FEEder LINks Ground Station) the TELecoms on all Earth Orbits (TELEO) payload in geostationary orbit (GEO).
- Fugate (2003) demonstrated pre-compensation of beams to an asset in LEO. Solar reflections and natural guide stars were used to deliver a beam that was pre-compensated for tip/tilt and turbulence to a satellite at 800 km altitude—no laser guide stars or Rayleigh beacons were used.

Phased Array Radar:

- Recent advancements have significantly reduced the costs of phased array radars in frequency bands that are potentially attractive for tracking centimeter-size debris. For example, Leolabs has developed a low-cost phased-array S-band radar. Similarly, SpaceX Starlink user terminals are phased-array in the Ka band and affordable enough for end users to purchase.

Critical Gaps:

Challenges associated with maintaining custody of 1 centimeter debris:

- This debris is not currently tracked. To maintain custody of the debris, it must first be discovered and then have its orbit rapidly determined.
- The uncertainties are high in tracking objects and propagating orbits. The uncertainty tends to grow with time due to the compounding effects of atmospheric drag, space weather, and other nongravitational perturbations that may be difficult to predict.

- The debris is small and thus the signal it reflects from a laser or radar will be much less than larger debris. This may require higher power and higher frequency emitters.
- To correct for atmospheric turbulence and tip-tilt errors with beam pre-compensation requires a consistent return of photons from the atmosphere and likely also the debris itself to close the adaptive optics loop. Getting sufficient returns from such a small object is very difficult even at night. Further, the debris is traveling so quickly across the sky that the adaptive optics system experiences an artificial wind; this exacerbates the challenge to correct for turbulence. Likewise, this rapid motion also exacerbates the tip-tilt challenges and the look-ahead problem.
- Radar systems in the X-band (or smaller wavelengths) can detect 1 centimeter debris; however, it is unclear whether any such systems have ever demonstrated the ability to track such debris. Phased-array radar systems in these wavelengths could likely perform the task but are prohibitively expensive.
- There is difficulty in integrating heterogeneous data in real time. Many different types of systems are used for object tracking, with different uncertainties, data formats, and possible proprietary restrictions.

Shortfalls And Decadal Surveys:

Civil Space Shortfall Ranking https://techport.nasa.gov/file/314645

1262: Small Debris Remediation

1476: Large Debris Remediation

1477: Debris Mitigation

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

References:

1. U.S. National Space Policy, 2020.
2. NASA’s Space Sustainability Strategy, Volume 1: Earth Orbit
3. Colvin et al. "Cost and Benefit Analysis of Orbital Debris Remediation" , NASA 2023, https://www.nasa.gov/wp-content/uploads/2023/03/otps_-_cost_and_benefit_analysis_of_orbital_debris_remediation_-_final.pdf
4. Locke at al.,"Cost and Benefit Analysis of Orbital Debris Remediation "Cost and Benefit Analysis of Mitigating, Tracking, and Remediating Orbital Debris", NASA 2024, https://www.nasa.gov/wp-content/uploads/2024/05/2024-otps-cba-of-orbital-debris-phase-2-plus-svgs-v3-tjc-tagged.pdf?emrc=224cd2

EXPAND.3.S26B: Autonomous Onboard Health Management for Small Spacecraft and Distributed Systems (SBIR)

Lead Center: ARC

Subtopic Problem Statement/Description:

As small spacecraft swarms proliferate in Earth, Moon, and someday Martian orbits, we will need automated tools to ensure their safety and operations. Orbital conjunctions, communications latency and bandwidth limitations are all challenges for safe future growth, and all depend in part on spacecraft health. On Earth, commercial industries have evolved an ecosystem of sensors, enabling Automation and Artificial Intelligence technologies for predictive maintenance, autonomous diagnostics, and autonomous repair of industrial systems and mobile platforms. Opportunities to explore these industry capabilities on orbit are rare, despite an increasing need to automate spacecraft processes as swarms and constellations proliferate. SmallSats represent both technology demonstration platforms for these technologies, as well as potential end-users. This SBIR opportunity is intended to spur the exploration of autonomous capabilities focused on health of individual small spacecraft and distributed swarms. We are looking for continuous on-board health management capabilities using sensors and software to 1) detect anomalies, 2) diagnose, isolate or localize faults, 3) reduce time to effect and impact estimation, and 4) autonomous safing, mitigation, recovery and/or repair. We also encourage the use of these on-board capabilities to maintain the performance of swarms when component spacecraft experience faults or are in “recovery”.

We are particularly interested in capabilities to:

- Inform successful response to “unknown faults” – faults not a-priori envisioned or defined during design– where as many as 40% of failure modes may go unidentified through Key Decision Point to Phase E (KDP E, the critical milestone for transitioning to operations). Effective and timely response of these is essential for mission success.
- Maintain system health in the face of environmental variability (such as changing illumination, radiation, or aerodynamic pressure), or degradation of onboard subsystems beyond the expected operating envelopes they may have been designed for and/or trained on. Such abilities are considered enabling in achieving fully autonomous spacecraft navigation and operations.

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

Primary Technology Taxonomy:

- Level 1: TX02 Flight Computing and Avionics

Desired Deliverables of Phase I:

We are looking for Phase I deliverables that include a concept of operation for sensors and software to continuously assess small spacecraft health and performance and distribute such information across the swarm or constellation. Primary spacecraft health metrics typically relate to spacecraft state and function, power, propulsion, Environmental Control and Life Support Systems (ECLSS), data management, communications, flight control, thermal management, and sensor functionality. At the swarm/constellation level, such metrics might relate to those that require a swarm/constellation reconfiguration.

The concept of operation should include specific sensing and software modalities, with Size, Weight and Power (SWaP) constraints appropriate to small spacecraft of less than 220 kg mass (so-called “Standard ESPA-class”). For example, sensors could include (but are not limited to) infrasound, radar, x-ray or seismic velocity for spacecraft structural assessments. Software may include classic approaches or Machine Learning (ML) / Artificial Intelligence (AI) enabled ones. Repair modes could be software or hardware focused or combined (e.g. robotic repair).

Finally, the Phase I deliverable shall identify the relevant metrics, Key Performance Parameters, and success criteria against which the Phase II deliverable's implementation will be measured against.

Desired Deliverables of Phase II:

The desired outcome of Phase II would be a prototype or minimal viable product of software or sensor demonstrated on a representative hardware environment. Ideally it would be a prototype in a form factor and at a technology maturity level (TRL 5-6) such that it could be integrated aboard a suborbital or hosted-orbital vehicle(s) for a technology demonstration through a post-Phase II activity (such as a Phase II-Extension). Performance shall be measured against the metrics, Key Performance Parameters, and success criteria defined in Phase I.

Desired Deliverable Types of Phase II:

- Prototype
- Software
- Digital Models

State of the Art:

The current state of the art for autonomous onboard spacecraft health management is characterized by systems that primarily rely on predefined rules, ground-based fault diagnostics, and limited onboard decision-making capabilities. While model-based systems, machine learning, and predictive diagnostics have shown promise, their implementation is constrained to specific failure modes and highly predictable environments. For small spacecraft, such systems are often limited by onboard computational resources, and most operations require significant human intervention, making them unsuitable for autonomous and real-time responses. Furthermore, swarm and constellation mission architectures have predominantly focused on formation flying and cooperative science objectives, with distributed health management still in its infancy. Technologies addressing unknown faults or adapting to dynamic environmental conditions remain largely undeveloped and untested, particularly in swarm configurations.

Critical Gaps:

Despite advances, current spacecraft health management systems lack capabilities for handling unknown faults autonomously, which account for a significant portion of mission failures. Systems struggle to adapt to evolving environmental conditions or degradation of onboard subsystems beyond design-time predictions. Small spacecraft pose unique challenges due to their limited processing and power capabilities, preventing integration of advanced diagnostics and repair mechanisms. At a swarm level, there are no robust frameworks for distributed fault management or coordinated response to failures in individual members while maintaining collective goals. Additionally, there is a lack of platforms to test these technologies in operational space environments, further hindering their development. For spacecraft swarms and constellations to scale effectively, significant innovations are required in lightweight, efficient autonomous health management systems capable of enabling resilience and continuity in dynamic, fault-prone environments.

Shortfalls And Decadal Surveys:

1438: Autonomy, Edge Computation, and Interoperable Networking for Small Spacecraft

1432: Rendezvous, Proximity Operations, and Debris Remediation using Small Spacecraft

1431: Access Beyond LEO for Small Spacecraft

1436: Efficient and Safe Higher Power Systems for Small Spacecraft

1437: Dynamic and Capable Thermal Control for Small Spacecraft

1545: Robotic Actuation, Subsystem Components, and System Architectures for Long-Duration and Extreme Environment Operation

1535: Autonomous Vehicle, System, Habitat, and Infrastructure Health Monitoring and Management

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

References:

1. Tipaldi, et al., 2020, On Applying AI-driven flight data analysis for operational spacecraft model-based diagnostics, Annual Reviews in Control, Volume 49, p. 197-211.
2. https://www.sciencedirect.com/science/article/abs/pii/S1367578820300213
3. https://arc.aiaa.org/doi/abs/10.2514/6.2024-4869
4. https://science.nasa.gov/wp-content/uploads/2024/09/andrat-final-report.pdf

Extravehicular Activity (EVA)

EVA.2.S26B: Mars Exploration Extravehicular Activity (EVA) Suit (SBIR) (previously H4.09)

Lead Center: JSC

Subtopic Problem Statement/Description:

This subtopic is soliciting development of systems to fill the base functions of an advanced portable life support system for extravehicular activity (EVA) suits on the Martian surface which could also be applicable to the lunar surface. It seeks to address deficits with previous developments as it relates to the base portable life support system (PLSS) functions: thermal control, O_2 supply, CO_2 removal systems, humidity control, and power supply. This list is in prioritized order based on the gap between current state of art (SOA) and estimated need for the Martian surface.

-Thermal control: Current SOA thermal control philosophy is to isolate the crew from the thermal environment as much as possible, use the metabolic and waste heat to warm the crew member, and reject excess heat to the environment. Isolation of the crew from the thermal environment may not be possible in the atmosphere of Mars, with pressures between 0.09 and 0.17 PSIA and temperatures between 68°F and -220°F. Viable proposals for this include but are not limited to: advanced insulative materials, evaporative coolers, phase change material, low power/mass heating schemes, variable emissivity radiators.

-O_2 supply: Current SOA O_2 supply relies on high pressure gaseous oxygen tanks. Recent work has suggested that liquid oxygen may be able to reduce on back mass, however this is of a much lower TRL. Viable proposals include but are not limited to liquid oxygen (LOX) systems that will work in reduced gravity, cryogenic liquid expanders that will keep up with both nominal metabolic use 0.4 g/min -4 g/min (400 BTU/hr to 3000 BTU/hr) and purge operations (7-15 g/min), and safety systems for LOX. System should be sized for 1.9 g/min consumption on average across 8 hours.

-CO_2 Control: Current SOA for CO_2 control in spacesuits requires rejection of CO_2 to the atmosphere, which will not be practical under Martian pressures (0.09 and 0.17 PSIA and 95% CO_2). Viable solutions include both systems that can sequester CO_2 until return to the habitat or systems that can reject CO_2 to the high CO_2 atmosphere. The systems should be capable of removing CO_2 from the vent stream flowing at 6 ACFM and 4.3 PSI, with injection rates between 0.5 g/min and 4.35 g/min, with an average of 2.2 g/min for 8 hours.

-Humidity Control: Historically condensing heat exchangers have been used, as the CO_2 system generated additional water. Current SOA CO_2 technology removes water as it removes CO_2, however this system must be adjusted for the Martian atmosphere. Viable humidity control scheme must either be a part of the CO_2 control or integrate independently with a wide range of potential CO_2 technologies.

Additional proposals in the areas of EVA consumables reduction and planetary protection will be considered.

Given the increased gravity of Mars compared to the lunar surface or deep space, minimizing total on back mass and volume will be critical in technology viability. Minimizing mass and volume can be a result of technological developments and lightweight advanced materials selection.

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

Primary Technology Taxonomy:

- Level1: TX06 Human Health, Life Support, and Habitation Systems
- Level 2: TX06.2 Extravehicular Activity Systems
- Level 3: TX06.2.2 Portable Life Support System

Desired Deliverables of Phase I:

- Subscale or bench scale demonstration of the technology with sufficient performance data to size next generation full scale prototype
- Testing results and analysis
- Final report

Desired Deliverables of Phase II:

- Full scale prototype of the technology
- Testing of the prototype under use case conditions.
- Analysis of the test results demonstrating acceptable level of performance and next steps to prepare the system for a ground development or flight unit.
- Documentation of testing results and analysis.
- Final report detailing unit specs, performance, and next steps for development

Desired Deliverable Types of Phase II:

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

State of the Art:

The current state of the art exists within two different programs, and as such encompasses a wide range of technologies. Both state of art (SOA) suits uses multi-layer insulation (MLI) to protect the crew from the thermal environment and then utilize water sublimation/evaporation to reject heat to deep space. Both suits use high pressure O_2 tanks for O_2 supply. The Extravehicular Mobility Unit (EMU) suit uses a metal oxide adsorbent to scrub CO_2, and a condensing heat exchanger to remove metabolic water and water produced by the metal oxide canister. The xEMU suit uses a pressure swing adsorption bed of supported liquid amines to remove both CO_2 and metabolic water. Current SOA for the lunar suit dumps water vapor, vent loop gas, and metabolic byproducts to the environment, leading to increased consumables (water and O_2) and little to no planetary protection.

Critical Gaps:

This proposal seeks to develop several new subsystems to fulfill the major purposes of the portable life support system (PLSS). The state of art (SOA) thermal control and humidity schemes are known to not work under the partial atmosphere on Mars, the SOA CO_2 system will increase the CO_2 level the crew is exposed to, and the O_2 supply will work but is likely to be too heavy under partial gravity for sustained missions, creating a limiter on EVA capacity.

Shortfalls And Decadal Surveys:

1529: EVA and IVA Suit System Capabilities for Mars Missions

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

References:

Additional information on the Mars Exploration Extravehicular Mobility Unit development plan can be found at https://ntrs.nasa.gov/api/citations/20250004024/downloads/ICES-2025-61.pdf

Human Surface Mobility (SURFMOB)

SURFMOB.1.S26B: Advanced Human Lunar Surface Mobility Technologies (SBIR) (previously H15.01)

Lead Center: JSC

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

Subtopic Problem Statement/Description:

NASA's Artemis missions aim to establish a long-term human presence on the Moon, requiring advanced capabilities for both human and robotic surface mobility. The Extravehicular Activity (EVA) and Human Surface Mobility (HSM) Program (EHP) seeks to provide safe, reliable, and effective mobility systems, including the Exploration EVA (xEVA) suits, Lunar Terrain Vehicle (LTV), Pressurized Rover (PR), and Lunar Utility Vehicle (LUV). To achieve these objectives, several critical technological gaps must be addressed, particularly concerning autonomous operations and the fundamental understanding of vehicle-regolith interactions in the lunar environment.

Autonomous Navigation and Control for Lunar Surface Mobility: Artemis crewed missions will involve extended uncrewed periods where surface assets and vehicles must operate autonomously or semi-autonomously to perform various tasks, including scientific exploration, vehicle relocation, and preparing for crew arrival. The lunar south pole presents unique and challenging environmental conditions, such as extreme temperatures, radiation, unknown soil properties, and harsh lighting. Furthermore, communications are characterized by significant time delays, latency, bandwidth limitations, and intermittent connections, unlike Earth-based or even Low-Earth Orbit (LEO) operations. Current remote command and control approaches are not suited for these operational constraints. Therefore, there is a critical need for advanced autonomous navigation, path planning, localization, soil mechanic forward control, and hazard detection/avoidance algorithms that enable high-progress-rate driving and robust operation despite limited situational awareness and communication challenges. This includes developing novel supervised autonomy, new simulation tools, and shared control paradigms to effectively integrate human oversight with onboard autonomous decision-making, ensuring efficient and safe operations when crew are away.

Context for Small Businesses:

The areas of autonomous mobility and advanced modeling/simulation are rapidly evolving, with many small businesses actively engaged in developing innovative solutions for terrestrial applications. NASA encourages these businesses to translate, adapt, and extend their expertise to meet the unique challenges of the lunar environment. While terrestrial autonomous driving still requires oversight and relies on resources not yet available on the Moon (e.g., GPS, rich training datasets, high-performance embedded processors, high-speed wireless communications), small businesses are uniquely positioned to innovate by adapting existing approaches or developing entirely new technologies. This subtopic provides an opportunity for small businesses to contribute directly to Artemis mission objectives, develop dual-use technologies with significant non-NASA commercialization potential, and differentiate themselves in a growing global space economy. Proposals should clearly demonstrate the applicability of their proposed solutions to lunar surface operations and show a viable path for integration with EHP flight projects like the Lunar Terrain Vehicle (LTV), Pressurized Rover (PR), and Lunar Utility Vehicle (LUV).

Expected TRL or TRL Range at completion of the Project: 1 - 6

Primary Technology Taxonomy:

- Level 1: TX04 Robotics Systems
- Level 2: TX04.2 Mobility
- Level 3: TX04.2.4 Surface Mobility

Desired Deliverables of Phase I:

Phase I deliverables are expected to focus on establishing the feasibility and foundational concepts of the proposed technology. Deliverables should demonstrate a clear proof-of-concept and provide a solid basis for further development in Phase II. Specific deliverables may include:

- Background Research and Feasibility Studies: Comprehensive analysis of existing state-of-the-art technologies, identification of critical gaps, and a detailed assessment of the proposed solution's technical viability for lunar surface applications.
- Conceptual Design and Trade Studies: A detailed conceptual design of the proposed technology, including an outline of its architecture, key components, and operational approach. This should be supported by trade studies justifying design choices and demonstrating an understanding of the lunar environment's constraints.
- Description of Proposed Solution: A clear and concise description of the intended solution, including its methodology and how it addresses the specific technological needs outlined in the subtopic scopes.
- Initial Proof-of-Concept Implementation and/or Testing: Evidence of the core concept's functionality, which may involve:
    - For any hardware development for Autonomous Navigation and Control: Initial software algorithms, and/or example programs demonstrating key technical advances (e.g., path planning algorithms, basic hazard detection, simulated remote control interface functions).
    - For any Modeling and Simulation development for Autonomous Navigation and Control: Initial prototype models, simulation results validating key physical interactions (e.g., rover navigation, wheel-soil interaction, soil mechanics, path planning, fault recovery), simulation environments, and preliminary test data illustrating model accuracy.

- Plans for Testing or Validation: A detailed plan outlining the approach for further testing, validation, and maturation of the technology in a relevant lunar analog environment or through advanced simulations in Phase II.
- Identification of Key Performance Parameters: Definition of measurable performance parameters and metrics that will be used to evaluate the technology's success and readiness for lunar application.

These deliverables will enable NASA to assess the potential of the proposed technology and will be instrumental in formulating a robust and targeted Phase II development plan.

Desired Deliverables of Phase II:

Phase II deliverables are expected to build upon the feasibility established in Phase I, resulting in a functional prototype that demonstrates tangible performance improvements relevant to lunar surface mobility. The deliverables should provide significant progress towards a flight-relevant system or capability. Specific deliverables may include:

- Software Source Code and Documentation: Fully developed and documented software source code for the proposed solution, including user manuals, installation guides, and detailed technical documentation.
- System Prototypes and Corresponding Design Details: A physical or high-fidelity software prototype that embodies the proposed technology. This includes detailed design specifications, engineering drawings (if applicable for hardware components), and integration plans.
- Test and Performance Data with Associated Analysis: Comprehensive test data collected from the prototype, demonstrating its performance against established metrics and requirements. This includes analysis of the data, highlighting the technology's capabilities and limitations in relevant simulated or analog lunar environments.
- Demonstration of hardware and simulation prototype performance:
    - For hardware development proposals: Demonstration of the software prototype integrated with a representative robot, rover, or flight computing hardware, showcasing improved autonomous navigation, path planning, hazard avoidance, or supervised control capabilities in a relevant simulated or analog lunar environment. This could include demonstrating robust operation under simulated communication delays and intermittent connectivity.
    - For simulation based proposals: Demonstration of the advanced modeling and simulation tools, accuracy comparison to ground truth data or proven models, demonstration of predictive natures or computation abilities. This could involve using the tools to evaluate a specific mobility system design or predict performance under various lunar terrain conditions.
- Infusion Path Development: A detailed plan outlining the next steps for maturing the technology beyond Phase II, including potential pathways for infusion into NASA missions and commercial applications.

These deliverables are intended to demonstrate the prototype's readiness for further advanced development and potential adoption by NASA programs like the Lunar Terrain Vehicle (LTV), Pressurized Rover (PR), or Lunar Utility Vehicle (LUV).

Desired Deliverable Types of Phase II:

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

State of the Art:

Terrestrial autonomous driving capabilities are still in the fledgling stages of widespread implementation and adoption, often requiring human oversight, whether in-vehicle or remote. These technologies rely heavily on resources unavailable on the Moon, including Global Positioning System (GPS), rich datasets for training machine learning algorithms, high-performance embedded processors, and high-speed wireless communications. Moreover, current machine vision algorithms are designed for terrestrial features like stop signs and road markings, which are irrelevant on the lunar surface. Therefore, significant adaptations or entirely new approaches are crucial to translate existing terrestrial performance levels to the lunar environment and expand mobile surface system capabilities to meet future operational requirements and ensure mission success.

Existing state-of-the-art consists of sensors predominantly developed for terrestrial autonomous mobility. However, commercial Light Detection and Ranging (LiDAR) technology is unproven in lunar surface conditions, necessitating the exploration of alternative technologies such as Radio Detection and Ranging (RADAR). While flight development to date has largely focused on in-space applications, a direct and dedicated focus on lunar surface survivability and performance requirements associated with surface mobility is urgently needed.

The lunar environment presents critical challenges for long-duration operation. Devices with lower power and less constrained thermal requirements are essential. Furthermore, sensors must be robust and suitable for extended operation in the extreme radiation, abrasive dust, and volatile thermal environment of the lunar south pole. Mobility reliant on visual cameras is severely hindered by the unique lighting conditions at the lunar south pole, underscoring the need for robust sensors that can overcome these environmental obstacles.

Critical Gaps:

Despite advancements in terrestrial autonomous systems and robotics, significant critical gaps exist in applying these technologies effectively to lunar surface mobility:

- Autonomous Navigation in Extreme Lunar Environments: Terrestrial autonomous driving systems heavily depend on robust GPS, rich sensor data, and high-bandwidth, low-latency communication networks—resources that are severely limited or absent on the Moon. A critical gap exists in developing autonomous navigation, localization, mapping, and hazard avoidance algorithms that are highly robust to GPS-denied environments, monochromatic and low-angle lighting conditions, and extreme temperatures of the lunar south pole, while being optimized for resource-constrained, space-rated computing platforms.
- Effective Human-Robot Coordination under Communication Constraints: Current remote command and control paradigms for space operations are insufficient for the unique lunar communication environment, which features significant time delays (approximately three seconds round trip) and intermittent communication. There is a critical gap in supervised autonomy and shared control strategies that can intelligently manage these latencies and unreliable links, enabling effective human-robot coordination and autonomous decision-making for complex tasks and extended uncrewed periods, far beyond current capabilities.

Shortfalls And Decadal Surveys:

This subtopic directly addresses critical technological gaps identified within NASA's architecture and aligns with goals articulated in various strategic documents and decadal surveys, particularly in the areas of:

- Robotics and Autonomous Systems: The need for enhanced autonomous navigation and control, as well as robust robotic capabilities for operating in challenging, communication-constrained environments, is a recurring theme across space exploration roadmaps and technology gap analyses. This subtopic directly contributes to reducing human-in-the-loop requirements for routine and hazardous tasks, enabling sustained lunar presence.

- Human Exploration and Operations: By advancing lunar surface mobility technologies, this subtopic is fundamental to achieving NASA's Moon-to-Mars objectives and the Artemis program goals. It supports the capabilities for extended human missions, increased operational efficiency during uncrewed periods, and safer exploration of the lunar surface, as outlined in documents like the NASA Moon to Mars Architecture Definition Document (Revision C).
- Planetary Science: Accurate modeling and simulation of lunar surface interaction are crucial for understanding the lunar environment, optimizing mobility system design for scientific instruments, and ensuring the success of lunar science missions. While not exclusively a planetary science subtopic, its contributions to understanding surface mechanics and developing robust exploration tools directly support the objectives of planetary science decadal surveys related to lunar exploration and in-situ resource utilization.
- Cross-Program Design Specification for Natural Environments (DSNE): The subtopic's focus on developing technologies operable and effective in the harsh environmental conditions of the lunar south pole (e.g., temperature extremes, radiation, harsh lighting, regolith interaction) directly responds to the challenges detailed in the DSNE. [SLS-SPEC-159 NASA NTRS]
- Architecture-Driven Technology Gaps: The technological needs outlined, particularly in autonomous operations under communication delays and adverse environments, are recognized as critical gaps within NASA's overall exploration architecture. This subtopic aims to mature technologies that directly address these identified shortfalls.

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

References:

1. NASA Facilities Available for Technology Development and Testing: [JSC Robotics NASA]
2. NASA Cross-Program Design Specification for Natural Environments (DSNE), current version Revision I as released on the NASA Technical Reports Server (NTRS). [SLS-SPEC-159 NASA NTRS]
3. Artemis information: [Artemis Program NASA]
4. EHP information: [NASA Suits and Rovers NASA]
5. Lunar Mobility Drivers and Needs, 2024 Moon to Mars Architecture Concept Review: [acr24-lunar-mobility-drivers-and-needs.pdf NASA]
6. Why Artemis Will Focus on the Lunar South Pole Region, 2022 Architecture Concept Review: [acr22-wp-why-lunar-south-polar-region.pdf NASA]
7. Extravehicular Activity & Human Surface Mobility Program: [NASA Suits and Rovers NASA]
8. NASA Technical Reports Server (NTRS) - general access: [NTRS NASA]
9. NASA Moon to Mars Architecture Definition Document (Revision C)

LAND – Space to Surface Operations (LAND)

LAND.1.S26B: Real-time Characterization of Regolith Stability during Planetary Descent & Landing (SBIR)

Lead Center: JSC

Participating Center(s): LaRC, MSFC

Subtopic Problem Statement/Description:

NASA is seeking the development of technologies that enable real-time regolith stability characterization during planetary descent and landing operations. Human-scale landing systems for the Moon currently in design under the NASA Artemis Program are orders of magnitude more massive than previous crewed Apollo landers from the 1960s-70s. While surface hazards (e.g., slopes, craters, and blocks) will be identified using data from orbital assets and on-board mapping sensors, knowledge of sub-surface hazards and variations in mechanical properties of the near-subsurface terrain will be limited. These factors have a direct impact on plume-induced erosion and landing stability. Data and observations of these properties obtained in-flight can inform safe landing site identification and further improve likelihood of mission success. To facilitate safe-site selection processes and safe touchdown maneuvers, new technologies are required to assess regolith stability including characteristics such as, but not limited to, bearing capacity, particle size distribution, sub-surface blocks/hazards, and predicted plume-induced erosion and/or pad sinkage.

Desirable solutions can span novel sensing technologies, methods leveraging data products from existing sensing systems, and/or algorithms that predict surface reactions given mechanical properties of the lander and regolith. Desirable solutions are robust to obscuration induced by thruster plume-surface interactions. Solutions must operate within the constraints of limited computational resources, mass, power, and data bandwidth typical of planetary landers (both crewed and uncrewed), while providing actionable information within the short timeline available (e.g., one minute to touchdown). Successful proposals must also include clear development milestones, including desired/possible testing opportunities, that present a path to spaceflight.

Pursuant to this problem, NASA seeks:

1. Novel Sensing Technologies: Active or passive sensors capable of measuring regolith mechanical properties during descent including, but not limited to:
    - Assessment of particle size distribution and surface compaction
    - Systems for sub-surface characterization for buried hazard detection
    - Spectroscopic methods correlated to mechanical properties
    - Acoustic or seismic sensing for material property assessment
2. Data Fusion and Analysis: Algorithms that leverage data from existing descent imaging systems (terrain relative navigation cameras, hazard detection lidars, doppler LiDAR, event cameras) to infer regolith stability characteristics without requiring new dedicated sensors
3. Predictive Modeling Capabilities:
    - Estimate bearing capacity and potential pad sinkage given lander mass distribution and observed/inferred regolith properties
    - Assess regolith strength and erosion potential during terminal descent
    - Uncertainty quantification to support risk-informed decisions

4. Integrated Systems: Combined sensor/algorithm approaches that provide comprehensive real-time regolith stability assessments specifically for descent and landing environments

Solutions will be evaluated based on their ability to:

- Provide actionable information within real-time operational constraints (processing time compatible with descent timeline)
- Operate at relevant altitudes and velocities during descent (from several kilometers to final approach and landing)
- Function in relevant planetary environments (lunar, Mars, icy bodies) with varying lighting conditions
- Achieve sufficient measurement accuracy and spatial resolution to inform safe site selection
- Meet realistic mass, power, volume, and data rate constraints for lander integration
- Demonstrate measurement fidelity through validation in relevant terrestrial or laboratory environments

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

Primary Technology Taxonomy:

- Level 1: TX09 Entry, Descent, and Landing
- Level 2: TX09.X Other Entry, Descent, and Landing

Desired Deliverables of Phase I:

1. Feasibility Study and Conceptual Design Report including:
    - Detailed technical approach and system architecture
    - Physics-based or empirical justification for the proposed measurement/prediction methodology
    - Trade study comparing alternative implementations
    - Identification of target planetary environments (Moon, Mars, other)
    - Analysis of measurement accuracy, precision, and uncertainty quantification
2. Performance Requirements Analysis:
    - Definition of key regolith parameters to be measured or inferred
    - Required sensing ranges, resolutions, and update rates
    - Estimated mass, power, volume, and data rate budgets
    - Processing latency analysis and computational requirements
    - Identification of operational constraints and environmental limitations
3. Proof-of-Concept Demonstration:
    - Laboratory or computational demonstration of core technical approach
    - Initial validation using simulants, existing datasets, or scaled experiments
    - Quantitative assessment of measurement capability against defined requirements
    - Documentation of demonstration methodology and results
4. Phase II Development Plan:
    - Roadmap for prototype development and testing

- Identification of required facilities and test resources
- Risk assessment and mitigation strategies

Desired Deliverables of Phase II:

1. Prototype System or Software Development:
    - Engineering prototype hardware (if applicable) or fully-developed software system
    - Detailed design documentation including:
        - System specifications and interface control documents
        - Hardware schematics, parts lists, and assembly procedures (if applicable)
        - Software architecture, source code documentation, and user guides (if applicable)
        - Calibration procedures and measurement uncertainty analysis (if applicable)
        - Integration of all sensing, processing, and output components
2. Comprehensive Prototype Testing and Validation Campaign:
    - Laboratory Testing:
        - Characterization with multiple regolith simulants representing different planetary environments
        - Measurement of bearing capacity, particle size distribution, or other target parameters
        - Comparison against ground-truth measurements from established techniques
    - Field Testing (as applicable):
        - Testing in relevant terrestrial analog environments
        - Integration with representative descent profiles or test platforms
        - Demonstration of real-time processing capabilities
    - Relevant Environmental Testing:
        - Testing under simulated thermal, vacuum, or atmospheric conditions as relevant
        - Assessment of performance across relevant lighting and surface conditions
        - Test Report documenting all validation activities and performance metrics
3. Commercialization and Transition Planning
    - Identification of potential commercial customers (e.g., commercial lunar landers, private Mars missions)
    - Comprehensive maturation plan towards space flight infusion (if applicable)
    - Phase III development plan for flight qualification or commercial product development

Desired Deliverable Types of Phase II:

- Analysis
- Test Results
- Hardware
- Prototype
- Software

State of the Art:

- Historically, regolith geotechnical properties have been determined from:
    - Limited in-situ sampling and measurements
    - Analysis of orbital data with limited resolution, often requiring data taken throughout a lunar day
- Plume-surface interactions and lofted regolith have previously been measured in test and flight environments with optical cameras, radar, LiDAR, and other remote sensors which are sensitive to obscuration by lofted material.
- Subsurface hazards and regolith composition for the Moon and Mars have been assessed using forward looking ground penetrating radar which is not suitable for real-time operations in its current design

Critical Gaps:

- High resolution, site-specific knowledge of non-terrestrial landing site surfaces and associated mechanical/geotechnical properties
- Onboard/real-time assessment of landing site safety effects to due surface mechanical properties
    - Uncertainty of inability for natural environment to remain stable under heavy load of lander
    - Uncertainty of erosion potential of regolith induced by plume-surface-interaction
    - Uncertainty of hidden sub-surface hazards which introduce risk of lander damage if lofted by PSI

Shortfalls And Decadal Surveys:

STMD Civil Space Shortfalls:

- 314: Real-time mapping sensors for active TRN and hazard detection relevant to Icy moon EDL environments
- 339: Integrated, Multi-Function Precision Landing Sensors for Crewed Lunar & Mars Missions
- 340: Integrated, Multi-Function Precision Landing Sensors for Robotic Missions
- 341: Robust Terminal Descent GN&C for Low-Visibility Conditions Induced by Plume Surface Interaction Effects
- 1130: Landing Operations Sensors for Extreme Temperature, Radiation, and Dust Conditions

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

References:

1. John Y. Liu, Po-Ting Chen, Robert Bocchino, Geoffrey Vaughan and Gavin F. Mendeck. "Hazard Detection Flight Software for Processing LIDAR Generated DEM," AIAA 2026-0330. *AIAA SCITECH 2026 Forum*. January 2026.
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LAND.2.S26B: Development and Modeling of Waterproofing Coatings or Surface Treatments for Reusable Thermal Protection Systems (TPS) (SBIR)

Lead Center: ARC

Participating Center(s): JSC

Subtopic Problem Statement/Description:

Reusable thermal protection system (TPS) tiles, originally developed for the Space Shuttle and now used in modern commercial spacecraft, are composed of Alumina Enhanced Thermal Barrier (AETB)—a low-density, high-porosity ceramic made from a silica and alumina fiber network. This porosity provides excellent thermal insulation during atmospheric re-entry by minimizing thermal conductivity. However, it also makes AETB highly susceptible to water absorption, which can lead to several structural failure modes: internal pressure during extreme thermal transitions from orbit to re-entry, cracking caused by freezing under ambient launch pad conditions, cryogenic fueling, or evaporative cooling at high altitude, and unexpected increases in launch weight. To mitigate these risks, tiles are treated with waterproofing agents through a labor-intensive process involving injection of toxic silanes such as dimethoxysilane (DMS) and methyltrimethoxysilane (MTMS). These treatments require extended curing periods to form strong Si–O–Si or Si–O–Al bonds for adhesion to AETB fibers and must be reapplied after each re-entry due to degradation. Furthermore, the emissive glass coating on the tile exterior restricts flow paths to the insulating fiber network, compounding these challenges. These limitations hinder the frequent launch cadences anticipated for reusable spacecraft by extending turnaround times between flights. NASA seeks modern waterproofing solutions for AETB and similar materials that accelerate treatment through improved chemistries and faster processes, reduce or eliminate toxic materials, and enhance coating durability and survivability under re-entry conditions.

Experimental development efforts are sought to identify modern waterproofing chemistries that meet all of the following criteria:

- Reduced moisture uptake of ceramic fibers at least commensurate to existing DMS and MTMS treatments
- Application timescales and thermal performance at least commensurate to existing DMS and MTMS treatments
- Ability to be injected or otherwise applied to tiles in situ on a spacecraft in open environments

Additionally, compared to existing chemistries (DMS/MTMS) and application approaches (injection), successful solutions will meet one or more of the following criteria:

- Involve formulations that are less toxic and/or have less volatile organic compound content
- Leverage new chemistries, surface treatments, or catalysts that accelerate both initial application to tiles and re-application post-flight
- Exhibit improved thermal performance and reduced degradation to enhance reusability
- Utilize application processes that increase per-tile throughput

Phase I shall demonstrate a waterproofing approach and quantify performance on porous silica or silica-alumina substrates akin to AETB tiles in laboratory environments. Performance quantification must include analysis of curing timescale, moisture absorption resistance of the substrate after application, and thermal degradation behavior.

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

Primary Technology Taxonomy:

- Level 1: TX01 Propulsion Systems
- Level 2: TX01.1 Chemical Space Propulsion
- Level 3: TX01.1.1 Integrated Systems and Ancillary Technologies

Desired Deliverables of Phase I:

Phase I will focus on developing and demonstrating a waterproofing approach for porous ceramic substrates similar to AETB tiles. Efforts will include identifying candidate chemistries or processes, applying them to representative materials, and quantifying key performance metrics in a laboratory environment. These metrics include curing time, moisture absorption resistance after treatment, and thermal degradation behavior under conditions simulating re-entry. The goal is to establish technical feasibility and provide data that supports scalability for operational use.

Desired Deliverables of Phase II:

Phase II will advance the technology to flight-relevant readiness through full-scale application and environmental testing. This includes demonstrating the waterproofing solution on actual AETB tiles or TPS components, validating performance under thermal cycling, freeze-thaw, and cryogenic conditions, and assessing durability across multiple simulated flight cycles. Additional objectives include optimizing application processes for rapid turnaround, confirming safety and environmental compliance, and delivering an integration plan for operational spacecraft. The outcome will be a robust, scalable waterproofing solution that reduces maintenance time, improves reusability, and supports high launch cadence goals.

Desired Deliverable Types of Phase II:

- Prototype

State of the Art:

Current state-of-the-art waterproofing for AETB tiles relies on a labor-intensive process that involves manually injecting toxic silane-based chemicals into each tile. For vehicles such as the Space Shuttle Orbiter, this treatment could require up to 72 hours to complete. Furthermore, the coatings degrade after each atmospheric re-entry, necessitating full re-application before subsequent flights. These limitations significantly increase turnaround time and operational cost, making them incompatible with the high-frequency launch cadence envisioned for modern reusable spacecraft.

Critical Gaps:

Existing waterproofing methods for AETB tiles are slow, toxic, and degrade after each flight, creating significant barriers to rapid spacecraft turnaround. New waterproofing chemistries and application techniques are needed to accelerate treatment, reduce environmental and safety concerns, and maintain performance across multiple re-entry cycles. Closing these gaps will enable higher flight cadence and operational efficiency for reusable spacecraft.

Shortfalls And Decadal Surveys:

National Cislunar Science and Technology Action Plan, NSTC/OST**P**

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

References:

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3. A. Caldwell et al., "New Development Activities at NASA Ames in Reusable TPS Materials." Composites, Materials, & Structures 47th Annual Conference, St. Augustine, FL, 2024. https://ntrs.nasa.gov/citations/20240000772

LAND.3.S26B: Low Cost Domestic Source for Blended Carbon and Phenolic Felt Batting or Yarn (SBIR)

Lead Center: ARC

Participating Center(s): LaRC

Subtopic Problem Statement/Description:

The need for advanced Entry, Descent, and Landing (EDL) technologies is emphasized in Objective 3.1 of NASA's 2022 Strategic Plan, which calls for innovations that reduce mission risk and cost while enabling new capabilities. These technologies are critical for NASA's science and exploration missions and for fostering growth in domestic industries through partnerships with academia, small businesses, and other government agencies. While existing Thermal Protection System (TPS) materials—such as rigid Phenolic Impregnated Carbon Ablator (PICA)—have supported missions like MSL, M2020, Stardust, and OSIRIS-REx, they are costly and time-intensive to manufacture and integrate. Even newer variants like Conformal PICA (C-PICA), though more cost-effective for lower heat flux environments, still require over a year from fabrication to integration. Emerging needs from NASA's Mars Exploration Program and commercial space companies highlight the demand for TPS materials with PICA-like performance that are low-cost, rapidly producible, and easy to integrate. These materials are essential for enabling frequent, cost-effective missions and rapid technology demonstrations.

This subtopic area solicits innovative technology solutions applicable to both felted or needled TPS concepts as well as 3D-woven preforms fabricated from specially blended carbon and phenolic fibers. Specifically, NASA is interested in the companies with the ability to blend carbon fibers (of >95% carbon content) with phenolic fibers with ratios > 60% carbon, to create battings for the fabrication of large-scale aeroshells. Advances are sought in the ability to fabricate uniform batting of at least 36-inches wide with scale up to 100 x 100 inches and ½ inch to 12 inch thickness. Challenges include maintaining an intimate blend ratio to maintain consistent areal weight and composition while also controlling fiber fracture of carbon fibers.

NASA is also interested in the ability to twist, and ply stretch broken fibers into a 4-ply blended yarn of varying carbon/phenolic/thermoset resin ratios (prefer phenolic or other nonbrittle fibers). Challenges include maintaining an intimate blend ratio to maintain consistent linear weight while also fabricating a high-quality yarn free from breaks, large yarn defects (ex. slubs and flames in the resin phase) and uniformity in diameter such that yarns are capable of being processed into 3D woven preforms for advanced Thermal Protection Systems.

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

Primary Technology Taxonomy:

- Level 1: TX09 Entry, Descent, and Landing
- Level 2: TX09.1 Aeroassist and Atmospheric Entry
- Level 3: TX09.1.1 Thermal Protection Systems

Desired Deliverables of Phase I:

The focus of Phase I for blended carbon/phenolic felted materials should be prototype hardware in billet form. Vendor should demonstrate ability to handle and process >95% carbon content carbon fibers - not PanOx/OPAN). Vendor should be able to demonstrate ability to fabricate battings and felt billets of the blended carbon and phenolic/kynol fibers of at least 60% carbon to kynol. In the final report, material property data including through thickness density, char yield, and shrinkage in both the in-plane and thru-thickness direction are desired.

The focus of Phase 1 for blended carbon/kynol yarns, should be demonstration of prototype stretch broken carbon fiber with phenolic/kynol (or surrogate) to demonstrate blending of stretch broken carbon/kynol fibers into a 4-ply yarn. Vendor should demonstrate ability to handle and process >95% carbon content carbon fibers.

Desired Deliverables of Phase II:

Phase II effort for demonstrating uniform blended carbon/phenolic battings should demonstrate batting of 100x100-inch dimensions to meet NASA specifications – those being 1) Carbon fiber of >90% carbon content blended with phenolic/kynol fiber of at least 60% carbon to phenolic and 2) felted thickness of >1 inch. 3) Materials shall be manufactured so as to reduce the damage to carbon fiber on equipment capable of commercial volume of felts with final densities from 0.135-0.200 g/cm^3. The desired deliverable from a Phase II would include an extension of Phase I using scaled up equipment to support commercial volume supply. A minimum of 3 differet Phase II material coupons produced on production equipment shall also be delivered for NASA evaluation of process repeatability.

Phase II effort for blended carbon phenolic yarn would demonstrate blending of stretch broken carbon/kynol fibers and detailed yarn testing, char, strength, yield, etc. to meet established NASA specifications - those being: 1) The carbon to phenolic in the yarn by mass shall be 63 ± 4% carbon and 37± 4% kynol, 2) The blended yield shall be 1140 yards/lb +/- 10%, 3) Yarn shall have a minimum strength of >13000cN and elongation of >1%, 4) Yarn shall have a twist in the "S" direction and shall be 115 +/- 15% T/m (twists per meter) (2.92 T/inch), 5) Yarn shall be manufactured so as to reduce presence of surface features such as slubs or flames.

Desired Deliverable Types of Phase II:

- Hardware
- Prototype
- Test Results

State of the Art:

The current state of the art for commercially available large scale blended high-purity carbon fibers with fibers is limited due to novelty of this technology combined with the difficulty of working with high purity carbon fibers.

Critical Gaps:

Development of a large scale, cost effective high volume production is non-existent, and NASA is in need of this to support development of NASA's MERINO (**M**aterials **E**ngineered for **R**e-entry using **I**nnovative **N**eedling **O**perations) TPS architectures.

A domestic capability for producing low cost blended phenolic/carbon yarn for NASA's 3D Woven thermal protection systems (3MDCP/HEEET) is non-existent and NASA is interested in developing this domestic capability for future missions as well as emerging commercial space applications.

Shortfalls And Decadal Surveys:

The need for investment in Entry, Descent and Landing (EDL) technologies is widely recognized within the Agency, derived in part from Objective 3.1 of the 2022 NASA Strategic Plan to "Innovate and Advance Transformational Space Technologies." The objective identifies multiple technology thrusts, among them, "technologies that have high potential for offsetting mission risk, reducing cost, and advancing existing or creating new capabilities - technology investments that enable NASA's science and human exploration missions and foster growth and job creation in domestic industries - through partnerships with universities, small businesses, and other Government agencies."

Similar priorities were emphasized again during the 2024 reorganization of STMD, which established 13 EDL Shortfalls to guide technology development efforts. This subtopic aligns with 3 of the 13 EDL Shortfalls:

1569: High Mass Mars Entry and Descent Systems

1567: Entry Capabilities for Small-Scale and Commercial missions

1572: Performance-Optimized Low-Cost Aeroshells for EDL

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

References:

1. Ellerby, Donald T., and Matthew J. Gasch. "Heatshield for extreme entry environment technology (HEEET) thermal protection system (TPS)." In Annual Conference on Composites, Materials, and Structures, no. ARC-E-DAA-TN72926. 2019.

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Lightweight Structures (LWS)

LWS.2.S26B: Softgoods Habitats Employing Layered or Trapped Unrefined Regolith Shielding (SHELTURS) (SBIR) (previously H5.05)

Lead Center: JSC

Participating Center(s): LaRC

Subtopic Problem Statement/Description:

This subtopic addresses and develops technologies that directly support risk reduction and enhancement of deployable softgoods habitats and other crewed inflatable structures. Inflatable habitats provide significant volume reduction for launch and landing through an atmosphere (such as Mars) yet can provide larger deployed volumes once in use versus heritage rigid pressure vessels. This is an area of current high interest to NASA and our industry partners, who are developing crewed inflatables for both in-space and surface habitation applications. Multiple NASA programs, including Artemis, NextSTEP (Appendix A: Habitation and Appendix R: Lunar Logistics and Mobility), Commercial LEO Destinations (CLD), and the Second Collaborations for Commercial Space Capabilities Opportunities (CCSC2), are engaged with industry on maturing and certifying these structures. In addition to volumetric efficiency, there is potential for inflatables to further reduce the required mass to the surface of the Moon and Mars by utilizing in-situ regolith as a means to protect the core structure from the environment and provide additional radiation shielding required for long duration missions. Hybrid surface habitats have been conceptualized that use softgoods for the pressure barrier and structural layers, in combination with piled or bagged regolith for environmental and radiation shielding. Regolith at depths of 2-3m can provide micrometeorite shielding, insulation from the thermal environment, and significant protection from long-term radiation exposure to the crew. Several concepts have been demonstrated for utilizing regolith including: sieving, adding binders, creating feed-stock for large-scale 3D printing, and sintering regolith into bricks or other rigid structure; however, they all require significant and specialized additional hardware and resources to be landed. The combination of regolith with inflatable structures enables use of the indigenous material in its original, raw form, without further processing or beneficiation, and has a clear mission benefit.

The focus of this subtopic is specifically on the development of novel approaches to combining the benefits of deployable, inflatable softgoods habitation with in-situ resource use of raw, unprocessed regolith to replace or augment the typical MMOD, thermal, and radiation layers. Using raw regolith minimizes the need for additional resources, energy, time and complexity of processing and allows for potential near-term testing and infusion to extend lunar surface missions. Some of the possible approaches include bagging, compressing, stacking, and leveraging softgoods to aid in encapsulation/securement. Deployable habitats also provide a means to aid in lifting these layers into place as part of their deployment on the surface. This hybrid approach could potentially minimize the required volume and mass of surface habitats and establish early beneficial usage of in-situ resources before more extensive processing capabilities become available possibly in later missions.

Parameters of Primary Concern:

- Approaches minimize the requirements on other surface assets, such as robotic bulldozers, processing plants, large surface power assets etc., to provide regolith and place where needed.
- Uses only raw, unprocessed regolith. (i.e. collected directly from the surface, without the need for binders, sintering, or other external resources.)
- Utilizes deployable softgoods structure as the primary crewed volume and takes advantage of the deployment if needed to help raise / place the regolith over its surface.
- Minimizes the amount of required regolith to encapsulate the habitat and creates a consistent and stabilized layer of regolith of 2-3m depth over the surface of the habitat.
    - More regolith could be placed for instance nearer the base, but analysis of the additional inefficiency and impact on other surface assets and time of construction should be considered.
- Provides analysis of amounts/densities of regolith needed to help define requirements on current or future excavation assets.

Questions to be addressed:

- How is the regolith obtained/gathered?
- How is it stabilized without the use of sintering or binding, e.g. bagged, how is the bag filled, and does it need to be sealed?
- How is the regolith raised into position on the habitat efficiently? How does it stay attached?
- How is the habitat protected from the regolith, so the underlying layers aren't damaged?
- What materials should be used to survive the environment including dust, thermal, MMOD, and radiation? (i.e. what depth of regolith is needed and what does it provide in terms of protection from these environmental factors?)

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

Primary Technology Taxonomy:

- Level 1: TX12 Materials, Structures, Mechanical Systems, and Manufacturing
- Level 2: TX12.1 Materials
- Level 3: TX12.1.1 Lightweight Structural Materials

Desired Deliverables of Phase I:

Phase I should layout the concept of operations for the approach, what assets are needed, how the regolith is obtained, captured/secured to the habitat. Analysis/research should be performed to determine what depth/distribution of regolith is needed and what environmental protection that enables. Prototyping of the collection, attachment, and stabilizing of the regolith or simulant/analog should be performed and demonstrated along with initial material selections/fabrication approach. The inflatable itself can leverage prior and current ongoing efforts in the development of crewed habitation, the focus here is on the integration with and design of the regolith protective layer. A full final report and in addition to an initial low fidelity prototype demonstration are expected.

Desired Deliverables of Phase II:

Phase II should include higher fidelity testing and prototyping of the concept, to include testing of the selected materials and components in a relevant environment. A representative sub-scale inflatable should be used in combination with the regolith attachment concept to demonstrate feasibility of the design. The fidelity of all components should be at a level that demonstrates there is a path to flight with the selected approach. Quarterly reports and a full final report, in addition to a prototype demonstration are expected.

Desired Deliverable Types of Phase II:

- Analysis,
- Test Results
- Hardware
- Prototype

State of the Art:

Current baseline habitats use rigid metallic pressure shells. These constrain the landed volume based on the launch and lander vehicles. Softgoods inflatables provide significant reduction in packaged volume and can deploy to larger volumes than comparable rigid vessels. Both rigid and deployable habitats require a multitude of external layers to protect the internal structure from the environment, which adds significant mass and bulk to the overall system. Separately, initial concepts for utilizing in-situ resources require significant additional infrastructure and resources for mining and extraction. The simplest type of ISRU is collecting and using the surface regolith, which robots such as the ISRU pilot excavator (IPEX) and similar assets can perform.

Critical Gaps:

The critical gap is developing feasible approaches/concepts to using initial ISRU resources to buy down risk of long-term habitation on the Lunar and Martian surfaces. ISRU is seen currently as a long-term future goal in regards to habitation, such as 3D printing habitats. But there is potential for near term usage of basic ISRU regolith collection to augment and possibly replace many of the required external layers of a habitat, with particular advantage to softgoods inflatable habitats where the deployment can be used to remove the need for lifting large amounts of regolith over the habitat with a separate asset.

Shortfalls And Decadal Surveys:

From the STMD 2026 shortfall list:

Provide efficient, outfitted habitation capable of long duration missions.

- Provide mass-efficient habitat structures capable of supporting mission relevant crew size and duration. Reference ESDMD #0306 for specific details.
- Manage the thermal environment of habitation systems for long duration missions.

Provide Earth-independent safety and crew health and performance countermeasures during long duration missions.

- Reduce adverse crew health outcomes due to radiation exposure via mass-efficient, mission compatible countermeasures.

Develop infrastructure and capabilities for assets to operate for extended duration in the lunar environment + Martian environment.

- Mitigate and survive high velocity impacts of small particles on lunar surface assets.

Deploy, assemble, and construct complex structures on the lunar surface.

- Perform site preparation and bulk regolith manipulation for infrastructure construction, including landing pads, berms, regolith overburden for radiation protection.

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

References:

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- Jablonski, A. M., and Kelly A. Ogden, "A Review of Technical Requirements for Lunar Structures – Present Status", Lunar Settlements, 2010.
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- Space Radiation and Astronaut Health: Managing and Communicating Cancer Risks (2021), National Academies of Sciences, Engineering, and Medicine. 2021. https://www.nationalacademies.org/read/26155/chapter/2.
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LIVE - Surface Infrastructure (LIVEI)

LIVEI.1.S26B: Surface Sustainability and Logistics: Dust Mitigation (SBIR)

Lead Center: JSC

Participating Center(s): KSC

Subtopic Problem Statement/Description:

Umbilicals for Extreme Environments – Dust Mitigation and Cryogenic Compatibility

Develop advanced umbilical systems for lunar and Martian surface operations that maintain reliable fluid and electrical transfer in highly abrasive, cryogenic, and dusty conditions. Solutions should align with the NASA Dust Mitigation Roadmap and support Artemis and Moon-to-Mars objectives by reducing operational risk and enabling sustainable exploration.

For definitions of umbilicals and umbilical systems, refer to ISO 15389.

Proposals should address:

- **Dust Intrusion Prevention:** Innovative sealing and connector designs for mating/demating operations.
- **Cryogenic Compatibility:** Materials and mechanisms that perform under extreme thermal cycles.
- **Dust-Tolerant Features:** Passive and active mitigation strategies (e.g., electrodynamic dust shields, advanced coatings, modular designs).
- **Durability & Maintainability:** Long-life designs (>15 years) suitable for EVA and robotic operations.

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

Primary Technology Taxonomy:

- Level 1: TX07 Exploration Destination Systems
- Level 2: TX07.2 Mission Infrastructure, Sustainability, and Supportability
- Level 3: TX07.2.5 Particulate Contamination Prevention and Mitigation

Desired Deliverables of Phase I:

Deliverables via Phase:

- **Phase I:TRL 4 = Component and/or breadboard validation in a laboratory environment.[6]**
  - The **basic technological components** are integrated to validate that they work together.
  - This validation happens **in a controlled lab setting**, not yet in a relevant or operational environment.
  - It goes beyond analytical studies—**hardware exists**, and **initial functional tests** are performed.

Expected Deliverables

- Detailed design concepts and trade studies for dust-tolerant umbilicals.
- Prototype hardware demonstrating dust mitigation features.
- Test data validating performance against NASA dust standards (e.g., NASA-STD-1008).
- Integration plan for surface systems and EVA operations.

Desired Deliverables of Phase II:

- **Phase II:TRL 6 = System/subsystem model or prototype demonstration in a relevant environment.**
  - A **prototype** or **system/model** is built and tested.
  - Testing occurs in a **relevant environment**, which for NASA often means:
    - Thermal-vacuum chambers
    - Lunar/Martian regolith simulants
    - Radiation environments
    - Other mission-representative testbeds
  - This is the transition point where technology stops being “lab-validated” and becomes **environment-validated**, bridging toward a full flight unit.

Expected Deliverables

- Detailed design concepts and trade studies for dust-tolerant umbilicals.
- Prototype hardware demonstrating dust mitigation features.
- Test data validating performance against NASA dust standards (e.g., NASA-STD-1008).
- Integration plan for surface systems and EVA operations.

Desired Deliverable Types of Phase II:

- Analysis
- Test Results
- Hardware
- Prototype

State of the Art:

The Apollo missions revealed the impact of lunar dust on components and mechanisms. Lunar dust particles are jagged and electrostatically charged, giving them the ability to bind or damage mechanisms and alter thermal properties. Reports documented clogged equipment and jammed mechanisms in every mission, regardless of surface duration, as well as clogged mechanisms in the Extravehicular Mobility Suit (EMS), including zippers, wrist and hose locks, faceplates, and sunshades [5-6]. Several astronauts remarked they could not have sustained surface activity much longer because clogged joints would have frozen up completely [2]. Effective dust mitigation strategies are needed to support longer duration stays on the lunar surface [3-4].

The NASA Dust Mitigation Roadmap includes Dust Tolerant Components, which includes mechanisms, connectors, bearings, and umbilicals. It is expected that interfaces for such components would be specified by NASA. As indicated in the roadmap, dust tolerant components are primarily being developed by Industry. NASA’s role is to characterize the technical challenges and provide guidance on relevant metrics.

There is currently no state of the art for umbilical systems for the lunar surface. These solutions are or will be developed as part of larger systems. Thus, the method by which the technology interfaces with larger systems or elements is critical.

Critical Gaps:

The extreme conditions of the lunar environment could drive the state of the art for this area. It is possible that existing solutions in subsea and/or crude oil applications are sufficient to meet the needs of the lunar environment, however the ability to get these technologies operable on the Moon would involve either modification, scaling, and or hardening of existing technology. There is currently no state of the art for umbilical systems for the lunar surface that are dust tolerant.

Shortfalls And Decadal Surveys:

This addresses the following 2026 Civil Space Shortfalls:

- Perform safe, Earth-independent Extravehicular Activities on the lunar surface.
- Develop infrastructure and capabilities for assets to operate for extended duration in the lunar environment.
- Deploy, assemble, and construct complex structures on the lunar surface.

- Produce propellant, consumables, and other usable materials from lunar resources to support human exploration and commercial activities.
- Develop infrastructure and capabilities for assets to operate for extended duration in the Martian environment.
- Perform safe, Earth-independent Extravehicular Activities on the Martian surface.
- Produce propellant, consumables, and other usable materials from Martian resources to support human exploration.
- Operate multi-agent robotic and crewed systems in cooperative planetary surface activities.
- Provide surface mobility and logistics for crew and assets on planetary surfaces. (Specifically, transfer pressurized gases between exploration assets on planetary surfaces)
- Provide robotic access to subsurface and atmospheric regimes.
- Efficiently and responsibly manage waste streams during long duration missions
- Provide efficient, outfitted habitation capable of long duration missions.

This addresses the following Architecture-Driven Technology Gaps from ADD Rev C.

- ESDMD #0201 Extreme Environment Avionics
- ESDMD #0301 Systems to Survive and Operate through Extended Periods of Lunar Shadow
- ESDMD #0501 Robotic Inspection, Maintenance, and Repair
- ESDMD #0503 In-Space & Surface Transfer of Earth-Storable Propellants
- ESDMD #0504 Autonomous Lunar Surface Structure Assembly and Construction
- ESDMD #0702 Waste Management
- ESDMD #0801 Lunar Dust-Tolerant Systems and Dust Mitigation
- ESDMD #0802 Mars Dust-Tolerant Systems and Dust Mitigation
- ESDMD #0803 Extravehicular Activity (EVA) and Intravehicular Activity (IVA) Suit System and Capabilities for Mars Missions
- ESDMD #0804 Robotic and Mobility Systems in Extreme Cold Environments on the Lunar Surface
- ESDMD #0806 Payload Offloading, Handling, and Manipulation for Surface Assets
- ESDMD #0903 Power Management and Distribution between Surface Elements
- ESDMD #1001 High-performance Actuators, Sensors, and Interfaces
- ESDMD #1107 Cryogenic Fluid Transfer
- ESDMD #1201 In-Situ Sample Storage and Processing

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

References

1. NASA Dust Mitigation Technology Roadmap

2. LSIC Template - NASA Technical Reports Server (NTRS)
3. Jimenez, N. et al (2022), LPSC Abstract 2572
4. NASA-STD-1008, 2021
5. ISO 15389
6. https://www.nasa.gov/directorates/somd/space-communications-navigation-program/technology-readiness-levels/

Science Instruments and Computing to Study Planetary Bodies (INSTALG)

INSTALG.3.S26B: Large-Scale Computing and Computational AI (SBIR) (previously S17.01)

Lead Center: ARC

Participating Center(s): GSFC

Subtopic Problem Statement/Description:

High performance computing (HPC) remains a critical part of NASA Science Mission Directorate's (SMD) infrastructure needed to address fundamental questions of science and seek answers in order to understand the Sun, Earth, Solar System, and beyond. HPC serves a specific need in numerical simulation as high fidelity and efficient computing capabilities are needed to tackle large-scale research and studies to investigate complex dynamic processes up to the scale of entire science ecosystems. One of the largest challenges facing the HPC community today is the tremendous amount of refactoring that is typically required of existing large scale applications in order to address the hardware paradigm shift that has taken place over the past 5 to 10 years to usher in the exascale era, which is now upon us—and this shift is expected to continue and become even more heterogeneous in the coming years. There is an urgent need for application refactoring and performance portability in this environment. A second challenge is the emergence of the field of quantum computing and assessment of its potential to drive breakthroughs needed to analyze and solve large scale science problems currently beyond the reach of classical computing methods.

The National Aeronautics and Science Administration (NASA) scientists and engineers are increasingly turning to large scale numerical simulation on supercomputers to advance understanding of complex systems and to conduct high fidelity science and engineering analyses. To address these challenges, novel software technologies are sought such as artificial intelligence (AI)/machine learning (ML) that will increase the mission impact of NASA's investments in supercomputing systems and associated operations and services.

Large Language Models (LLMs) are increasingly capable for use in HPC for tasks like code generation and analysis and have potential for further use with some data privacy and security concerns addressed for secure adoption.

Small Language Models (SLMs) are emerging to address applying mechanistic interpretability to smaller tasks like OpenMP (OMP) code completion, data race detection, and OMP code generation. SLMs are emerging for HPC physics by offering efficient, resource-light AI for tasks like code generation, data analysis, and model acceleration, fine-tuned on domain-specific data for physics code principles, enabling faster, localized AI within complex scientific workflows, using like quantization techniques to run on less hardware, making them ideal for specific physics problems.

Proposals should demonstrate a relation to fields of study relevant to SMD or demonstrate the portability to SMD disciplines. Innovative computation technology directly targeting a stated NASA need outside of an SMD application will still be considered, but offerors are strongly encouraged to identify at least one relevant NASA subject matter expert and relevant project.

Proposals should also demonstrate awareness of the state of the art of their proposed technology and should leverage existing commercial capabilities and research efforts where appropriate, including open source software and open standards.

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

Primary Technology Taxonomy:

- Level 1: TX11 Software, Modeling, Simulation, and Information Processing
- Level 2: TX11.6 Ground Computing

Desired Deliverables of Phase I:

Technical feasibility demonstration with supporting research results demonstrating NASA relevance. Documentation of a path toward a Phase II deliverable and application of software design to support multiple disciplines (if applicable).

Desired Deliverables of Phase II:

Prototype demonstration along with documentation of development and capabilities, including operating instructions. Plan scaling upwards to commercialization or infusion into NASA programs.

Desired Deliverable Types of Phase II:

- Prototype
- Software
- Analysis
- Test Results

State of the Art:

Current and future NASA science requires at least 100x more powerful supercomputers and 1,000x higher application parallelism in 10 years without an increased energy demand. The current NASA data landscape also involves technologies for high fidelity computational simulation and data analytics are distinct and interfacing between tools is inefficient. As science data continue to grow in volume and complexity, innovative and novel software solutions are sought to further enable exascale compute capabilities while offering benefits to supercomputing users and facilities that can be readily adapted into supercomputing operations in efficient and cost effective ways.

Critical Gaps:

Critical gaps that this subtopic addresses are:

- Increase the achievable scale and complexity of computation, data ingest, and/or data assimilation required with large-scale numerical simulations.
- Reduce the cost of achieving a given level of application performance through the use of AI/ML tools.
- Enhance the efficiency and effectiveness of NASA's supercomputing operations and services.

- Enhance the supercomputer application area in data analytics that expand to other mission customers using AI/ML.
- Use of AI/ML techniques for code refactoring with the goal of improved application performance, scalability and optimization on target hardware and computing environments.

The NASA supercomputing environment is characterized by:

- HEC systems operating behind a firewall to meet strict information technology (IT) security requirements.
- Communication intensive applications.
- Massive computations requiring high concurrency.
- Complex computational workflows and immense datasets.
- The need to support hundreds of complex application codes, many of which are frequently updated by the user/developer.
- Encouragement to develop new application areas like AI/ML.

Shortfalls And Decadal Surveys:

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:

1. "NASA High-End Computing Program User Needs Assessment 2020," National Aeronautics and Space Administration: https://hec.nasa.gov/workshop20/HEC_Needs_Assessment_2020.pdf
2. Wang, B.; Wang, J., "Application of Artificial Intelligence in Computational Fluid Dynamics," Industrial Engineering Chemistry Research. 2021, Vol. 60, No. 7, pp. 2772-2790: https://pubs.acs.org/doi/10.1021/acs.iecr.0c05045
3. Usman, A.; Rafiq, M.; Saeed, M.; Nauman.; Almqvsit, A.; Liwicki, M., "Machine Learning Computational Fluid Dynamics," Swedish Artificial Intelligence Society Workshop (SAIS). 2021, pp. 1-4: https://ieeexplore.ieee.org/document/9483997
4. Xu, Z.; Chen, X.; Chi, L.; Liu, J.; Gong, C., "A mesh quality discrimination method based on convolutional neural network," 2020 IEEE International Conference on Artificial Intelligence and Computer Applications (ICAICA). 2020, pp. 481-486: https://ieeexplore.ieee.org/document/9182623
5. "High-End Computing Capability," National Aeronautics and Space Administration: https://www.nas.nasa.gov/hecc
6. "Computational & Information Sciences and Technology Office," National Aeronautics and Space Administration: https://science.gsfc.nasa.gov/cisto

INSTALG.4.S26B: Detectors and Integrated Electronics (SBIR) (previously S11.04)

Lead Center: JPL

Participating Center(s): GSFC

Subtopic Problem Statement/Description:

A number of NASA funded missions are envisioned in the next decade that will support Artemis exploration, in situ resource utilization guiding, Artemis astronaut field work, explore the universe, investigate Extreme Weather on Earth, impacts of space weather on Earth system, support detailed characterization of Mars system in preparation for future crewed landers, and be sent to outer planets for exploration. The heart of these missions are the science instruments, and in turn, the heart of the science instrument is the detector system. This subtopic is seeking new and innovative detector and supporting systems for upcoming NASA missions. Infrared (IR) and Far-Infrared (Far-IR) cover a wide spectrum that is important for understanding our planet as well as the constantly changing universe around us. NASA is seeking new technologies or improvements to existing technologies to meet the detector needs of future missions, as described in the most recent decadal surveys for Earth science, planetary science, astrophysics, and in the NASA Moon-to-Mars program.

Selected components are needed for ambient-temperature operation, and other components for cryogenic temperature operation. Critical gaps that should be addressed include those for low-power and low-cost readout integrated electronics and Far-IR-/submillimeter-wave detectors.

Please note that the following areas are excluded from INSTALG.4.S26B this year:

- Technologies for visible detectors, with the exception of superconducting, are not being solicited this year.
- Technologies for lidar detectors are not being solicited this year.
- Superconducting detector technologies in the high energy spectrum (offerors are suggested to consider COSMO.1.S26A).

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

Primary Technology Taxonomy:

- Level 1: TX08 Sensors and Instruments
- Level 2: TX08.1 Remote Sensing Instruments and Sensors

Desired Deliverables of Phase I:

Research, analysis, feasibility studies, detailed design, or determination of the trade space and detailed optimization of the design. In some circumstances, simple prototype models for the hardware can be demonstrated and tested.

Desired Deliverables of Phase II:

Studies, a working prototype that can be tested at one of the NASA centers is highly desirable. Phase II deliverables should also include/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
- Prototype

State of the Art:

Efficient multipixel readout electronics are needed both for room-temperature operation as well as cryogenic temperatures. We can produce millions-of-pixel detector arrays at IR wavelengths up to about 14 µm, only because there are ROICs available on the market. Without these, high-density large-format IR arrays such as quantum well (QW) IR photodetectors, HgCdTe, and strained-layer superlattices would not exist. The Moore's Law corollary for pixel count describes the number of pixels for the digital camera industry as growing in an exponential manner over the past several decades, and the trend is continuing. The future of very long-wave detectors such as far-IR and submillimeter-wave detectors is moving toward tens of thousands of pixels and beyond. Readout circuits capable of addressing their needs do not exist, and without them the astronomical community will not be able to keep up with the needs of the future.

Critical Gaps:

Detector arrays and readout integrated electronics:

- Infrared photodiode arrays: Low power dissipation, in-pixel digital read-out integrated circuit (DROIC) for high-dynamic-range IR imaging and spectral imaging (10 to 240 Hz operation) focal plane arrays (FPAs) to circumvent the limitations in charge well capacity. Large form factor (2 & 4 Mpix) DROIC based arrays with >10 Hz full-array readout operation. Event-based and AI-driven ROICs to allow on-board processing and data reduction. Ambient temperature proximity electronics. Material characterization testbeds for ensuring performance and uniformity for very large format arrays. High-performance spectral filters monolithically integrated to detector/FPA.
- Microwave Kinetic Inductance Detectors (MKID)/ transition-edge sensor (TES) detectors: A radiation-tolerant, digital readout system is needed for low-temperature detectors such as MKIDs or other detector types that use microwave-frequency-domain multiplexing techniques. Each readout channel of the system should be capable of generating a set of at least 1,500 carrier tones in a bandwidth of at least 1 GHz with 14-bit precision and 1-kHz frequency placement resolution. The returning-frequency multiplexed signals from the detector array will be digitized with at least 12-bit resolution. A channelizer will then perform a down-conversion at each carrier frequency with a configurable decimation factor and maximum individual subchannel bandwidth of at least 50 Hz. The power consumption of a system consisting of multiple readout channels should be at most 20 mW per subchannel or 30 W per 1-GHz readout channel. That requirement would most likely indicate the use of a radio-frequency (RF) system on a chip (SoC) or application-specific integrated circuit (ASIC) with combined digitizer and channelizer functionality.
- Bolometric arrays: Low-power, low-noise cryogenic multiplexed readout for large-format two-dimensional (2D) bolometer arrays with 1,000 or more pixels, operating at 65 to 350 mK. Superconducting readout capable of reading two TES per pixel within a 1-mm^2 spacing. The wafer-scale readout capable of being indium-bump bonded directly to 2D arrays of membrane bolometers. Row and column readout with very low crosstalk, low read noise, and low detector noise-equivalent power degradation.

Far-IR-/submillimeter-wave detectors:

- Novel materials and devices: New or improved technologies leading to measurement of trace atmospheric species (e.g., CO, CH4, N2O, ices), minerals, or broadband energy balance in the IR and Far-IR from geostationary and low-Earth orbital platforms. Of particular interest are new direct detector or heterodyne detector technologies made using high- temperature superconducting films (e.g., thin-film YBCO or MgB2, or multilayered engineered superconductors with tunable critical temperature) or engineered semiconductor materials, especially 2D electron gas (2DEG) and quantum wells (QWs).
- Array receivers: Development of a robust wafer-level packaging/integration technology that allow high-frequency-capable interconnects and allow two dissimilar substrates (i.e., silicon and GaAs) to be aligned and mechanically "welded" together. Specially develop heterogeneous integration technology that can

support submillimeter-wave (frequency above 300 GHz) arrays. Compact and efficient systems for array receiver calibration and control are also needed.

- Receiver components: Development of advanced terahertz receiver components is desired. Such components include:
    - Novel concepts for room-temperature-operated receivers for Earth science with competitive noise performance (goal of 5 times the quantum limit in the 500 to 1,200 GHz range).
    - Local oscillators capable of spectral coverage 2 to 5 terahertz (THz), output power up to >2 mW, frequency agility with >1 GHz near chosen terahertz frequency, and continuous phase-locking ability over the terahertz- tunable range with <100 kHz line width. Both solid-state (low-parasitic Schottky diodes) as well as quantum cascade lasers (for f > 2 THz).
    - Components and devices such as mixers, isolators, and orthomode transducers, working in the terahertz range, that enable future heterodyne array receivers.
    - Novel receiver architectures such as single-sideband heterodyne terahertz receivers and high-precision measurement accuracy for multiple lines.
    - Application-specific integrated circuit (ASIC)-based SoC solutions are needed for heterodyne receiver backends. ASICs capable of binning >6 GHz intermediate frequency bandwidth into 0.1 to 0.5 MHz channels with low power dissipation (<0.5 W) would be needed for array receivers.
    - Novel quasi-optical devices for terahertz beam multiplexing for a large (16+) number of pixels with >20% bandwidth.
    - Low-power, low-noise intermediate-frequency (IF) amplifiers that can be used for array receivers, operated at cryogenic as well as room temperature.
    - Novel concepts for terahertz preamplifiers from 300 GHz to 5 THz.

Shortfalls And Decadal Surveys:

"Pathways to Discovery in Astronomy and Astrophysics for the 2020s," (Astro2020), National Academies: https://nap.nationalacademies.org/catalog/26141/pathways-to-discovery-in-astronomy-and-astrophysics-for-the-2020s

"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

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: Near-Term (Less than 5 years)

References:

1. Meixner, M., Armus, L.; Battersby, C.; Bauer, J.; Bergin, E.; Cooray, A.; et at., "Overview of the Origins Space telescope: science drivers to observatory requirements," Space Telescopes and Instrumentation 2018: Optical, Infrared, and Millimeter Wave. 2018, Vol. 10698, pp. 221-231: https://asd.gsfc.nasa.gov/firs/docs/
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7. Risacher, C.; Güsten, R.; Stutzki, J.; Hübers, H. W.; Bell, A.; Buchbender, C., et al., "The upGREAT 1.9 THz multi-pixel high resolution spectrometer for the SOFIA Observatory," Astronomy & Astrophysics 595. 2016, No. A34: https://www.aanda.org/articles/aa/pdf/2016/11/aa29045-16.pdf

8. Goldsmith, P. F., "Sub-millimeter heterodyne focal-plane arrays for high-resolution astronomical spectroscopy," URSI Radio Science Bulletin. 2017, Iss. 362, 53-73: https://ieeexplore.ieee.org/iel7/7873543/8267362/08267373.pdf

9. Staguhn, J. G. et al., "Performance of backshort-under-grid kilopixel TES arrays for HAWC+," Journal of Low Temperature Physics. 2016, Vol. 184, pp. 811-815: https://ntrs.nasa.gov/citations/20170002399

10. Datta, R., et al., "Characterization of Kilopixel TES detector arrays for PIPER," American Astronomical Society Meeting Abstracts# 231. 2018, Vol. 231, pp. 152.19: https://ui.adsabs.harvard.edu/abs/2018AAS...23115219D/abstract#:~:text=We%20present%20measurements%20of%20the,time%20constant%2C%20and%20noise%20performance.

11. Reintsema, C.D.; et al., "A Time Domain SQUID Multiplexing System for Large Format TES Arrays," 2023: https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=31361

12. Mellberg, A.; et al., “InP HEMT-based, Cryogenic, Wideband LNAs for 4-8 GHz operating at very low DC-Power,” Conference Proceedings. 14th Indium Phosphide and Related Materials (Cat. No.02CH37307). 2002, pp. 459-462:https://ieeexplore.ieee.org/document/1014467

13. Montazeri, S.; Bardin, J. C., "A sub-milliwatt 4–8 GHz SiGe cryogenic low noise amplifier," 2017 IEEE MTT-SInternational Microwave Symposium (IMS). 2017, pp. 160-163: https://ieeexplore.ieee.org/document/8058937

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INSTALG.5.S26B: Remote-Sensing Technologies (SBIR) (previously S11.03)

Lead Center: GSFC

Participating Center(s): JPL, LaRC

Subtopic Problem Statement/Description:

This subtopic solicits component- to subsystem-level technologies that advance remote sensing instruments for Earth Science, Planetary Science, and Astrophysics missions. The scope includes Active Microwave, Passive Microwave, and LiDAR technologies that enable measurements of the atmosphere, surface, subsurface, oceans, cryosphere, and planetary bodies. Emphasis is placed on innovations that improve performance while reducing size, weight, power, and cost (SWaP-C), and that are suitable for maturation by small businesses and transition toward future NASA missions.

Although these sensing modalities address distinct measurement objectives, they share common technical challenges, including calibration stability, environmental robustness, long-term reliability, and deployment on spaceborne, airborne, and distributed platforms. Advances in enabling components, subsystems, and techniques are increasingly required to support next-generation observing architectures such as SmallSats, CubeSats, constellations, and other resource-constrained platforms with demanding performance requirements.

Priority technology needs within this unified Remote Sensing Technology subtopic are organized by sensing modality: Active Microwave, Passive Microwave, and LiDAR. Each area emphasizes time-critical technology gaps at approximately TRL 3–5, with clear mission relevance, well-defined performance metrics, and realistic paths to infusion into future NASA science missions.

LiDAR:

Lidar systems provide high-resolution measurements of atmospheric composition, winds, aerosols, clouds, surface topography, and planetary terrain for Earth science, planetary science, and spacecraft navigation applications. Technologies are sought that reduce system complexity and SWaP-C while enabling new or enhanced measurement capabilities from ground-based, airborne, and space-based platforms. Advances of interest include next-generation laser and detection architectures that support key lidar modalities such as backscatter profiling, spectral absorption, altimetry, and Doppler wind sensing, addressing critical observational gaps in current and future missions. **Expected TRL Progression:** ~TRL 3 (Phase I) to TRL 6 (Phase II)**.**

Active Microwave:

Active microwave technologies, including radar and active RF sensing systems, are essential for future Earth and planetary science missions, providing sensitivity to surface deformation, subsurface structure, vegetation, hydrology, cryosphere processes, and atmospheric dynamics. Advances in enabling components, subsystems, and techniques are required to support future mission infusion under constrained size, weight, power, and cost (SWaP-C), including SmallSat, CubeSat, airborne, and distributed sensing architectures.

Active microwave remote sensing underpins a range of Earth and planetary science applications that motivate continued technology development. Key drivers include Surface Biology and Geology (SBG) and Surface

Deformation and Change (SDC), including follow-on science building on NISAR, which demand compact, calibration-stable radar systems with improved sensitivity and revisit capability.

Additional drivers include low-frequency radar for subsurface sensing on Earth and planetary bodies (e.g., icy worlds, groundwater, and small-body tomography), motivating advances in deployable and steerable apertures; RF–photonic technologies that improve frequency generation, waveform control, and phase stability across multiple science areas; compact, low-SWaP multi-frequency millimeter-wave radar systems for atmospheric, cloud, precipitation, and surface sensing; and emerging quantum-enabled techniques, including Rydberg-based microwave sensing enabled by advances in microwave–optical interfaces and compact laser subsystems. **Expected TRL Progression**: ~TRL 3 (Phase I) to TRL 5 (Phase II).

Passive Microwave:

Passive microwave radiometers and spectrometers enable measurements of temperature, humidity, clouds, precipitation, soil moisture, ocean salinity, and planetary molecular species. Technologies are sought to improve sensitivity, calibration stability, bandwidth, and resilience to interference, while significantly reducing SWaP-C. **Expected TRL Progression**: ~TRL 3 (Phase I) to TRL 5 (Phase II).

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

Primary Technology Taxonomy:

- Level 1: TX08 Sensors and Instruments
- Level 2: TX08.1 Remote Sensing Instruments and Sensors

Desired Deliverables of Phase I:

Proposed technologies must be clearly applicable to subsystem- or system-level remote sensing solutions (e.g., lidar, active or passive microwave) and tied to a defined measurement objective, rather than stand-alone components without system context.

Demonstrate technical feasibility of the proposed technology solution through research, analysis, and/or modeling and define a credible path to a Phase II prototype. Deliverables typically include a technical report, system/subsystem design, modeling/simulation results, risk assessment, and (where appropriate) limited prototype or subcomponent demonstrations.

Desired Deliverables of Phase II:

Deliverables must include a functional prototype component or system, capable of laboratory demonstration, along with verifiable test data and analysis. The prototype should preferably be suitable for operation in a relevant environment (e.g., ground-based station, aircraft platform, or science platform amply defended by the proposer) and represent a viable solution for airborne and/or space-flight applications in the near future. The final deliverable must also delineate the further work required to transition the technology to full operational and/or commercial use.

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

- Analysis
- Prototype
- Hardware
- Test Results

State of the Art:

The current state-of-the-art in remote sensing is supported by established programs and technologies, but is generally constrained by limitations in size, weight, power, and cost (SWaP-C), sensitivity, resolution, or revisit time.

- Lidar/Optical Systems: Lidar is a key technology with interest that overlaps with the commercial market. Current systems provide capabilities for backscatter profiling of aerosols and clouds, laser spectral absorption of trace gases, altimetry, and Doppler wind measurements. Some advanced lidar instruments are already operational, such as the HALO lidar, which is a fully completed and qualified laser system currently utilized for drop-in airborne operations.
- Active Microwave Systems: Flagship missions like NISAR (NASA-ISRO Synthetic Aperture Radar) are currently operating, providing essential data but with revisit times on the order of a week. For planetary science, low-frequency band electronics and antennas have been successfully used for subsurface studies, exemplified by MARSIS and SHARAD for Mars, and REASON planned for the Europa Clipper mission. At the component level, S- and L-band amplifiers are widely used in commercial telecommunications and for agricultural remote sensing applications, and monolithic microwave integrated circuits (MMICs) are available in dimensionally small, mass-produced form factors. Advances in quantum radars/receivers are strongly desired. Quantum sensing (QS) has the ability to transform space-based science, particularly by substantially increasing the spatial and temporal resolution of remote sensing measurements needed to understand Earth's climate variability.
- Passive Microwave Systems: Microwave sensors, such as radiometers, are in use on past and current missions including Tempest-D, Sentinel-6, Jason-3, SWOT, and COWVR. While essential, the current instrumentation is limited in sensitivity due to factors like system noise, 1/f noise, radio frequency interference, or calibration uncertainty. Hyperspectral microwave radiometry (both ASIC- and photonic-based) is an emerging technology. Microwave-photonic systems may provide performance benefits for high-frequency sources and frequency conversion.

Critical Gaps:

<u>Active microwave:</u>

- **Quantum**
  1. Rydberg Atom–Based Integrated RF Sensor Head: Integrated vapor-cell sensor heads (<5 cm³ active volume), thermally stabilized (±0.1 °C) for multi-band RF coupling for atom-mixer architectures (L–K band, 1–20 GHz) for RF super-heterodyning with integrated local oscillator (LO) signals and exciters; Baseband to MHz readout bandwidth (≥1 MHz); Electric-field sensitivity ≤1 µV/m/√Hz (goal <0.1 µV/m/√Hz); Linear dynamic range >60 dB; Fiber-coupled probe/coupler delivery (e.g., 510 nm / 780–852 nm systems); Optical linewidth <100 kHz; vibration-tolerant packaging (airborne/LEO)
  2. Arrayed Cell Architectures: 10×10 pixel Rydberg Cs/Rb arrays within <15 cm aperture; Spatial RF sampling for reflector-fed L–K band focal planes with Rydberg Rf receivers; Reconfigurable electrode or field-coupling geometries; Cross-channel isolation of >30dB for coherent operation.
- **Millimeter-wave**
  1. Integrated Transceiver Modules (10–400 GHz): Ka (35 GHz), V (64–70 GHz), W (94–95 GHz) priority; Technologies to enable efficient, high-power, high-duty cycle, low-SWaP, long-lifetime power amplifiers (10-400 GHz, with special emphasis on 13 GHz, 36 GHz, 60-75 GHz, 94 GHz, 155-175 GHz, 240 GHz, 380 GHz). Both solid-state and vacuum electronics technologies are acceptable.
  2. Architectures: MMIC/ASIC-based up/down conversion; FMCW/chirped waveform support; Low SWaP radar transceiver and/or duplexer modules from 94-400 GHz with improved isolation, switching performance, and efficiency.

- **Distributed Radar**

  Timing & Position Synchronization: Relative timing precision <100 ps; Position knowledge <1 cm for L-band coherence; VHF–Ka band support

Passive microwave:

- **Ultra-Low-Noise Receiver Front Ends**
  1. Total-power, pseudo-correlation, and polarimetric receivers
  2. Frequency coverage from microwave through submillimeter-wave (up to ~5 THz)
  3. Receiver noise figures exceeding current state of the art

- **RF Frontends**
  1. MMIC LNAs operating from 20–200 GHz with: Noise figure <4.5 dB, Gain >20 dB, increased linearity desired for RFI resilience
  2. Submillimeter-wave LNAs (~1.2 THz) with: 10% fractional bandwidth
- **1/f Noise and Long-Term Stability Mitigation**
  1. Techniques to reduce gain and offset drift over periods >1s to multi-day timescales
  2. Architectures supporting ultra-stable radiometric measurements
- **Advanced Digital and Photonic Signal Processing**
  1. ASIC- and FPGA-based spectrometers with: >10 GHz instantaneous bandwidth, Low power consumption (<1 W/GHz target), >8192 channels, Radiation-hardened and minimized power dissipation
  2. Microwave photonic spectrometers enabling: 100–200 GHz instantaneous RF bandwidth, Reduced mass & power compared to digital-only systems
- **Photonic Sources/Modulators:**
  1. Sources using photomixing: Up to 300 GHz and up to 1 mW.
  2. Electro-optic modulators that operate up to 600 GHz.
- **THz Quantum Cascade Lasers (QCLs) as Local Oscillators**
  1. Output power >500 µW in the 2.5–3 THz range
  2. Output power >250 µW at 4.7 THz
  3. Wide tunability >100 GHz
  4. Suitable for pumping pixel arrays of superconducting hot electron bolometer mixers and room-temperature Schottky diode mixers
  5. Applications include planetary and heliophysics heterodyne sensing systems
- **Additive & Advanced Manufacturing for RF Systems**
  1. Integrated RF modules combining active & passive components
  2. Low-loss interconnects & distribution networks
  3. Demonstrated repeatability, reproducibility, and environmental robustness

Lidar:

- **Compact Systems for Space Applications**
    1. Advances to reduce cost, size, and complexity of lidar instruments for SmallSat, CubeSat, and UAV packages
    2. Focus on reducing complexity and environmental sensitivity while maintaining performance metrics
    3. Novel thermal management systems to increase efficiency and decrease physical footprint
    4. Innovative materials to reduce weight for lidar-specific components
- **Advanced Laser Technologies for Space Applications**
    1. Compact, efficient, tunable, and rugged narrow-linewidth pulsed lasers for lidar
    2. Specific wavelengths for various atmospheric and environmental applications (e.g., 290-320 nm, 486 nm, 532 nm, 935nm, 1064 nm, 2000 nm, etc.)
    3. Desired pulse rates and energies: 1-10 kHz (>1 mJ) and 20-100 Hz (>100 mJ)
    4. Single frequency and frequency-agile sources for spectral absorption applications
    5. Cryogenic lasers for enhanced efficiency and new materials
    6. Photonic Integrated Circuit (PIC)technology supporting tunable lasers, phase modulators, amplifiers and photodiodes on a single chip. Single chip with two tunable lasers that can achieve <10µs response time , >20 GHz mode hop free tuning, >10nm coarse tuning and >1mW power ex-facet.
- **2D Scanners**
    1. High-speed, low-SWaP non-mechanical scanners
    2. Large aperture (>50 cm) non-mechanical beam steering
- **3D Mapping and Hazard Detection**
    1. Compact high-efficiency 3D lidar for planetary range and surface reflectance measurements
    2. High-resolution 3D lidar for stratospheric platforms and wild fire tracking and prevention
    3. Reconfigurable lidar technologies with single-photon sensitivity and variable dynamic range
    4. Ground and LEO-based lidar systems for orbital debris detection and tracking

Shortfalls And Decadal Surveys:

1. "Planetary Science and Astrobiology Decadal Survey 2023-2032," National Academies: https://www.nationalacademies.org/our-work/planetary-science-and-astrobiology-decadal-survey-2023-2032
2. "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
3. "Surface Deformation and Change (SDC)," National Aeronautics and Space Administration: https://science.nasa.gov/earth-science/decadal-sdc
4. "Planetary Boundary Layer (PBL)", National Aeronautics and Space Administration: https://science.nasa.gov/earth-science/decadal-pbl
5. "Surface Topography and Vegetation (STV)," National Aeronautics and Space Administration: https://science.nasa.gov/earth-science/decadal-stv

6. "Surface Biology and Geology (SBG)," National Aeronautics and Space Administration: https://science.nasa.gov/earth-science/decadal-surveys/decadal-sbg/
7. Earth Science Decadal Survey," National Aeronautics and Space Administration: https://science.nasa.gov/earth-science/decadal-surveys/

This scope addresses shortfalls identified in the Civil Space Shortfall Ranking including:

- [Ranked 20th] ID 1626: Advanced Sensor Components: Imaging
- [Ranked 137th] ID 1602: 3D/3D+ Imaging and Tomography of Complex Features and Dynamical Processes
- [Ranked 67th] ID 1599: Quantum Sensors That Use Atoms, Ions, and Spin

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

References:

1. "Surface Deformation and Change (SDC)," National Aeronautics and Space Administration: https://science.nasa.gov/earth-science/decadal-sdc
2. "Planetary Boundary Layer (PBL)," National Aeronautics and Space Administration: https://science.nasa.gov/earth-science/decadal-pbl
3. "Surface Topography and Vegetation (STV)," National Aeronautics and Space Administration: https://science.nasa.gov/earth-science/decadal-stv
4. "Sensing Our Earth from Above," National Aeronautics and Space Administration: https://science.larc.nasa.gov/lidar/
5. "Sciences and Exploration Directorate," National Aeronautics and Space Administration: https://science.gsfc.nasa.gov/sci/
6. "Global Precipitation Measurement Mission," National Aeronautics and Space Administration: https://gpm.nasa.gov
7. "Surface Topography and Vegetation (STV)," National Aeronautics and Space Administration: https://science.nasa.gov/earth-science/decadal-stv
8. "Civil Space Shortfalls," National Aeronautics and Space Administration: https://www.nasa.gov/spacetechpriorities
9. "NISAR NASA-ISRO SAR Mission," Jet Propulsion Laboratory: https://nisar.jpl.nasa.gov/
10. "RainCube," Jet Propulsion Laboratory: https://www.jpl.nasa.gov/missions/radar-in-a-cubesat-raincube/
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12. "Earth Sciences," National Aeronautics and Space Administration: https://earth.gsfc.nasa.gov/
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15. Racette, P.; Lang, R. H., "Radiometer design analysis based upon measurement uncertainty," Radio science. 2005, Vol. 40, Iss. 05, pp. 1-22: https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2004RS003132
16. Cooke, C. M.; Leong, K. M.; Zamora, A.; Gorospe, B. S.; Mei, X. B.; Kangaslahti, P.; et al., "A 670 GHz integrated InP HEMT direct-detection receiver for the tropospheric water and cloud ice instrument," IEEE Transactions on Terahertz Science and Technology. 2021, Vol.11, Iss. 5, pp. 566-576: https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9442381
17. Ogut, M.; Brown, S.; Misra, S.; Kittlaus, E.; Kangaslahti, P.; Murakowski, J.; Gehl, M., "Ultra-Wideband Microwave Photonic Spectrometer for Planetary Boundary Layer Sensing," 2023 IEEE Photonics Conference (IPC). 2023. pp. 1-2: https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=10360746
18. Hoppe, D. J.; Khayatian, B.; Sosnowski, J. B.; Bruneau, P.; Johnson, A.; Reising, S. C.; Brown, S. T., "A three-frequency feed for millimeter wave radiometry," Microwave and Optical Technology Letters. 2012, Vol. 54, No. 11, pp. 2483-2487: https://onlinelibrary.wiley.com/doi/pdfdirect/10.1002/mop.27118

Space Communications and Navigation (COMNAV)

COMNAV.1.S26B: Flight Dynamics and Navigation Technologies (SBIR) (previously H9.03)

Lead Center: GSFC

Participating Center(s): JPL, MSFC, JSC

Subtopic Problem Statement/Description:

NASA is planning increasingly ambitious space missions resulting in unique demands of flight dynamics and navigation algorithms across a variety of designs and operations.

This subtopic seeks advancements in autonomous navigation and maneuvering technologies to reduce dependence on Earth-based tracking, orbit determination, and maneuver planning operations. Trajectory optimization design algorithm advancements that support or enable autonomous technologies are also requested. Future missions require a high degree of onboard autonomy that combines higher level mission planning with onboard state estimation and maneuver targeting/optimization. Relevant NASA applications include precision landing, rendezvous and proximity operations, noncooperative object capture, crewed and uncrewed missions in cislunar space, multiple small body rendezvous/flyby missions, formation flying, constellation design, and coordinated operations between Earth orbit, cislunar space, libration orbits, and deep space.

Specific priorities include:

- Application of autonomous guidance and navigation algorithms into onboard planning and scheduling algorithms.
- Computationally efficient algorithms and software that can be run onboard for safe, precision landing on small bodies, planets, and moons, including real-time 3D terrain mapping, autonomous hazard detection and avoidance, and terrain relative navigation algorithms that leverage active lidar-based imaging.
- Computer vision techniques to support optical/terrain relative navigation and/or spacecraft rendezvous/proximity operations at unmapped bodies without a long survey/mapping phase and can operate in low and variable lighting conditions.

- Demonstration of high-performance space computing-type assets integrated with complex navigation and guidance algorithms, such as SLAM, TRN, or in-flight convex optimization.
- Novel guidance and trajectory optimization algorithms to prototype with ground simulators or onboard spacecraft to reduce onboard mission system uncertainty and/or maintain in-flight operations constraints.
- Design of guidance algorithms modeling low-thrust propulsion in a multi-body dynamical environment, including small-body exploration.
- Advancement of time estimation using onboard clock and observable processing algorithms for supporting end user spacecraft precision PNT.

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

Primary Technology Taxonomy:

- Level 1: TX05 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems
- Level 2: TX05.4 Network Provided Position, Navigation, and Timing
- Level 3: TX05.6.1 Orbital Debris Tracking

Desired Deliverables of Phase I:

Phase I research shall demonstrate technical feasibility and deliver preliminary software to NASA, as well as present an integration plan with future stakeholders.

The Phase I software or algorithm deliverable should demonstrate proof of concept tied to material mentioned in the subtopic problem statement/description. An integration plan should include potential stakeholders, a proposed plan of technology maturation to an algorithm or software deliverable for a potential stakeholder, and an initial list of risks and mitigation to that maturation plan.

Desired Deliverables of Phase II:

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

The Phase II software or algorithm deliverable should demonstrate the technology innovation in its complete or preliminary integration and testing form as tied to material mentioned in the subtopic problem statement/description.

Desired Deliverable Types of Phase II:

- Analysis
- Software
- Research (STTR Only)

State of the Art:

Current state of the art of flight dynamics and navigation algorithms are optimized to ground based computing capabilities and design iterated to support previous NASA missions requirements and subsequent model fidelity. Across the industry, these algorithms are developed to state-of-the-art(SOTA) ground computing resources that require significant processing and power consumption needs.

Current autonomous navigation and maneuvering algorithms rely heavily on the ground for tracking data, data processing, and decision making. Be it ground supporting or onboard, trajectory guidance algorithms fall into categories of direct, indirect, and global optimization methods depending on problem definition and resource limitations. Current SOTA methods for ground support or onboard algorithms for a variety of mission problems can include, but are not limited to, single/multiple shooting methods [1], direct collocation and nonlinear programming methods [2], sequential convex programming, Pontryagin's minimum principle, particle swarm, monotonic basin hopping [3], genetic algorithms, and many other variants. Navigation algorithms look at using unique onboard navigation measurement models such as optical [9], terrain relative [9], and lidar based algorithm processed alongside various state estimation methods. The extended Kalman filter is an industry standard of state estimation, but methods such as unscented Kalman filter and others are potential SOTA standard estimation methods [10,11].

Critical Gaps:

NASA's flight dynamics and navigation systems currently depend heavily on ground support for tracking, data processing, and decision-making. As missions venture farther from Earth and involve multiple coordinating spacecraft, communication delays make ground-based navigation impractical. NASA currently has limited navigational and guidance technologies that permit fully autonomous approach, proximity operations, distributed spacecraft operations, and landing without support from Earth-based resources.

Existing guidance algorithms rely on simplified optimal control methods designed to minimize computational demands. These methods require strict constraints (such as convex objective functions and observable, controllable system states) to function reliably. Complex missions in sensitive dynamical regimes routinely push these guidance algorithm limits; it is standard to have a human in the loop analyst to compensate for mission system uncertainty and design iteration with other mission components. Technology developments that support novel algorithms on the ground or robustness to established guidance algorithms are desired.

Shortfalls And Decadal Surveys:

This subtopic addresses technology shortfall gaps from the July 2024 NASA Civil Space Shortfall Rankings Report (https://www.nasa.gov/wp-content/uploads/2024/07/civil-space-shortfall-ranking-july-2024.pdf?emrc=7dbadc):

- Position, Navigation, and Timing (PNT) for In-Orbit and Surface Applications (ID 1557)
- Autonomous Guidance and Navigation for Deep Space Missions (ID 1531)
- Deep Space Autonomous Navigation (ID 1559)

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

References:

1. General Mission Analysis Tool (GMAT): https://software.nasa.gov/software/GSC-18094-1, https://gmat.atlassian.net/wiki/spaces/GW/overview?mode=global
2. Collocation Stand Alone Library and Toolkit (CSALT) Software: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170003690.pdf
3. Evolutionary Mission Trajectory Generator (EMTG)Software: https://software.nasa.gov/software/GSC-16824-1, https://github.com/nasa/EMTG
4. Copernicus: https://software.nasa.gov/software/MSC-26673-1 , https://www.nasa.gov/centers/johnson/copernicus/index.html .
5. Mission Analysis Low-Thrust Optimization (MALTO) Software: https://software.nasa.gov/software/NPO-43625-1
6. Mission Analysis, Operations, and Navigation Toolkit Environment (MONTE) Software: https://montepy.jpl.nasa.gov/
7. Core Flight System (cFS) Software: https://cfs.gsfc.nasa.gov/

8. LunaNet: https://esc.gsfc.nasa.gov/news/_LunaNetConcept
9. Goddard Image Analysis and Navigation Tool (GIANT) Software: https://github.com/nasa/giant
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11. autoNGC: https://ntrs.nasa.gov/api/citations/20240005228/downloads/autoNGC_SMD_Software_Workshop.pdf
12. Mercer, Carolyn, et al., "Autonomous Navigation Demonstration Relevance Assessment Team (ANDRAT) Report," https://science.nasa.gov/wp-content/uploads/2024/09/andrat-final-report.pdf

COMNAV.2.S26B: Lunar 3GPP Capability Development (SBIR) (previously H9.08)

Lead Center: GRC

Participating Center(s): JSC

Subtopic Problem Statement/Description:

Terrestrially, substantial investments have been made in the Third Generation Partnership Project (3GPP) standards and technology over the past several decades of 3G/4G/5G development and operation. NASA is seeking to leverage this extensive development for the deployment of cost-effective and highly capable networking systems within the lunar communications architecture. However, operating in the lunar environment can be drastically different than operating terrestrially. This subtopic encourages the development that is needed to adapt terrestrial 3GPP technologies into a format suitable for the lunar environment, whether in terms of hardware (e.g. radiation hardening), software (e.g. lunar analysis tools), or modeling (e.g. lunar regolith propagation and scattering). This technology is urgently needed to close gaps in the lunar communications architecture and support the mission objectives of the Artemis program.

NASA's Space Communications and Navigation (SCaN) program seeks innovative approaches to leverage terrestrial cellular technologies, standards, and architectures to establish and grow an adaptable and interoperable lunar communications infrastructure capable of supporting a wide range of future lunar mission users through lunar surface assets as well as orbiting relay constellations. The Lunar Third Generation Partnership Project (3GPP) Capability Development subtopic specifically focuses on 3GPP-compatible hardware that can operate in space and on the lunar surface, channel modeling pertinent to operation of 3GPP networks on the lunar surface, advances in 3GPP waveforms beneficial to deployment of lunar networks, and demonstration of capabilities for Non-Terrestrial Networks (NTN) applicable to use from lunar orbit to lunar surface.

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

Primary Technology Taxonomy:

- Level 1: TX05 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems
- Level 2: TX05.2 Radio Frequency
- Level 3: TX05.2.7 Innovative RF Technologies

Desired Deliverables of Phase I:

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

Desired Deliverables of Phase II:

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

Desired Deliverable Types of Phase II:

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

State of the Art:

NASA's Draft LunaNet Interoperability Specification has baselined 3GPP release 16 or later for short-to-medium range wireless networking with mobility and roaming.

The technology need for the lunar communication architecture includes:

- SWaP-efficient 3GPP hardware deployable as hosted payloads on lunar missions (habitats, rovers), surface assets (Commercial Lunar Payload Services (CLPS) landers), or orbital assets.
- Connectivity between surface and orbital assets for trunk links, continuous coverage of the lunar south pole and far side, as well as potential direct-to-handheld orbital 5G links.
- Effective characterization of 3GPP network performance in the lunar environment through channel modeling and emulation.
- Efficient use of lunar communication spectrum while avoiding the generation of interference (e.g., sensitive radio astronomy science concerned with very low out-of-band emissions).

Critical Gaps:

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

- Space qualification of terrestrial 3GPP hardware and standards such as radiation hardening and survivability at extreme temperatures (-180 °C to +130 °C on the lunar surface, RF front end only).
- Implementation of 3GPP-capable systems on SWaP-constrained platforms.
- Operation of 3GPP networks in GPS-denied environments.
- Direct-to-handheld (DTH) connectivity, including tolerance for high Doppler and high latency from lunar orbit.

- Device-to-device connectivity when one or more devices cannot see a 5G tower.
- Precision PNT over the surface link to augment availability and precision of overhead navigation assets.

Shortfalls And Decadal Surveys:

The 2026 Civil Space Shortfalls indicates the following shortfall: "Operate multi-agent robotic and crewed systems in cooperative planetary surface activities", with the associated need described as: "Provide scalable, reliable surface-to-surface communications between assets on the lunar surface that is usable by all participating elements." A subsequent relevant need is to: "Achieve safe, efficient human-robot interactions for exploration missions, secure command and control over high-latency, bandwidth-limited networks, or implement reliable automated safing sequences." The references for these shortfalls and needs are ESDMD #0103 (Moon) and ESDMD #1005 in the NASA Moon-to-Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix.

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

References:

Several related reference documents include:

1. 2025 NASA M2M Communications and Navigation Needs for the Foundational Exploration Segment: https://ntrs.nasa.gov/api/citations/20250010953/downloads/ACR25%20-%20WP%20-%20FE%20CPNT%20v2.pdf
2. 2023 NASA M2M Lunar Communications and Navigation Architecture White Paper: https://www.nasa.gov/wp-content/uploads/2024/01/lunar-communications-and-navigation-architecture.pdf?emrc=f1a91a
3. 2020 NASA Technology Taxonomy: https://www.nasa.gov/sites/default/files/atoms/files/2020_nasa_technology_taxonomy.pdf
4. LunaNet Interoperability Specification: https://www.nasa.gov/wp-content/uploads/2025/02/lunanet-interoperability-specification-v5-baseline.pdf
5. International Communications System Interoperability Standards (ICSIS): https://ntrs.nasa.gov/citations/20240016079
6. *IOAG Future Lunar Communications Architecture Report: https://ioag.org/wp-content/uploads/gravity_forms/6-1a23b5e730ab942f4b44183168a5bb93/2025/04/Lunar-communications-architecture-study-report-FINAL-v1.3.pdf*
7. Space Frequency Coordination Group Recommendation REC SFCG 32-2R6 - Communication and Positioning, Navigation, and Timing Frequency Allocations and Sharing in the Lunar Region: https://sfcgonline.org/index.php?gf-download=2025%2F07%2F%2FREC-SFCG-32-2R6-Freqs-for-Lunar-Region.pdf&form-id=7&field-id=9&hash=e20034f86a3e9a1c685e6793f481a7b286be2ac3685380754b50b02126c38dce
8. CCSDS 883.0-B-1: https://ccsds.org/Pubs/883x0b2.pdf

Space Precision Components: Galaxies to Atoms (COSMO)

COSMO.2.S26B: Cryogenic Systems for Instruments (SBIR) (previously S16.07)

Lead Center: GSFC

Participating Center(s): JPL

Subtopic Problem Statement/Description:

Cryogenic cooling systems are essential for the advancement of NASA's science goals. Cryogenic cooling is required for telescopes and other instruments that detect electromagnetic radiation in the sub-mm through near-infrared wavelength band, as well as ultra-sensitive detectors for sub-mm through x-ray photons. Thus, cryogenics is an essential part of many advanced NASA missions in Astrophysics, Earth Science, and solar system exploration. Development of miniature, low power cryogenic coolers will enhance the science capability of SmallSats and CubeSats for Earth and Lunar observations, including swarm arrays of SmallSats for high-resolution remote sensing. They also enhance the capability of small in-situ instruments on landers and rovers.

Additionally, quantum mechanical behavior becomes more readily apparent at low temperatures. Many of the devices currently under development for manipulation of quantum states, such as quantum memory, require cryogenic temperatures. Thus, cryogenics will likely be necessary for future on-orbit quantum communication and sensing systems.

This SBIR subtopic seeks ideas to improve cryogenic cooling systems that cover a broad range of temperatures. At the higher cryogenic temperature range (> 20 K), smaller, lower power devices are emphasized. Such coolers would enable new capability, such as near and mid-IR instruments on SmallSats and CubeSats for Earth and Lunar observations, as well as on instruments for outer planet missions, where power budgets are tightly constrained. In the low temperature range (10 K > T > 4 K), improved cryocoolers are needed primarily for astrophysics, for cooling of far and mid-IR optics and for cooling sensitive detectors. In the very low temperature range (T < 4 K), advances in magnetic coolers enable the use of large arrays of ultra - sensitive superconducting detectors. While these detectors are primarily needed for astrophysics, quantum communication applications are also a growing area of interest. The subtopic also seeks ideas for related cryogenic technologies, including:

- Advanced heat transport technologies to efficiently cool remotely located detectors, or transport cryocooler waste heat to radiators. This includes reliable solid-state conductors with variable thermal conductance to enable one cryocooler to efficiently cool two or more targets at significantly different temperatures with varying heat inputs
- Advanced thermal insulation systems
- Low power dissipation actuators

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

Primary Technology Taxonomy:

- Level 1: TX14 Thermal Management Systems
- Level 2: TX14.1 Cryogenic Systems

Desired Deliverables of Phase I:

Phase I must deliver a Proof-of-concept demonstration, which can include a subscale prototype or a breadboard-level device test for components, validating critical design parameters.

Desired Deliverables of Phase II:

Phase II must deliver a working prototype or functioning hardware ready for functional and environmental testing in relevant environments, demonstrating critical performance parameters. The deliverable must include a plan delineating the further work required for full operational and commercial use.

Desired Deliverable Types of Phase II:

- Hardware
- Prototype

State of the Art:

The current State of the Art (SOA) for spaceflight cryocoolers is currently exemplified by hybrid systems like the Mid-Infrared Instrument (MIRI) cooler on the James Webb Space Telescope (JWST), which provides approximately 55 mW of cooling at 6 K. However, miniature cryocoolers struggle to operate within the tight power constraints of outer planetary missions, and no lightweight coolers (less than 3 kg) can provide cooling below 20 K. For sub-Kelvin cooling, the SOA is the Hitomi mission's adiabatic demagnetization refrigerator (ADR), which provides 0.35 uW of cooling at 0.050 K with a 95% duty cycle. Furthermore, current cryogenic actuators (motors with resistive windings) have a high heat dissipation of approximately 0.5 W at 4 K, which is at least 20 times too high for flight instruments.

Critical Gaps:

Orders-of-magnitude reduction in exported vibration from coolers, especially at frequencies below a few hundred hertz, for instruments with tight pointing requirements (Tier 1 Technology Gap in 2024 ABTR).

Development of miniature, high-efficiency cryocoolers (input power less than 20 W, mass less than 400 g) for SmallSats/CubeSats to provide cooling below 20 K, and low-cost, radiation-hard cryocooler electronics.

Development of sub-Kelvin cooling systems that provide continuous cooling with high power (greater than 5 uW at 50 mK) and a 100% duty cycle, needed for future large-pixel arrays (Tier 1 Technology Gap in 2024 ABTR).

Small, precise motors and actuators with extremely low power dissipation (less than 25 mW at 4 K) and superconducting windings.

Advancements in thermal insulation systems, including innovative concepts to reduce layer-to-layer thermal conduction in multi-layer insulation (MLI) below 70 K and superior solutions for radiation insulation of bipods.

Reliable solid-state conductors with variable thermal conductance (0.05 to 0.005 W/K) to efficiently cool multiple targets at significantly different temperatures.

Improvements in components for ADRs, such as high cooling-power-density magnetocaloric materials and compact, lightweight superconducting magnets (4 T field at greater than 10 K).

Shortfalls And Decadal Surveys:

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:

1. "Astrophysics Biennial Technology Report 2024," National Aeronautics and Space Administration: https://apd440.gsfc.nasa.gov/images/tech/2024 ABTR.pdf
2. "Quantifying MLI thermal conduction in cryogenic applications from experimental data," Ross, R. G., IOP Conference Series: Materials Science and Engineering. 2015: https://iopscience.iop.org/article/10.1088/1757-899X/101/1/012017/pdf
3. "Cryogenic Thermal Coatings Final Report," Gibson, T. L.; Nurge, M. A.; Youngquist, R. C.; et al., 2022: https://ntrs.nasa.gov/api/citations/20220016987/downloads/CFT-RPT-0015%20Cryogenic%20Thermal%20Coating%20Final%20Report Basic Native Final WO%20Signature%20Page.pdf
4. "Thermodynamic performance of the 3-stage ADR for the Astro-H Soft-X-ray Spectrometer instrument," Shirron, P. J.; Kimball, M. O.; James, B. L.; et al., Cryogenics. 2016: www.sciencedirect.com/science/article/pii/S001122751500137X

COSMO.3.S26B: AI for Rapid Development of Space Precision Components (SBIR) (previously S17.06)

Lead Center: GSFC

Participating Center(s): Not Defined

Subtopic Problem Statement/Description:

NASA's Text-to-Spaceship Vision has highlighted the potential for AI-enabled, agentic design automation to accelerate space hardware development and improve performance through rapid iteration and broader trade-space exploration. Future astrophysics missions require space precision components with extreme stability, alignment control, low noise, and high reliability across thermal, structural, optical, cryogenic, and electronics domains. These components are often custom, tightly coupled across disciplines, and developed through long, iteration-heavy cycles that drive schedule and cost risk. NASA seeks innovative AI-enabled design automation approaches that can reduce the time from requirements to manufacturable, verified designs for instrument and observatory components by at least 5×, while improving performance, traceability, and manufacturability.

This subtopic solicits AI-based design automation tools or frameworks that ingest concise requirements (natural language, MBSE artifacts, or standard digital files such as STEP and IGES), generate a candidate design, execute embedded physics-based or surrogate analyses, and return a verification report with pass/fail metrics traceable to requirements. Approaches may use agentic workflows and, where multiple disciplines are coupled, multi-agent workflows in which specialized agents collaborate across domains such as structures, thermal, optics, electronics, and manufacturing to automate handoffs and converge on validated designs with human engineers in the loop for expert review. Solutions should be applicable to one or more precision component classes relevant to astrophysics instruments and observatories, including but not limited to optomechanical mounts and benches, thermal control hardware, detector packaging and readout integration, precision mechanisms, cryogenic interfaces, structures and materials for stability, optical elements and optical system layouts, and manufacturing process planning for tight tolerances.

Proposed solutions must focus on hardware design acceleration and, in Phase I, demonstrate feasibility on at least one subsystem or component relevant to astrophysics mission needs. Preference will be given to approaches that: (1) demonstrate an end-to-end automated design loop completed at least 5× faster than current practice, (2) incorporate embedded analyses with requirement-traceable metrics, (3) provide real-time manufacturability feedback for relevant techniques including CNC machining, additive manufacturing, PCB fabrication, composites, and optics fabrication using open standards (STEP/STEP-NC, IPC-2581, FMI, REST/JSON, and optical prescription and wavefront representations), and (4) use an agentic or plug-in architecture that can add capabilities for additional subsystems in Phase II.

Note that generative AI specifically for instrument optical hardware technologies should be directed to COSMO.4.S26B while this subtopic is for AI-based frameworks.

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

Primary Technology Taxonomy:

- Level 1: TX11 Software, Modeling, Simulation, and Information Processing
- Level 2: TX11.4 Information Processing and Artificial Intelligence

Desired Deliverables of Phase I:

- Demonstrate a prototype AI-based design automation workflow on at least one astrophysics-relevant precision component or subsystem, including a defined use case and baseline process.
- Define inputs and outputs, including the requirements ingestion method and exported design artifacts (for example CAD, drawings with GD&T, BOM, analysis models and reports, interface definitions, manufacturing and inspection data packages, and optical prescription and tolerance outputs where applicable).
- Demonstrate embedded analysis capability (physics-based and or surrogate) with requirement-traceable pass/fail metrics and documented assumptions and limits of applicability.
- Provide quantitative evidence supporting at least 5× cycle-time reduction potential for the demonstrated use case, including the baseline, measurement method, and repeatable workflow steps.
- Demonstrate compatibility with agentic workflows by exposing the core workflow functions (requirements ingestion, design generation, analysis execution, manufacturability evaluation, and verification reporting) through open, documented APIs suitable for orchestration by external agents.
- Deliver a Phase II plan that identifies the target component class, validation and test approach, manufacturability pathway, integration and API plan, and intended infusion targets.
- Provide a Phase I final report and demonstration package (inputs, outputs, scripts or configuration, and sample artifacts) sufficient for independent evaluation by NASA.

Desired Deliverables of Phase II:

- Integrated, user-operable design automation prototype that ingests requirements, generates design outputs, runs embedded analyses, and produces a verification report with traceability to requirements.
- Demonstration on an astrophysics-relevant precision component or subsystem at higher fidelity, including manufacturability assessment and production-ready data products.
- Fabricated prototype hardware or equivalent manufacturing demonstration (as appropriate to the component class), with test or verification evidence supporting performance claims.
- Open, documented APIs and data interfaces enabling compatibility with broader digital engineering workflows and orchestration within agentic and multi-agent design workflows (for example STEP/STEP-NC, IPC-2581, FMI, REST/JSON as applicable).
- Transition package including integration guidance, performance metrics, validation results, and an infusion and commercialization plan aligned with NASA astrophysics mission needs and adjacent precision-instrument markets.

Desired Deliverable Types of Phase II:

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

State of the Art:

The current state of practice for developing precision space instrument components relies on human-led engineering workflows using computer-aided design and physics-based simulation (structural, thermal, optical, cryogenic, electronics), followed by extensive design-build-test iteration. Digital engineering has improved data management and analysis throughput, and select efforts use generative design, topology optimization, and machine-learning surrogates for narrow problems. However, most missions still depend on sequential, discipline-specific design loops, with manufacturability and verification often addressed late in the cycle and requirements traceability maintained through manual processes. Most engineering toolchains are not designed for orchestration within agentic workflows or for multi-agent collaboration across coupled disciplines (for example structures and thermal, or optics and optomechanics), so cross-domain handoffs remain labor intensive and difficult to automate. As a result, iteration speed and cost constraints frequently limit the ability to fully explore the design trade space, which can drive early selection of non-optimal architectures and reduce the opportunity to identify substantially higher-performance component and instrument designs.

Critical Gaps:

Key gaps between the state of the art and the needed capability include:

1. Limited end-to-end automation from requirements to design, analysis, and verification for flight hardware, especially for instrument-grade precision components.
2. Insufficient multi-physics integration across disciplines, which leads to late discovery of cross-coupled behaviors (for example thermoelastic distortion affecting optical stability or cryogenic performance).
3. Lack of requirement-traceable, pass/fail verification reporting generated directly from the design loop, increasing mission assurance burden and review-cycle time.
4. Limited real-time manufacturability feedback during early design, resulting in avoidable redesigns tied to tolerances, yield, or process constraints for machining, additive manufacturing, electronics packaging, composites, and optics fabrication.
5. Immature methods for establishing trust, validation, and certification of AI-enabled engineering tools for high-consequence flight hardware decisions.
6. Limited capability to rapidly explore large, multi-objective design spaces under uncertainty, increasing the likelihood of converging on designs that meet minimum requirements but miss significantly better mass, stability, thermal, optical, or cost performance.
7. Lack of open, documented APIs and standardized interfaces that enable compatibility with agentic workflows and multi-agent orchestration across disciplines, including auditable records of tool actions and handoffs suitable for engineering review.

Shortfalls And Decadal Surveys:

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

- Emplace and maintain large, stable space platforms and observatories.

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

References:

1. "NASA Astrophysics," National Aeronautics and Space Administration: https://science.nasa.gov/astrophysics
2. "Astrophysics Biennial Technology Report 2024," National Aeronautics and Space Administration: https://apd440.gsfc.nasa.gov/images/tech/2024 ABTR.pdf
3. "NASA Turns to AI to Design Mission Hardware," National Aeronautics and Space Administration: https://www.nasa.gov/directorates/stmd/tech-showcase/nasa-turns-to-ai-to-design-mission-hardware/
4. "Ask Me Anything: Multidisciplinary Space Hardware Design Automation Leveraging AI Techniques," National Aeronautics and Space Administration: https://youtu.be/0pYiw5Q2-xQ?list=PLYhPXp5DK0iuKzk2m_-wkVCjyjNivJjVC&t=619

COSMO.4.S26B: Instrument Technologies, Free-Form Optics, and Stray-Light Suppression (SBIR) (previously S12.04)

Lead Center: GSFC

Participating Center(s): MSFC, JPL

Subtopic Problem Statement/Description:

NASA seeks to push the state-of-the-art in instrumentation development for its science missions at all levels and across the spectrum, as motivated by the National Academy Astro 2020 Decadal Report and the Astrophysics Technology Update 2025. These reports highlight critical technologies, including the design, manufacturing, coating, and metrology of optical components and systems, that are essential for enabling future space observatory missions. This subtopic seeks instrument development to address the critical gaps for optical components and systems identified by these reports.

Examples of advanced instrument and optical components of interest are MEMS mirrors, diffraction gratings, prisms, deformable mirrors (DMs), including surfaces with aspheric and free-form prescriptions, and free-form photonic components. Areas of optical systems development include design and modeling, non-sequential and physical optics effects and artificial intelligence-guided design, wavefront sensing and control, stray light mitigation and suppression, instrument alignment, integration, and test, and advanced spectrometer technologies.

Successful proposals will show traceability to an identified technology need, subtopic critical gap, and present a feasible plan to develop the proposed technology for infusion into a potential, future NASA mission and/or into a commercial or other-Government product or process.

Note that detector technologies should be proposed to INSTALG.2.S26A or COSMO.1.S26A based on wavelength.

Note that observatory technologies should be proposed to COSMO.5.S26B.

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

Primary Technology Taxonomy:

- Level 1: TX08 Sensors and Instruments
- Level 2: TX08.1 Remote Sensing Instruments and Sensors

- Level 3: TX08.1.3 Optical Components

Desired Deliverables of Phase I:

Phase I deliverables typically include Reports, Analysis, and proof of concept Demonstration.

The analysis must focus on modeling and analytical techniques to predict the suitability of the proposed design.

The demonstration should show that the end product proposed can achieve specified requirements, providing a proof of concept that directly informs the subsequent Phase II effort.

Desired Deliverables of Phase II:

Phase II deliverables are Analysis, Demonstration, a Prototype, and Implement ability and Scalability.

The central deliverable is a Breadboard with test results that show sufficient data verifying the performance of the proposed design, resulting in a demonstrable prototype.

Phase II deliverables must also delineate any further work that would be required to bring the technologies to full operational and/or commercial use.

The technology needs to be able to be implemented into a mission and scale.

The expected outcome after Phase II is the delivery of system/subsystem units that have undergone successful demonstration of appropriate-TRL performance tests.

Desired Deliverable Types of Phase II:

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

State of the Art:

The current state of the art (SOA) for specialized optical components is defined by the need for high precision but constrained by significant cost and maturity limitations in fabrication. The entire process of optics manufacturing, metrology, coating, testing, and assembly is currently very costly and time-consuming. In the realm of thin-film coatings, filter manufacturing processes have successfully produced high transmission, narrow passbands on planar and very small, curved surfaces, but new deposition techniques are required to achieve the necessary uniformity on large and highly curved surfaces.

The field of free-form optics is in the early stages of development; while a freeform mirror with a grating can greatly reduce component count and size, their design and fabrication remains costly. The metrology of these complex optical components is also difficult and challenging due to their large departure from conventional planar or spherical shapes. Nonetheless, the trend is clear: future optical systems, particularly for low-cost missions like CubeSats, are moving toward these non-rotational symmetric surfaces to increase the field of view, expand the operational temperature range, and enable efficient, small packages.

Critical Gaps:

Priority critical gaps include (not in any particular order):

- Large diameter (> 2.5 mm) MEMS mirrors with high speed 2D scan capability, large tilt angle (> 7.5 deg), low hysteresis, high resonance frequency (> 2 kHz), low absorption at 1064 nm/1550 nm, high laser damage threshold for high peak power high repetition rate pulsed lasers, and good point knowledge (error < 0.02 deg 3-sigma).
- Freeform gratings for FUV applications, and methods for non-contact metrology of surface prescription and error across spatial scales for optics and other sensitive components (e.g., electrically-sensitive devices).
- The capability to characterize coating scatter in the Vacuum UV and far IR for a variety of different substrates (e.g., from matte to specular) with high dynamic range with high absolute accuracy and NIST traceability. This would aid in the development of surface properties for non-sequential modeling of optical system performance toward, e.g., stray light mitigation.
- BRDF (Bidirectional Reflection Distribution Function) instrumentation to characterize the scatter of black coatings to be used as masks in the UV (Lyman-alpha (Lyα)) and far IR.
- Physically accurate methods for modeling the performance of optical gratings, including short-wavelength performance and with full accuracy regarding parameters like polarization.
- Methods for non-contact metrology of surface prescription and error across spatial scales for optics and other sensitive components (e.g., electrically-sensitive devices).
- The use of generative design algorithms and artificial intelligence for problems in instrument optical design and modeling (note that AI-enhanced mission and observatory design should be proposed to S17.05).

Shortfalls And Decadal Surveys:

This subtopic directly responds to multiple high-priority civil space shortfalls and is strongly aligned with the Astro2020 Decadal Survey, particularly in support of the Habitable Worlds Observatory flagship mission. It also addresses recommendations from the Heliophysics Decadal Survey and Roadmap (2014-2033). The technologies sought are considered enabling and urgent for achieving key science objectives in exoplanet characterization, early universe observations, and high-energy astrophysics.

Decadal Surveys

Astro2020 Decadal Survey (Primary):

"The 2020 National Academies' Decadal Report specifically identifies optical components and the ability to manufacture and perform precise metrology on them needed to enable several different future missions" .

Key Astro2020 Recommendations:

- Development of X-ray observatory technologies
- Habitable Worlds Observatory (HWO) - the flagship mission recommended by Astro2020
- Optical coating technology investment for future UV, optical, exoplanet, and infrared missions

Heliophysics Decadal Survey (2014-2033): identifies the coating technology for space missions to enhance the rejection of undesirable spectral lines and improve space/solar-flux durability of extreme UV (EUV) optical coatings as well as coating deposition to increase the maximum spatial resolution" .

Key Technology Gap Documents Referenced:

The subtopic directly addresses technology gaps identified in:

1. 2024 Astrophysics Biennial Technology Report

   Link: https://apd440.gsfc.nasa.gov/images/tech/2024_ABTR.pdf
2. Current Technology Gap Priorities

   Link: https://apd440.gsfc.nasa.gov/tech_gap_priorities.html
3. 2022 Exoplanet Exploration Program Technology Gap List

   Link: https://exoplanets.nasa.gov/internal_resources/2269/

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

References:

1. "Habitable Worlds Observatory," National Aeronautics and Space Administration: https://cor.gsfc.nasa.gov/studies/habitable-worlds/hwo.php
2. "Cosmic Origins," National Aeronautics and Space Administration: https://cor.gsfc.nasa.gov/
3. "Exoplanet Discovery," National Aeronautics and Space Administration: https://exoplanets.nasa.gov/what-is-an-exoplanet/technology/
4. "NASA in-Space Assembled Telescope (iSAT) Study," National Aeronautics and Space Administration: https://exoplanets.nasa.gov/exep/technology/in-space-assembly/iSAT study/
5. "NASA Astrophysics," National Aeronautics and Space Administration: https://science.nasa.gov/astrophysics
6. "Astrophysics Technology Development," National Aeronautics and Space Administration: https://www.astrostrategictech.us/
7. "Astrophysics Biennial Technology Report 2024," National Aeronautics and Space Administration: https://apd440.gsfc.nasa.gov/images/tech/2024_ABTR.pdf
8. "Current Technology Gap Priorities," National Aeronautics and Space Administration: https://apd440.gsfc.nasa.gov/tech gap priorities.html
9. "Astrophysics Technology Update 2025," National Aeronautics and Space Administration: 2025_ATU_Final_Rev02_091825-compressed.pdf
10. Astrophysics Technology Reports Technology Resources - NASA Science

COSMO.5.S26B: Advanced Observatory Technologies: Mirrors, Structures, Systems, Fabrication and Metrology (SBIR) (previously S12.03)

Lead Center: MSFC

Participating Center(s): GSFC, JPL, GRC

Subtopic Problem Statement/Description:

This subtopic solicits solutions/advances for technologies that enable or enhance enable NASA's Advanced Observatory capability. Advanced Observatories are required to accomplish NASA's high-priority science at all levels (Flagship, Probe, Medium-Class Explorers (MIDEX), Small Explorers (SMEX), CubeSat, rocket, Pioneer and balloon) and for all wavelength regions from x-ray to ultra-violet/visible to mid- and far-infrared, even to sub-mm.

Gaps needed to enable Advanced Observatories are identified and prioritized in the "2024 Astrophysics Biennial Technology Report", "Current Technology Gap Priorities", and the "2022 Exoplanet Exploration Program Technology Gap List".

Technologies, applied either singularly or in combination, that close the identified gaps to enable advanced observatory capability include but are not limited to:

- Mirror Substrate Materials: homogeneous properties that enable technical specifications.
- Mirror Substrate Design: Stiffness, Mass, Mechanical and Thermal Stability
- Support Structure: Deployment, Adjustability, Mechanical and Thermal Stability
- Optical Fabrication and Test to required surface specifications
- Wavefront Sensing and Control

Observatory mirror systems are defined as the substrate (material and core structure), supporting structure with associated mechanisms, and active wavefront or thermal sense and control systems. The most important metrics after performance (collecting area, diffraction limit, angular resolution, and wavefront stability) are affordability, or areal cost (cost per square meter of collecting aperture), and mass. The ability to predict 'in-use' performance via validated, integrated structural thermal opto-mechanical performance (STOP) modeling is also important.

Proposals as sought that can help bridge technological gaps that limit the capability and feasibility of these next-generation science platforms. Successful proposals must show traceability to an identified technology gap and subtopic critical gap, show clear advancement over state of the art, and present a feasible plan to develop the proposed technology for infusion into a potential NASA Mission or into a commercial product or process.

Note that detector technologies should be proposed to INSTALG.2.S26A or COSMO.1.S26A based on wavelength. And optical technologies that enable instruments should be proposed to COSMO.4.S26B.

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

Primary Technology Taxonomy:

- Level 1: TX08 Sensors and Instruments
- Level 2: TX08.2 Observatories

Desired Deliverables of Phase I:

Ideal Phase 1 deliverable is (1) either a sub-scale component or breadboard that validates proposed technology in a laboratory environment; (2) preliminary design and manufacturing plan that demonstrates feasibility to scale technology to flight and integrate into a mission, or to develop technology into a laboratory instrument or commercial product. While detailed analysis will be conducted in Phase II, Phase 1 must do a feasibility analysis and perform sufficient preliminary design and analysis to address how optical, mechanical (static and dynamic), and thermal designs and performance analyses will be done to show compliance with all requirements. Past experience or technology demonstrations that support the design and manufacturing plans will be given appropriate weight in the Phase 2 evaluation.

Desired Deliverables of Phase II:

Ideal Phase 2 project further advances the technology and delivers a flight-qualifiable and scalable observatory system prototype, sub-system or relevant components (with TRL in the 4 to 5 range); or a commercial product that enables the design, fabrication and/or testing of Advanced Observatories.

- If the Phase 2 is developing an observatory technology, hardware deliverables (i.e. prototype, sub-system or relevant components) would be accompanied by all necessary documentation, including the performance assessment and all data on processing and material properties. A successful mission-oriented Phase II would have a credible plan to deliver for the allocated budget a fully assembled and tested assembly or component that can be integrated into the potential mission as well as demonstrate an understanding of how the engineering specifications of their system meets the performance requirements and operational constraints of the mission (including mechanical and thermal stability analyses). Phase II deliverables should also include/delineate any further work that would be required to bring the technologies to full operational and/or commercial use.
- If the Phase 2 is developing a commercial instrument to enable Advanced Observatories, then the Phase 2 deliverable should be the commercial instrument with all necessary operational documentation.

Please note that MSFC has several polishing stations that can be used as implementation testbeds, including Zeeko, OptiPro and a 2-m swing-arm polisher. Offerors are encouraged to seek facility agreements, if needed, during proposal development.

Desired Deliverable Types of Phase II:

- Analysis
- Hardware
- Prototype

State of the Art:

State of Art (SOA) for an X-ray observatory is defined by Chandra for high-angular resolution and IXPE for thin mirrors with medium-angular resolution. Performance SOA is ~10 arcsec angular resolution. This is limited by ability to manufacture mirror shells and assemble those shells into a telescope. Current SOA in CNC polishing of full shell substrate, grazing incidence optics yields better than 2.5 arcsec HPD on the mandrel used for replicating shells. Additionally, optics manufacturing, metrology, coating, testing, and assembly is very costly and time consuming. X-ray space mirrors cost $4M to $6M per square meter of optical surface area. Finally, current stray light suppression is bulky and ineffective for wide field of view telescopes.

SOA for an UVO Observatory is defined by Hubble and the soon to be launched Roman space telescopes to be 2.4-m monolithic diameter with diffraction limit of 500 nm and operating at ~ 300K. Both the Hubble and Roman primary mirrors are very stiff (Hubble is ~ 400 Hz). Roman's thermal control is < ~ 1-mK.

SOA for a large deployed segmented aperture telescope is defined by the Webb space telescope to be ~ 6-m diameter, with a diffraction limit of ~ 1 to 1.5 micrometers and operating at 50K. Webb's primary mirror structure first mode is ~ 16 Hz. Its segments have rocking modes from 40 to 50 Hz. And its secondary mirror tower first mode is < ~ 7 Hz. The Webb primary mirror assembly cost was $4M to $6M per sq meter.

Critical Gaps:

Current critical gaps for Advanced Observatories include (in no particular order):

- X-ray observatories require manufacturable, stiff, thin mirrors with broadband high reflectance coatings and effective stray light suppression. Improvements advancing state of the art include:

    - 2 arcsec or better angular resolutions and
    - 1 to 5 m2 collecting areas.
    - Improvements are sought to reduce the areal cost of an X-ray mirror assembly to a target goal of \$1M to \$100K per m^2.
- UV/Optical observatories desire telescopes with monolithic apertures from 1.5 to 6 m, or segmented apertures from 6 to 16 m, with diffraction-limited performance as good as 0.3 µm.
    - For observatories with a coronagraph an instrument is needed that can quantify diffuse (and if possible angular) scattered light at angles between 50 and 500 milli-arc-seconds from specular caused by micrometeoroid impacts. Please note that micrometeoroid impacts consist of a central ballistic crater surrounded by a large (20-mm or more) fracture or spall region.
    - Observatories with segmented apertures need:
        - Mirrors from 1.5 m to 3.5 m size with 80% (nominal) light-weighting, greater than 150 Hz first mode, surface figures less than 5 nm rms, and less than 5 ppb/K coefficients of thermal expansion (CTE) homogeneity.
        - Structure and deployment technologies to produce the required aperture size and produce the required performance. Of special importance is the structure's mechanical and thermal stability, and ability to shield the primary mirror from micrometeoroid impacts.
        - Active sense and control technology is required to maintain the required performance. Mirror areal density depends upon available launch vehicle capacities (ranging from 15 to 150 kg/m^2).
    - Improvements are sought to reduce the areal cost of UV/O mirror assembly to a target goal of \$1M to \$4M per m^2.
- Far-IR observatories require telescopes with apertures from 1.5 to 6 m monolithic or 16 m segmented with diffraction-limited performance as good as 5 µm operating at lower than 10 K (survival temperature from 4 k to 315 K). Mirror substrate thermal conductivity at 4 K must be greater than 2 W/m·K. Ideally, the mirror should have less than 100 nm rms surface figure change from 300 K to 10 K. Mirror areal density goal is 25 kg/m^2 for the primary mirror substrate and 50 kg/m^2 for the primary mirror assembly (including structure). Primary mirror areal cost goal is below \$100K/m^2.
- CubeSAT missions need low-cost, compact, scalable, diffraction-limited, and athermalized off-axis reflective and on-axis telescopes. One potential mission is for near-infrared/short-wave-infrared- (NIR/SWIR-) band optical communication.
- Balloon missions require light-weight observatories (because of balloon mass lift constraints) that can meet mid-IR diffraction limited performance over the temperature range and at all elevation angles. Furthermore, balloon missions are significantly cost constrained.

Computer-controlled polishing is an example of a technology that can be developed to address gaps in more than one of the above areas. Computer-controlled polishing is a mature technology for normal incidence UVOIR mirrors, but it is not mature for X-ray and aluminum far-infrared mirrors. Technology advances beyond current SOA include:

1. Polishing UVO space-flight mirrors to less than 5 nm rms to enable on-orbit 300 nm diffraction limited observatories
2. Allowing for direct force closed-loop control
3. Reducing alignment precision requirements
4. Optimizing the machine for polishing cylindrical optics through simplifying the axis arrangement and the layout of the polishing machine.

Shortfalls And Decadal Surveys:

National Research Council NASA Technology Roadmap Assessment ranked advanced mirror technology for new x-ray telescopes as the #1 Object C technology requiring NASA investment. This underscores the critical importance of this technology area to NASA's mission objectives. National Academies' Astro 2020 Decadal Report specifically identifies studies of optical components, and the ability to manufacture, coat, and perform metrology on them, as required to enable future X-ray and UV/Optical/IR observatory missions. Advanced mirror technology for X-ray optics continues to be a NASA Astrophysics technology gap priority.

"Pathways to Discovery in Astronomy and Astrophysics for the 2020s," (Astro2020), National Academies: https://nap.nationalacademies.org/catalog/26141/pathways-to-discovery-in-astronomy-and-astrophysics-for-the-2020s

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

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

"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

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

- Emplace and maintain large, stable space platforms and observatories

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

References:

1. "NASA Astrophysics," National Aeronautics and Space Administration: https://science.nasa.gov/astrophysics
2. "Astrophysics Biennial Technology Report 2024," National Aeronautics and Space Administration: https://apd440.gsfc.nasa.gov/images/tech/2024 ABTR.pdf
3. "Current Technology Gap Priorities," National Aeronautics and Space Administration: https://apd440.gsfc.nasa.gov/tech_gap_priorities.html
4. "The 2022 Exoplanet Exploration Program Technology Gap List," National Aeronautics and Space Administration: https://exoplanets.nasa.gov/internal_resources/2269/
5. "Astrophysics Technology Development," National Aeronautics and Space Administration: https://www.astrostrategictech.us/
6. Dankanich, J. W.; Kremic, T.; Hibbitts, K.; Young, E. F.; Landis, R., "Planetary Balloon-Based Science Platform Evaluation and Program Implementation," 2016, No. GRC-E-DAA-TN24412: https://ntrs.nasa.gov/api/citations/20160003075/downloads/20160003075.pdf
7. "Columbia Scientific Balloon Facility," National Aeronautics and Space Administration: https://www.csbf.nasa.gov/docs.html
    - Additional information about scientific balloons.
8. Edwards, B. L., "NASA’s current activities in free space optical communications," International Conference on Space Optics—ICSO 2014, 2017, Vol. 10563, pp. 255-263: https://doi.org/10.1117/12.2304175

- An example of an on-axis design has been utilized in the Lunar Laser Communications Demonstration (LLCD).

9. Roberts, W. T., "Discovery deep space optical communications (DSOC) transceiver," Free-Space Laser Communication and Atmospheric Propagation XXIX. 2017, Vol. 10096, pp. 229-243): https://doi.org/10.1117/12.2256001
    - An example of an off-axis design is being developed by the Jet Propulsion Laboratory (JPL) for Deep Space Optical Communications (DSOC).

Space Weather (SPWX)

SPWX.2.S26B: Sensors and Instrumentation for Space Environment Measurement (SBIR) (previously S14.02)

Lead Center: GSFC

Participating Center(s): MSFC, LaRC

Subtopic Problem Statement/Description:

From *The Next Decade in Solar and Space Physics: Exploring and Safeguarding Humanity's Home in Space (2025*), "a robust and sustained technology development program 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."

For the subtopic *Sensors and Instrumentation for Space Environment Measurement*, development of advanced remote-sensing and in situ instrument technologies and components suitable for Heliophysics missions for solar and geospace science, Moon2Mars, and space weather applications are the solicited technologies that must be capable of withstanding operation in space environments. These environments include the expected pressures, radiation levels, launch and impact stresses, and range of survival and operational temperatures. This solicitation prioritizes key sensor subsystems' technology developments that result in a reduction of mass, power, volume, and data rates for instruments and instrument components without loss of scientific capability while providing greater scalability for mass production.

Expected TRL or TRL Range at completion of the Project: 3 - 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 must deliver analysis or a test report, a prototype of an instrument subcomponent, or a full working instrument prototype. It should also describe expected test regimens for the completed technology, including required facilities or equipment, and provide a general timeline for testing (including Phase II and beyond).

Desired Deliverables of Phase II:

Phase II must deliver a prototype or demonstration of a working instrument or subcomponent, which may also include analysis or test reports. 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
- Hardware
- Prototype

State of the Art:

The current State of the Art is limited by the trade-off between instrument size and scientific capability, particularly for the emerging constellation-type missions that require reduced mass, power, and volume. Mass production of instruments is highly limited due to the mass, power, volume of current sensors. Existing instrumentation and technologies can accurately measure many key geospace and solar parameters only on large, dedicated satellite platforms and require significant development timelines.

Critical Gaps:

This subtopic seeks technological innovations to address critical gaps in:

- Instruments and technologies that enable Decadal Survey priority missions.
- System science-enabling small instruments designed for mass production.
- Intelligent sensors with embedded AI/ML processing.
- High-voltage control elements (e.g., optocouplers or transistors) and ultra-high-voltage power supplies for space that reduce size, mass, and power.
- Technologies to enable remote sensing of magnetic fields in the solar corona and neutral winds in the upper atmosphere.
- Energetic Neutral Atom (ENA) imaging technologies.
- Light detection and ranging (LIDAR) systems for high-power, high-frequency geospace remote sensing (e.g., lasers for detecting the sodium layer).
- Relativistic electron accelerator technologies for active sounding.
- Technologies for precise radiometry at terahertz (THz) bands (1-5 THz range, particularly 4.7 THz), focusing on reducing size, mass, and power, and improving signal-to-noise ratio (SNR).
- Technologies or components enabling auroral, airglow, geospace, and solar imaging at Visible, FUV/EUV, and soft X-ray wavelengths (e.g., mirrors, gratings, filters with high-reflectance coatings).
- Fast-cadence solid-state detectors or camera systems for imaging in the EUV and for soft or hard X-rays (0.1 to hundreds of keV), preferably with the ability to detect individual photons.
- Technologies to improve or enable the rejection of background X-rays in the 1 to 300 keV range.
- Magnetic core materials suitable for incorporation into science-grade flux-gate magnetometers.
- Technologies to support the development of boomless magnetometers.
- Technologies for improved detection of low-energy (less than 10 keV) ions and electrons and for the efficient conversion of neutrals (less than 1 keV) to charged particles.

- Technologies to efficiently measure very low energy <10eV particles (neutrals, ions, or electrons).
- Compactly stowed, lightweight, long, straight, and rigid booms as part of deployment mechanisms for sensitive electric and magnetic instrumentation compatible with CubeSats or SmallSats.
- Technologies for black coatings are effective at rejecting extreme ultraviolet (EUV) photons and resistant to atomic oxygen.

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: Near-Term (Less than 5 years)

References:

1. "Our Dynamic Space Environment: NASA Heliophysics Science and Technology Roadmap for 2014-2033," National Aeronautics and Space Administration: https://explorers.larc.nasa.gov/HPSMEX/MO/pdf_files/2014_HelioRoadmap_Final_Reduced_0.pdf
2. Christe, S., et al., "2023 HEliophysics Strategic Technology Office (HESTO) Gap and Trend Analysis," Zenodo, Jun. 21, 2023: https://zenodo.org/record/8091762
3. "NASA Science Missions," National Aeronautics and Space Administration: https://science.nasa.gov/science-missions/

Technology for In Situ Science Operations on Planetary Bodies (INSITU)

INSITU.1.S26B: Fault Management Technologies for Autonomous Systems (SBIR) (previously S17.03)

Lead Center: GRC

Participating Center(s): ARC, MSFC

Subtopic Problem Statement/Description:

NASA SMD seeks to answer many long-standing questions about our planet, Sun, solar system, and beyond as well as enable space exploration. NASA's science program has well over 100 spacecraft in operation, formulation, or development, generating science data accessible to researchers everywhere. As science missions have increasingly complex goals—often on compressed timetables—and have more pressure to reduce operation costs, system autonomy must increase in response. Fault management is a critical enabling factor in autonomous systems to determine proper corrective actions after an unplanned event, large disturbance, or fault.

Fault management (FM) is a key component of system autonomy, serving to detect, interpret, and mitigate failures that threaten mission success. Robust FM must address the full range of hardware failures and also must consider failure of sensors or the flow of sensor data, harmful or unexpected system interaction with the environment, and problems due to faults in software or incorrect control inputs—including failure of autonomy components themselves. Challenges related to linear, nonlinear, discrete, or continuous systems must be considered in the design of the approach. For example, critical subsystems such as the electric power system (EPS) and attitude control systems (ACS) require advanced FM techniques to achieve extremely high levels of mission reliability. Furthermore, interactions between subsystems should also be investigated, as the effect of faults may propagate from one critical system to another.

This subtopic addresses particular interest in onboard FM capabilities, namely, onboard sensing approaches, computing, algorithms, and models to assess and maintain spacecraft health. The higher goal is to provide a system capability for management of future spacecraft. Offboard components such as modeling techniques and tools, development environments, and verification and validation (V&V) technologies are also relevant, provided they contribute to novel or capable onboard FM.

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

Primary Technology Taxonomy:

- Level 1: TX10 Autonomous Systems
- Level 2: TX10.2 Reasoning and Acting Technologies

Desired Deliverables of Phase I:

Phase I must deliver an Initial proof of concept of the novel Fault Management (FM) technology. Deliverables include:

- Thorough documentation of the innovation, its status, approach, foundational concepts, operating theory, mathematical basis, and requirements for application.
- Results including strengths and weaknesses found and measured performance in tests where possible.
- Demonstration of technical feasibility and NASA relevance, showing a path toward a Phase II prototype demonstration.

Desired Deliverables of Phase II:

Successful completion of a Phase II effort implies development of a novel Fault Management technology through at least the prototype stage. Deliverables include:

- For algorithmic innovations: development code or prototype applications, demonstrations of capability, and results of algorithm stress testing.
- For procedural innovations: sample artifacts such as workflows, model prototypes and schema, functional diagrams, examples, or tutorial applications.
- Test reports that discuss maturation of the technology, implementation difficulties overcome, and quantifiable, reproducible results against a relevant mission dataset.
- Description of commercial potential and future work expected to adapt the technology to other applications.
- Establishment of a preliminary performance model describing technology metrics and requirements.

Desired Deliverable Types of Phase II:

- Analysis
- Prototype
- Software

State of the Art:

Despite lessons learned from past missions, spacecraft failures are still not uncommon, and reuse of FM approaches is limited. This illustrates the deficiencies in current approaches to handling faults in all phases of the flight project lifecycle. The need exists at both extremes of space exploration: At one end, well-funded, resource-rich missions continue to experience difficulties due to system complexity, computing capability that fails to keep pace with expanding mission goals, and risk-averse design. This ultimately curtails mission capability and mission objectives when traditional fault management approaches cannot adequately ensure mission success. At the other end, very small and high-risk missions are flourishing because of advances in computing, microdevices, and low-cost access to space. However, autonomy and FM are increasingly seen as essential because of the high probability of faults and extreme resource limitations that make deliberative, ground-directed fault recovery impractical.

Critical Gaps:

Needed innovations in FM can be grouped into the following two categories:

1. FM operations approaches: This category encompasses FM "in-the-loop," including algorithms, computing, state estimation/classification, machine learning, model-based reasoning, and digital twin technologies. Further research into fault detection and diagnosis, prognosis, fault recovery, and mitigation of unrecoverable faults is needed to realize greater system autonomy and resiliency.
2. FM design and implementation tools: Also sought are methods to formalize and optimize onboard FM, such as model-based system engineering (MBSE). New technologies to improve or guarantee fault coverage, manage and streamline complex FM, and improve system modeling and analysis significantly contribute to the quality of FM design and may prove decisive in trades of new versus traditional FM approaches. Automated test case development, false positive/false negative test tools, model V&V tools, open-source software tools, and test coverage risk assessments are examples of contributing technologies.

Specific algorithms and sensor technologies are in scope, provided their impact is not limited to a particular subsystem, mission goal, or failure mechanism. Novel artificial-intelligence-inspired algorithms, machine learning, etc., should apply to this subtopic if, and only if, their design or application is specific to detection, classification, or mitigation of system faults and off-nominal system behavior. Although the core interests of this subtopic are spacecraft resilience and enabling spacecraft autonomy, closed-loop FM for other high-value systems such as launch vehicles and test stands is also in scope, particularly if the techniques can be easily adapted to spacecraft.

Expected outcomes and objectives of this subtopic are to mature the practice of FM, leading to better estimation and control of FM complexity and development costs, more flexible and effective FM designs, and accelerated infusion into future missions through advanced tools and techniques.

Specific objectives include the following:

- Increase spacecraft resilience against faults and failures.
- Increase spacecraft autonomy through greater onboard fault estimation and response capability.
- Increase collection and quality of science data through mitigation of interruptions and fault tolerance.
- Enable cost-effective FM design architectures and operations.
- Determine completeness and appropriateness of FM designs and implementations.
- Decrease the labor and time required to develop and test FM models and algorithms.
- Improve visualization of the full FM design across hardware, software, and operations procedures.
- Determine the extent of testing required, completeness of verification planned, and residual risk resulting from incomplete coverage.

- Increase data integrity between multidisciplinary tools.
- Compare distributed versus centralized FM implementation.
- Standardize metrics and calculations across FM, systems engineering (SE), safety and mission assurance (S&MA), and operations disciplines.
- Improve costs and implementation risks of FM while improving capability, such that benefits demonstrably outweigh the risks, leading to mission infusion.

Shortfalls And Decadal Surveys:

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

- Autonomously monitor, inspect, maintain, and repair space assets.

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

References:

1. "Fault Management Handbook," National Aeronautics and Space Administration: https://share.google/CHHgajs5EsfZeJZ1X
2. "NASA Spacecraft Fault Management Workshop", National Aeronautics and Space Administration: https://www.nasa.gov/offices/oce/documents/2012 fm workshop.html
3. "System Health Management: with Aerospace Applications," Wiley: https://www.wiley.com/en-us/System+Health+Management+with+Aerospace+Applications-p-9781119998730
4. "2018 Autonomy Workshop," National Aeronautics and Space Administration: https://science.nasa.gov/technology/2018-autonomy-workshop

INSITU.2.S26B: Sample Handling, Processing, and Control for In-Situ Lunar and Planetary Science Instruments (SBIR) (previously S13.02)

Lead Center: ARC

Participating Center(s): JPL, GSFC

Subtopic Problem Statement/Description:

Technologies are sought to enable sample handling, processing, and control during future in-situ lunar and planetary missions. The proposed technologies should address critical gaps between the state of the art and technology needs that directly address in-situ sample handling, processing, and control requirements for lunar and/or planetary science instrumentation. Proposed technologies should facilitate effective, representative, unambiguous, and accurate sample analysis in a manner that does not modify the sample (chemically, physically, biologically) in an unpredictable or poorly understood manner that could compromise science results. Of particular interest are technologies that address future mission needs described in the National Research Council Planetary Decadal Survey report, "Origin, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032" and/or in the "Artemis III Science Definition Team (SDT) Report." Technologies that address the needs of multiple payload instruments or stand-alone instruments are desired, as are technologies capable of operating in multiple relevant environments.

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

Primary Technology Taxonomy:

- Level 1: TX04 Robotics Systems
- Level 2: TX04.3 Manipulation
- Level 3: TX04.3.4 Sample Acquisition and Handling

Desired Deliverables of Phase I:

Feasibility determination, proof of concept, operations, and function simulations and/or measurements, and a detailed plan for Phase II development. Documentation should include the technology development status at the end of the Phase I period of performance, including a comparison to the state of the art.

Desired Deliverables of Phase II:

Phase II must deliver a working component or subsystem breadboard, brassboard, or prototype (TRL 4 to 6) to NASA. The deliverable should include interface specifications, along with documentation of development, capabilities, and performance, and operating instructions. The documentation should also include/delineate any additional development needed for further TRL advancement and/or commercial use.

Desired Deliverable Types of Phase II:

- Analysis,
- Prototype,
- Hardware,
- Software,
- Test Results

State of the Art:

Technologies are being sought to support advanced, next-generation, fully autonomous or automated planetary analytical instrumentation. There are currently many instrument technologies in development for in-situ solar system exploration; descriptions of the state of the art can be found in the references cited above in the references section. These references also summarize the state of the art and point out technology gaps that are associated with requirements related to sample handling, processing, and control. For example, the National Academies Planetary Decadal Survey Report identifies the need to advance technologies for front-end sample handling and preprocessing without modifying/destroying sample physical/chemical properties, as well as robust material separation with mitigation of contamination sources. Proposed technologies should reduce risk related to sample processing, handling, and control in consideration of resource limitations that are typical of planetary missions relative to current state-of-the-art technologies.

Critical Gaps:

Technologies and subsystems are sought to address one or more of the following challenges (not in priority order) associated with SMD missions:

Sample Transfer Technologies - that reduce the risks related to the transfer of samples to science instruments. Examples include systems that crush, grind, comminute, pulverize, dissolve, or suspend, as needed, prior to distributing samples according to the requirements of relevant analytical science instruments.

Sample Distribution and Manipulation Technologies - capable of handling suspensions, solutions, slurries, dry particles, or dust. Examples include aqueous and non-aqueous liquid-phase samples or sample slurries/suspensions, and pneumatic transfer of particles/dust/powders.

Separation Technologies - that provide appropriate sample fractions to analytical instruments, including particle size sorting (e.g., screening, sieving, filtering) and phase separation, e.g. to separate water/ice from regolith.

Extraction Technologies - that separate and concentrate analytical targets (including organic molecules and biosignature compounds) from bulk samples (e.g., regolith, soil, and/or ice); examples include solid-phase extraction and organic and aqueous solvent extraction.

Processing Technologies - that modify samples for analytical analysis, including chemical derivatization, concentration or dilution, addition of standards or calibrants, removal of physical or chemical interferences (e.g. bubbles, high salt concentrations). In all cases, these functions must be appropriate for the requirements of analytical instruments for planetary science missions.

Technologies focusing on the development of micro or nano systems components such as valves, pumps, phase separators, and engineering sensors (e.g., temperature, pressure, flow etc.) that are compatible with planetary environments are welcome, so long as they are focused on eventual inclusion into larger sample-handling architectures.

Please note that for sample acquisition technologies proposers, may consider S13.01, "Robotic Mobility, Manipulation, and Sampling," and for science instruments, proposers may consider S13.05, "In-Situ Instruments and Instrument Components for Lunar and Planetary Science."

Shortfalls And Decadal Surveys:

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

"Civil Space Shortfalls," National Aeronautics and Space Administration: https://www.nasa.gov/spacetechpriorities/

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

References:

1. National Academies Planetary Decadal Survey report, "Origin, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032:" https://nap.nationalacademies.org/catalog/26522/origins-worlds-and-life-a-decadal-strategy-for-planetary-science
2. “Artemis III Science Definition Team Report," National Aeronautics and Space Administration: https://www.nasa.gov/wp-content/uploads/2015/01/artemis-iii-science-definition-report-12042020c.pdf
3. "The Scientific Context for Exploration of the Moon," National Academies:https://nap.nationalacademies.org/catalog/11954/the-scientific-context-for-exploration-of-the-moon
4. "The Global Exploration Roadmap," National Aeronautics and Space Administration: https://www.nasa.gov/wp-content/uploads/2015/01/ger_2018_small_mobile.pdf?emrc=4abb2f
5. "The Mars Future Plan," National Aeronautics and Space Administration: https://science.nasa.gov/planetary-science/programs/mars-exploration/future-of-mars-plan/
6. "Moon to Mars Objectives," National Aeronautics and Space Administration: https://www.nasa.gov/wp-content/uploads/2022/09/m2m-objectives-exec-summary.pdf?emrc=119caf#:~:text=Operations%20Goal%3A%20Conduct%20human%20missions,the%20completion%20of%20the%20missions.

7. "NASA's Moon to Mars Architecture," National Aeronautics and Space Administration: https://www.nasa.gov/wp-content/uploads/2024/12/esdmd-001-add-rev-b.pdf?emrc=5ffbf41.
8. "Roadmap to Ocean Worlds (ROW)," Lunar and Planetary Institute: http://www.lpi.usra.edu/opag/ROW
9. "Ocean Worlds," National Aeronautics and Space Administration: https://www.nasa.gov/specials/ocean-worlds/
10. National Academies of Sciences, Engineering, and Medicine report, "A Science Strategy for the Human Exploration of Mars": https://www.nationalacademies.org/publications/28594
11. "Civil Space Shortfalls," National Aeronautics and Space Administration: https://www.nasa.gov/spacetechpriorities/

INSITU.3.S26B: Robotic Mobility, Manipulation, and Sampling (SBIR) (previously S13.01)

Lead Center: JPL

Participating Center(s): ARC, GRC, GSFC

Subtopic Problem Statement/Description:

The NASA Planetary Science Decadal Survey for the 2023-2032 decade identifies missions to solar system bodies, including to comets, asteroids, Ceres, Mars, Earth's Moon and ocean worlds, which require new mobility, manipulation, and sampling technologies. This call also prioritizes technologies enabling Moon-to-Mars missions. Component technologies for low-mass and low-power systems tolerant to the in situ environment (e.g., temperature, radiation, dust) are of particular interest. Mobility systems will provide surface, aerial, and subsurface access to sites of interest. Surface mobility will include long-range day and night driving access to scientifically important terrains. Manipulation technologies are needed to deploy sampling tools to the surface and transfer samples to in situ instruments and sample storage containers. Sampling systems are needed to acquire samples. Minimization of mass and energy, adherence to strict contamination control requirements, and the ability to work reliably in a harsh mission environment are important characteristics for the systems.

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

Primary Technology Taxonomy:

- Level 1: TX04 Robotics Systems
- Level 2: TX04.2 Mobility
- Level 3: TX04.3.4 Sample Acquisition and Handling

Desired Deliverables of Phase I:

Proposals should show an understanding of relevant science needs and engineering constraints and present a feasible plan, including a discussion of challenges and appropriate testing, to fully develop a technology relevant to a NASA program.

Desired Deliverables of Phase II:

Phase II deliverables should have demonstrated performance to at least technology readiness level 4 demonstrating capability relevant to specific mission types and planetary environments.

Desired Deliverable Types of Phase II:

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

State of the Art:

Planetary surface mobility systems are currently limited to relatively benign terrain and operator commanded motions. The Mars 2020 Ingenuity and Titan Dragonfly rotorcraft indicate the potential for enhanced mobility from aerial systems. Ocean worlds exploration presents new environments and unique challenges not met by existing mobility and sampling systems. New mobility, manipulation, and sampling technologies are needed to enable new types of missions and missions to different and challenging environments.

Critical Gaps:

Autonomous long-range surface mobility will enable access to more distributed surface locations. Rough terrain mobility will enable access to steep and rocky slope areas not currently accessible with surface mobility. Aerial mobility could enable access to terrains not accessible via mobility systems and faster traverse to new regions. Sampling from aerial systems would enable enhanced science from terrain unreachable by surface mobility systems.

Specific areas of interest include the following:

- Low mass components to enable aerial mobility and associated sampling systems.
- Heaterless actuators for long-distance surface mobility.
- 10-meter Mars subsurface access drill, sampling, and sample transfer.
- Perception sensors and algorithms for challenging lighting conditions.
- Low size, weight, and power distributed motor controllers for manipulation and mobility.
- Dust-tolerant, robotically-mated electrical connectors for lunar and planetary applications.
- Navigation technologies for surface, aerial, and subsurface mobility, e.g. surface slip and embedding detection, long-range day and night traverse, and access to rough terrain.
- Development of robust foundation models for planetary robotics addressing the scarcity of high-fidelity data from flight missions.

Shortfalls And Decadal Surveys:

Shortfalls: 2026 Civil Space Shortfalls, https://www.nasa.gov/spacetechpriorities/

- Develop infrastructure and capabilities for assets to operate for extended duration in the Martian environment.
- Provide surface mobility and logistics for crew and assets on planetary surfaces.
- Provide robotic access to subsurface and atmospheric regimes.
- Collect and return preserved science samples and other products to Earth facilities.

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

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

References:

1. SMD Science-enabling Technology: https://science.nasa.gov/technology/
2. NASA Planetary Exploration Science Technology Office (PESTO) https://www1.grc.nasa.gov/space/pesto/
3. Report on Robotics Technology for NASA's Planetary Science Exploration: https://www1.grc.nasa.gov/wp-content/uploads/PESTO_Robotics_Technology_Needs_March_2024_2.pdf
4. "Mars Exploration: Missions," National Aeronautics and Space Administration: https://mars.nasa.gov/programmissions/
5. "Solar System Exploration," National Aeronautics and Space Administration: https://solarsystem.nasa.gov/
6. "Ocean Worlds," National Aeronautics and Space Administration: https://www.nasa.gov/specials/ocean-worlds/
7. "New Frontiers," National Aeronautics and Space Administration: https://science.nasa.gov/planetary-science/programs/new-frontiers/
8. "Planetary Science and Astrobiology Decadal Survey 2023-2032," National Aeronautics and Space Administration: https://www.nationalacademies.org/our-work/planetary-science-and-astrobiology-decadal-survey-2023-2032
9. Civil Space Shortfalls: https://www.nasa.gov/spacetechpriorities/

INSITU.4.S26B: Variable Gravity Sample Preparation and Analysis (SBIR) (previously S15.02)

Lead Center: GRC

Participating Center(s): ARC, KSC, MSFC

Subtopic Problem Statement/Description:

The Biological and Physical Sciences Division (BPS) within NASA's SMD sponsors long-duration microgravity research aboard the International Space Station (ISS). Experimental samples traditionally have been prepared in ground-based laboratories and launched to the ISS where experiments are conducted. Limited analyses of test samples can be conducted aboard the ISS, but most experiments require preserving, storing, and returning the samples to Earth where detailed analyses are conducted. Consequently, the pace of scientific discovery has been sluggish due to the inability to quickly conduct the iterative process of research that includes the ability to either synthesize or adjust sample composition on-orbit based on real-time diagnostic measurements. As such, BPS has established a Rapid Low Earth Orbit Science Goal [1] to develop new capabilities that provide on-orbit analysis, in-situ measurements, and sample and experiment preparation to allow for on-orbit iterative science to be conducted by trained crew.

With the pending retirement of the ISS, other means of conducting low gravity research in the space environment and making their critical measurements need to be considered.

Over the last several years, 2860 smallsats (those having a mass less than 1200 kg) compromised 97% of all spacecraft launched in 2023. Nearly 1000 smallsats that were launched that year had a mass less than 10 kg [2]. Research on these platforms needs to accommodate, power, propulsion, data acquisition and control, telemetry, and the actual experiment and its instrumentation.

NASA's exploration mission is currently focused on lunar exploration. Not only is fundamental research needed to develop effective solutions to the engineering challenges associated with a sustained human presence on the lunar surface, the ability to conduct investigations on the lunar surface provides an opportunity to examine phenomena at an intermediary gravity level. Typical payloads envisioned for payload and research investigations on the lunar surface are constrained to weigh no more 50 kg, require less than 25 watts of steady-state power, and use less than 200 watts of startup power from a 28 VDC source. Data telemetry rates will average about 300 kbps.

Technologies are sought to enable and advance the in situ analysis of samples in the low gravity environment, either in low Earth orbit (LEO) or beyond low Earth orbit (BLEO).

Proposals must identify a science research diagnostic capability for biological or physical science (combustion, fluid physics, material science or soft matter) research and the relevance of the hardware capabilities to measuring the desired research phenomena. The proposal must identify the potential size, weight, and power envelope of the technology 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).

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

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 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, concept of operations, and an engineering development unit developed and tested 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
- Prototype
- Test Results
- Hardware

State of the Art:

The current State of the Art for biological and physical science research hardware in space shows two main limitations: (1) 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. (2) Most existing analysis instrumentation have been custom-built for a specific organisms or physical science phenomena and therefore lack the desired modularity and extensibility.

Critical Gaps:

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

Proposed instruments should address one or more 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

"Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032" https://www.nationalacademies.org/publications/26522

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

- Collect and return preserved science samples and other products to Earth facilities

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

References:

1. "NASA's Low Earth Orbit Microgravity Strategy" https://www.nasa.gov/wp-content/uploads/2024/12/2024-12-lms-final-goals-and-objectives.pdf
2. "Smallsats by the numbers 2025" https://brycetech.com/reports/report-documents/smallsats-2025/BryceTech_Smallsats-by-the-Numbers-2025.pdf
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5. "Space Biology Beyond LEO Instrumentation & Science Series Science Working Group 2022 Annual Report," 2023: https://ntrs.nasa.gov/citations/20230008417
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INSITU.5.S26B: Contamination Control and Planetary Protection (SBIR) (previously S13.04)

Lead Center: ARC

Participating Center(s): GSFC, JPL

Subtopic Problem Statement/Description:

The contamination control (CC) and planetary protection (PP) subtopic develops new technologies or supports new applications of existing technologies to measure, manage, and mitigate the presence and spread of undesired microbial, particulate, and molecular sources. The goal is to produce clean and characterized spacecraft, instrumentation, or hardware. Innovative solutions are sought for characterization, modeling and simulation, and mitigation of contamination induced by spacecraft, instruments, crew, and planetary environments. Understanding potential CC and PP contaminants and preventing the contamination of our spacecraft and instruments supports the integrity of NASA sample science and mitigates other potential impacts to spacecraft function.

Novel approaches to measuring, managing, and mitigating microbial, particulate, and molecular (including water vapor) contamination sources support NASA's ability to produce compelling scientific results, ensure nominal hardware operations, and comply with planetary protection requirements to prevent forward contamination (the transfer of viable organisms from Earth to another planetary body) and backward contamination (the transfer of material from another planetary body that may pose a biological threat to Earth's biosphere).

NASA's Moon-to-Mars architecture presents particularly pressing challenges for CC and PP: many current CC and PP methodologies are not applicable for crewed missions to destinations where extant life may exist. New technology gaps include methods to prevent both forward contamination and back contamination during crewed exploration of Mars, to maintain the fidelity of ongoing study of that environment and to prevent exposure of crew to environmental hazards.

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

Primary Technology Taxonomy:

- Level 1: TX07 Exploration Destination Systems
- Level 2: TX07.3 Mission Operations and Safety
- Level 3: TX07.3.5 Planetary Protection

Desired Deliverables of Phase I:

Phase I must deliver a Proof of concept for a technology, simulation code, protocol, or method. This includes relevant research and analysis (e.g., simulation code for contamination control) that is ready for flight project testing or sampling approaches/analyses that could be adapted for use by sampling instruments/spacecraft/facilities.

Desired Deliverables of Phase II:

Phase II must deliver a prototype hardware, software, method, protocol, or approach that has a viable and immediate infusion or adaptation into flight project work. The deliverable should be as close as possible to the relevant environment of interest (TRL 6) and include all necessary data and documentation.

Desired Deliverable Types of Phase II:

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

State of the Art:

Spacecraft **contamination control (CC)** requirements and practices are evolving rapidly as planetary mission science objectives emerge to target the unambiguous *in situ* or returned detection of organic molecules and signs-of-life (i.e., biosignatures). Stringency in contamination requirements and practices is also driven by critical Earth and astrophysical science missions with highly-sensitive detectors, particularly with advances in detection of ultraviolet, low-level particulate (e.g., for atmospheric aerosols), and low-level organic (e.g., for Earth pollution monitoring of volatile organic compounds) signatures. Improved characterizations of spacecraft- and payload-induced sources of contamination, both molecular and particulate, and of their transport properties and interactions with surfaces are therefore necessary for future missions to enable the proactive mitigation of harmful effects; to protect spacecraft, instrument, and science mission performance; and to demonstrate compliance with stringent requirements across mission lifetimes. The development of novel technology to expand current methods for clean launch capabilities (e.g., purge, environmental control systems) is a critical gap as future missions may not require a cruise stage or other protective housing over the main operational flight hardware. Other typical needs relate to characterizing and mitigating [1] the multispecies outgassing of molecular contaminant from spacecraft materials under typical environmental conditions (including vacuum, thermal variance, and radiation exposure); [2] molecular adsorption/desorption and diffusion processes with respect to substrates and the effects of thin contaminant films on, e.g., optical systems; [3] the induced contamination properties of chemical and electric propulsion systems including impingement effects and droplet or soot dispersal; and [4] the effects of particulate material on spacecraft materials and surfaces in atmosphere and vacuum including their adhesion/removal properties, induced thermo-optical property degradations, and abrasion (particularly so for lunar regolith). Experimental and physics-based modeling approaches that advance states-of-the-art in the characterization and mitigation of spacecraft-induced contaminants are of interest, either independently or in combination.

Planetary protection (PP) methodologies are used to achieve an extremely low microbial bioburden on spacecraft leaving Earth for sensitive planetary destinations. International regulations limit the number of viable spore-forming organisms on spacecraft, depending on destination; moreover, any terrestrial biological contamination can compromise missions searching for extraterrestrial life.The current state of the art encompasses technologies from the 1960s to 1970s Viking spacecraft era, along with more recent advancements in sterilization and sampling technologies. The predominant means to control biological contamination on spacecraft surfaces is a combination of heat microbial reduction processing and mechanical removal via solvent cleaning processes (e.g., isopropyl alcohol cleaning). While vapor hydrogen peroxide (VHP) has been approved by NASA, concentration variability, delivery mechanisms, and material compatibility concerns currently limit flight mission infusion of VHP. After microbial reduction, hardware is protected in a cleanroom environment (ISO 8 or better) using protective coverings during spacecraft integration and assembly. This process of terminal sterilization followed by recontamination prevention has been conducted for in-flight biobarriers employed for either entire spacecraft (Viking) or for spacecraft subsystems (Phoenix spacecraft arm). Environmental assessments are implemented to understand recontamination potential for cleanroom surfaces and air. Biological cleanliness is verified through the NASA standard assay, a culture-based method. Some DNA-based methodologies have been adopted by spaceflight projects, including targeted sequencing of 16S and 18S ribosomal nucleic acids, and metagenomic approaches are currently undergoing development. Rapid cleanliness assessments can be performed to inform engineering staff about biological cleanliness during critical hardware assembly stages, including total adenosine triphosphate (tATP) and limulus amoebocyte lysate (LAL) assays. However, these are not currently accepted as methods for verification of planetary protection compliance. Variability in detector performance thresholds in the low biomass limit remain a challenge to the infusion of ATP luminometers for spaceflight verification and validation.

Critical Gaps:

Critical gaps for CC include:

- Analytical and physics-based modeling technologies and techniques to quantify and validate submicron particulate contamination.
  - Particulate and molecular transport modeling and simulation for scenarios of simple and complex spacecraft geometries with electrostatic loads, vibro-acoustic/launch loads, and particle detachment and attachment capabilities in continuum, rarefied, and molecular flow environments.
  - Modeling and simulation of particulate flux for assessment of contamination scenarios using gas dynamic approaches (e.g., with direct simulation Monte Carlo (DSMC) and Boltzmann formulations).
- Testing and measurement of molecular outgassing rates down to 3.0×10^{-15} g/cm^2/s with mass spectrometry, under flight conditions (in vacuum and across a wide range of operating temperatures), and with combined exposure to natural environments (e.g., high-energy radiation, ultraviolet radiation, atomic oxygen exposure).

- Launch barrier technologies and modeling or other measurements of launch environment contaminant flux.
- Low-energy surface material coatings to prevent or minimize contamination.
- Improved experimental and theoretical characterizations of particulate adhesion/removal properties, thermo-optical property effects, and abrasion. Lunar dust or regolith is of high relevance, as are mitigation approaches.

Critical gaps for PP include:

- Probabilistic modeling of biological contamination fate to drive biological assurance cases for spacecraft cleanliness. This is rapidly becoming an emerging need for understanding biological cleanliness, distributions of biological contamination, and behaviors of biologicals on spacecraft/instrument surfaces. Models may include transport and inactivation processes during assembly, processing, and transit, ideally leveraging empirical measurements made during assembly. A high level of certainty is required for model outcomes to be used for demonstrating requirement compliance.
- Assessment of DNA from low-biomass surfaces (<0.1 ng/L DNA), from 1 to 5 m^2 of surface. Advancements in multiple parts of the DNA assessment process are encouraged, including but not limited to:
  - Improvement of methods to lyse cells/spores.
  - New technologies for producing ultra-pure reagents and technologies for testing and validating the low level of analyses of interest associated with low biomass sampling.
  - Sampling devices that are suitable for reproducible (at a certification level) detection of low biomass and compounds (e.g., viable organisms, DNA) but also compliant with spaceflight environmental requirements (e.g., cleanroom particulate generation, electrostatic discharge limits).
- Quantification of a spectrum of viable organisms and non-viable biological particles. Advanced technologies to detect and verify organic compounds and biologicals on spacecraft hardware prior to launch.
- Recontamination prevention/mitigation systems to prevent recontamination and cross-contamination throughout the spacecraft lifecycle (build, test, launch, cruise, operations).
- Enhanced microbial reduction/sterilization modalities that are compatible with:
  - Siverse materials used in spacecraft and scientific instruments
  - Planetary samples, to prevent back contamination without compromising chemical measurements
  - In situ use, for in-flight sterilization of diverse materials during exploration missions.
- Containment systems:
  - To reduce/prevent forward contamination of a planetary environment by crew activities
  - Quarantine facilities to manage back contamination risk, at multiple mission phases
- Sample collection systems:
  - Technologies that store, seal, and contain samples with an appropriate sensitivity to environmental conditions during transport from the planetary body where samples are collected to the return to Earth
  - End-to-end sample return functions to ensure containment and pristine preservation of materials (e.g., technologies that support in-flight verification of sample containment or in-flight correctable sealing technologies).

Shortfalls And Decadal Surveys:

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

- Provide efficient, outfitted habitation capable of long duration missions.
- Collect and return preserved science samples and other products to Earth facilities.
- Efficiently and responsibly manage waste streams during long duration missions.
- Develop an affordable and resilient supply chain for space exploration.

This subtopic is critical to enable science work that answers the following priority question from Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032 (2022):

- Q11. Search for life elsewhere: Is there evidence of past or present life in the solar system beyond Earth and how do we detect it?

Technology developed by this subtopic secondarily supports all other Decadal priority questions requiring flight missions (i.e. probes, landers) that might approach or contact planetary bodies that might harbor extraterrestrial life, even if they are not life-detection missions. Such missions must still comply with international planetary protection regulations.

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

References:

1. "Planetary Protection," National Aeronautics and Space Administration: https://planetaryprotection.nasa.gov
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3. COSPAR Policy on Planetary Protection. (2024). Space Research Today, no. 220. https://cosparhq.cnes.fr/cospar-policy-on-planetary-protection/
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6. ISO 14644-1, International Organization for Standardization: https://www.iso.org/obp/ui/#iso:std:iso:14644:-1:ed-2:v1:en
7. ISO 14644-12, International Organization for Standardization: https://www.iso.org/standard/53393.html
8. "Controlling Contamination for Spacecraft Sterilization," NASA: https://ntrs.nasa.gov/api/citations/19960044619/downloads/19960044619.pdf

INSITU.6.S26B: Plant Research Technologies for Space (SBIR) (previously S15.01)

Lead Center: KSC

Participating Center(s): ARC

Subtopic Problem Statement/Description:

In agriculture, a good crop stand is defined as having a field of healthy and vigorous plants with uniform growth and is one of the pillars of successful crop production as it determines yield potential. Achieving a good crop stand depends on several factors, including seed health, early seedling vigor, adequate preparation of the land (for field agriculture), quality of growth substrates (for Controlled Environment Agriculture; CEA), and management techniques, such as delivering/maintaining the right amount of water and fertilizer. The production of good crop stands, therefore, will be critical for the establishment of space agriculture on the Moon and Mars because mission complexity and limited crew time will likely leave very little or no room for re-planting.

NASA is interested in technologies that will minimize the risk of catastrophic crop failure due to poor crop stands. This interest will focus on technologies and methods for anchoring seeds to the growth medium and automating the delivery of water to obtain uniform seed germination and maintain vigorous early seedling growth in enclosed environmentally controlled small plant habitats. Moreover, concepts and sensors that will provide information on percent germination, seedling uniformity, seedling survival, measurements that are indicative of a good or bad crop stand in these small plant habitats, are desired. Applicants responding to this SBIR subtopic should describe how their proposed concepts/technology will provide resources (e.g., water, fertilizer) and maintain conditions (e.g. lighting, pressure, humidity, etc.) necessary for ensuring: (1) that seeds maximally germinate in the plant habitat; and (2) that seedlings continue to uniformly grow up to 21 days allowing for the collection of relevant measures on crop stand quality using the proposed monitoring concepts/technology. Plants in future space controlled-environment agriculture (CEA) will be grown under a reduced pressure exploration atmosphere of 56.5 kPa (8.2 psia), 34% O_2, and 66% N_2. Investigators who integrate this exploration atmosphere into their small plant habitat engineering concepts will, therefore, be viewed favorably.

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 demonstrate the proof of concept and provide a written report describing initial testing of the technology or principles in the laboratory, with the end of Phase I producing a clear path toward hardware development. A geometric digital model of the concept in the proposer's native CAD format may also be included as a Phase 1 deliverable.

Desired Deliverables of Phase II:

The expected deliverable at the end of Phase II will be a working prototype or engineering development unit that will work with the plant habitat to consistently ensure the production of good crop stands for CEA. During the Phase II, the proposer is expected to provide a geometric digital model of the prototype in the proposer's native CAD format, as well as in a standard CAD interchange format, STEP/STP being the most preferred. Phase II will include demonstration of this hardware's functionality at a remote location chosen by NASA. An assessment of the technology business case (i.e., cost and revenue forecast, market size, potential customers, etc.) is also required.

Desired Deliverable Types of Phase II:

- Prototype

State of the Art:

State-of-the art is advanced engineering that will maximally increase crop stands and sensors that will inform crew on best management approaches to successfully establish crops in future CEA systems or deployable plant habitats on the Moon and Mars.

Critical Gaps:

The technology will help fill a gap in understanding how exploration atmospheres affect plant biological processes, while contributing knowledge that will minimize the risk of catastrophic crop failure in extraterrestrial settings resulting from poor, early-plant establishment.

Shortfalls And Decadal Surveys:

This subtopic directly addresses the 2023 Decadal Survey's (Ensuring the Future of Biological and Physical Sciences Research: A Decadal Survey for 2023-2032), recommendation of establishing a BLiSS (Bioregenerative Life Support Systems) research campaign. Crop production in spacecraft, as well as on the lunar and Martian surfaces, will not be a one-size-fits-all, as different crops and the different conditions of each environment will likely require different technological needs. While NASA is already developing food production systems, additional designs for controlling and monitoring these systems may be required to deal with all these variables, which will be critical to meet NASA's exploration goals.

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

References:

1. Wright HC, Fountain L, Moschopoulos A, Ryan AJ, Daniell TJ, Cullen DC, Shaughnessy B, Cameron DD (2023) Space controlled environment agriculture offers pathways to improve the sustainability of controlled environmental agriculture on Earth. Nature Food 4(8):648-653. doi: 10.1038/s43016-023-00819-5.
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8. Stutte GW, Yorio NC, Edney SL, Richards JT, Hummerick MP, Stasiak M, Dixon M, Wheeler RM (2022) Effect of reduced atmospheric pressure on growth and quality of two lettuce cultivars. Life Sci Space Res (Amst). 34:37-44. doi: 10.1016/j.lssr.2022.06.001

SBIR 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	SBIR/STTR Subtopic Number	Subtopic Title
TX01 - Propulsion Systems	TX01.2 – Electric Space Propulsion	GO.2.S26B	Development of cost-effective 3D printing of SOA Hall thruster magnetic circuits
	TX01.3 - Aero Propulsion	AERO.2.S26B	Quiet Performance-Aircraft Propulsion Noise
	TX01.4 - Advanced Propulsion	GO.3.S26B	Advanced Momentum Management and Propellantless Control Technologies for Solar Sail Spacecraft
TX02 - Flight Computing and Avionics		ENABLE.2.S26B	High Performance Onboard Computing
		EXPAND.3.S26B	Autonomous Onboard Health Management for Small Spacecraft and Distributed Systems
TX04 - Robotics Systems	TX04.2 - Mobility	SURFMOB.1.S26B	Advanced Human Lunar Surface Mobility Technologies
		INSITU.3.S26B	Robotic Mobility, Manipulation, and Sampling
	TX04.3 - Manipulation	INSITU.2.S26B	Sample Handling, Processing, and Control for In-Situ Lunar and Planetary Science Instruments
TX05 - Communications,	TX05.2 – Radio Frequency	COMNAV.2.S26B	Lunar 3GPP Capability Development

Navigation, and Orbital Debris Tracking and Characterization Systems	TX05.4 - Network Provided Position, Navigation, and Timing	COMNAV.1.S26B	Flight Dynamics and Navigation Technologies
	TX05.X - Other Communications, Navigation, and Orbital Debris Tracking and Characterization Systems	EXPAND.2.S26B	Orbital Debris Tracking
TX06 - Human Health, Life Support, and Habitation Systems	TX06.2 – Extravehicular Activity Systems	EVA.2.S26B	Mars Exploration Extravehicular Activity (EVA) Suit
TX07 - Exploration Destination Systems	TX07.2 - Mission Infrastructure, Sustainability, and Supportability	LIVEI.1.S26B	Surface Sustainability and Logistics: Dust Mitigation
	TX07.3 - Mission Operations and Safety	INSITU.5.S26B	Contamination Control and Planetary Protection
TX08 - Sensors and Instruments	TX08.1 - Remote Sensing Instruments/Sensors	INSTALG.4.S26B	Detectors and Integrated Electronics
		INSTALG.5.S26B	Remote-Sensing Technologies
		COSMO.4.S26B	Instrument Technologies, Free-Form Optics, and Stray-Light Suppression
	TX08.2 - Observatories	COSMO.5.S26B	Advanced Observatory Technologies: Mirrors, Structures, Systems, Fabrication and Metrology
	TX08.3 - In-Situ Instruments/Sensor	INSITU.4.S26B	Variable Gravity Sample Preparation and Analysis
		INSITU.6.S26B	Plant Research Technologies for Space
		SPWX.2.S26B	Sensors and Instrumentation for Space Environment Measurement
TX09 - Entry, Descent, and Landing	TX09.1 - Aeroassist and Atmospheric Entry	LAND.2.S26B	Development and Modeling of Waterproofing Coatings or Surface Treatments for Reusable Thermal Protection Systems (TPS)

		LAND.3.S26B	Low Cost Domestic Source for Blended Carbon and Phenolic Felt Batting or Yarn
	TX09.X – Other Entry, Descent, and Landing	LAND.1.S26B	Real-time Characterization of Regolith Stability during Planetary Descent & Landing
TX10 - Autonomous Systems	TX10.1 - Situational and Self Awareness	AERO.1.S26B	Health Management and Sensing Technologies for Sustainable Aviation Fuel Systems
	TX10.2 - Reasoning and Acting	INSITU.1.S26B	Fault Management Technologies for Autonomous Systems
TX11 - Software, Modeling, Simulation, and Information Processing	TX11.4 – Information Processing and Artificial Intelligence	COSMO.3.S26B	AI for Rapid Development of Space Precision Components
	TX11.6 - Ground Computing	INSTALG.3.S26B	Large-Scale Computing and Computational AI
TX12 - Materials, Structures, Mechanical Systems, and Manufacturing	TX12.1 - Materials	AERO.5.S26B	Improved Material Discovery through Leveraging Novel Modeling and Experimental Approaches
		LWS.2.S26B	Softgoods Habitats Employing Layered or Trapped Unrefined Regolith Shielding (SHELTURS)
		ENABLE.1.S26B	Laser Welding System and Integrated Real-Time Nondestructive Inspection
TX13 - Ground, Test, and Surface Systems	TX13.2 - Test and Qualification	AERO.6.S26B	Aeronautics Ground Test and Measurement Technologies: Diagnostic Systems for High-Speed Flows and Icing
TX14 - Thermal Management Systems	TX14.1 - Cryogenic Systems	COSMO.2.S26B	Cryogenic Systems for Instruments
	TX14.X - Other Thermal Management Systems	AERO.3.S26B	Advanced Thermal Management for High-Efficiency Engine Cycles
TX15 - Flight Vehicle Systems	TX15.X – Other Flight Vehicle Systems	AERO.8.S26B	Fuel to Electric Conversion
		AERO.4.S26B	Flight Test Measurement Technologies

TX16 - Air Traffic Management and Range Tracking Systems		AERO.7.S26B	Airspace Operations and Safety

Attachment 26B.1 SBIR 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 SBIR 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. (RFO DEVIATION Sep 2025)
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. (DEVIATION 12-01A)(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 UNCLASSIFIED 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

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

SBA Certifications required for Phase I

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